IMPACTS OF BIOFUEL PRODUCTION AND NAVIGATION IMPEDIMENTS ON AGRICULTURAL TRANSPORTATION AND MARKETS

A Dissertation

by

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ABSTRACT

This study investigated the impacts of U.S. biofuel production and barge navigation impediments on agricultural transportation and markets. Both past and future impacts of U.S. biofuel production levels mandated by the Renewable Fuel Standards of the Energy Policy Act of 2005 (RFS1) and the Energy Independence and Security Act of 2007 (RFS2) were examined. Examination of barge navigations impediments included analysis of the impact of lock failure and low water levels on rivers due to drought, on agricultural transportation, and on consumer welfare. All scenarios were simulated using the International Grain Transportation Model, a price endogenous mathematical programming model.

The results showed that RFS-associated (RFS1 and RFS2) U.S. corn ethanol production increased the total corn supply and diverted corn from non-ethanol consumption, reduced regional grain transportation volumes, and contributed to a rise in corn prices. The results of the forward-looking scenarios indicated that grain exports and transport volumes were increased. Exports from Gulf ports increased by 41%, while grain movements by rail increased by 60%. Additional investments in the expansion of the grain handling capacities of Gulf ports and the railroad industry are needed in the near future unless a large increase in biofuel production occurs.

The results of navigation impediment scenarios indicated that both lock failures and low water levels on rivers adversely affect U.S. grain exports. The Gulf ports were most negatively impacted, relative to Pacific Northwest and Atlantic ports. Truck and barge freight volume declined while rail freight volume increased. Because trucks deliver grain from grain elevators to barge locations, truck volume also decreased in response to the decline in barge volume. The scenarios imposed welfare losses on society with most accruing to consumers, while the barge industry lost $10-154 million in revenue. The low water levels were more expensive than the lock failures. Major rehabilitation of the locks is needed to avoid lock failures and more dredging of the shallow parts of the river system is required because of frequent droughts.

DEDICATION

To my parents, beloved wife, and children

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NOMENCLATURE

AMS	Agricultural Marketing Service
ASM	Agricultural Sector Model
AWO	American Waterways Operators
BEA	Bureau of Economic Analysis
BG	Billion Gallons
CIS	Capital Investment Strategy
CRD	Crop Reporting District
CS	Consumer Surplus
ERS	Economic Research Service
FAPRI	Food and Agricultural Policy Research Institute
FAS	Foreign Agricultural Service
FASOM	Forest and Agricultural Sector Optimization Model
FOB	Free on Board
GCM	Global Circulation Model
GDP	Gross Domestic Product
IGTM	International Grain Transportation Model
IMTS	Inland Marine Transportation System
IPCC	Intergovernmental Panel on Climate Change
MAPE	Mean Absolute percentage Error
MG	Million Gallons

MLE	Maximum Likelihood Estimation
MMT	Million Metric Tons
MRS	Mississippi River System
MT	Metric Ton
MTS	Mountain States
NASS	National Agricultural Statistics Service
NOPA	National Oilseed Processors Association
OLS	Ordinary Least Squares
PCP	Posted County Prices
PNW	Pacific Northwest
PS	Producer Surplus
RFS1	Renewable Fuel Standards 1
RFS2	Renewable Fuel Standards 2
ROW	Rest of the World
STB	Surface Transportation Board
TTI	Texas Transportation Institute
USACE	U.S. Army Corps of Engineers
USD	U.S. Dollars
USDA	United States Department of Agriculture
VAR	Vector Auto Regression
VECM	Vector Error Correction Model

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1. INTRODUCTION

Agricultural transportation and grain markets are affected by grain supply and demand conditions as well as access to and costs of transportation modes. Major influential factors include the recent expansion in corn based biofuel production and access to the Mississippi River. This dissertation investigates the implications of U.S. biofuel production and barge transportation impediments on transport system usage and market conditions.

1.1 Background on Biofuels

Production of biofuels grew exponentially during the last decade. Biofuel production prospects and market penetration have been influenced by a number of policies. One influential policy involves developments under the Clean Air Act involving the oxygenate requirement for gasoline. Ethanol is one such oxygenate and its usage has been promoted by bans placed on alternative oxygenates. A significant acceleration in biofuel growth in the United States is due to energy independence policies, such as the Renewable Fuel Standards (RFS) Provisions of the Energy Bills in 2005 (H.R.6-2005) and 2007 (H.R.6-2007), also known as RFS1 and RFS2 respectively. Energy price rises were also influential. Ethanol production experienced high growth in the early 2000’s. Data from the Renewable Fuels Association (RFA 2012) and the U.S. Department of Agriculture’s Economic Research Service (USDA-ERS 2012a) indicated that 1.6 billion gallons of ethanol was produced in 2000. This required 630 million bushels of corn with production of ethanol increasing to 3.9 billion gallons in 2005 (from 1.6 billion bushels of corn) and 13.2 billion gallons in 2010 (from 5 billion bushels of corn). This unprecedented explosion in corn demand for fuel production strengthened the linkages between agricultural and energy commodities (Hayes et al. 2009). Corn and soybean prices increased from $2 and $5.66 per bushel in 2005 to $5.18 and $11.30 in 2010 respectively (USDA-ERS 2012a, USDA-ERS 2012b). Regional grain transportation volumes and modal shares changed (Marathon and Sparger 2012).

1.2 Background on Transport

Grain markets are also influenced by Mississippi River System barge navigation conditions and can be negatively affected by river lock failures and low water levels on the river, due to drought. A well-developed and competitive U.S. surface and water transportation system provides agricultural shippers with a highly efficient and low-cost system of transportation (Marathon and Sparger 2012) making them more competitive in world markets. Despite being competitive, barges, railroads, and trucks complements each other. Any major disruption in one transportation mode affects the other modes and consequently may lead to imbalance and inefficiency in entire transportation system. Inland waterway transportation plays an important role in U.S. agriculture's ability to compete in world markets. For example, a five-year-average modal shares of rail and barge in grain exports accounted for 48% and 44% respectively in 2010. According to Marathon and Sparger, truck (73%) and rail (26%) had the largest modal shares in domestic grain transportation.

Most of the corn and soybeans that originate from the Midwest pass through one or more Mississippi River System locks on their way to market. If river system segments are closed due to one or more lock failures, U.S. producers' cost advantage is eroded because of diverting grain to more expensive modes of transportation. This makes well-maintained and reliable navigation facilities important. As of 2010, 54% of the Inland Marine Transportation System's (IMTS) lock structures were more than 50 years old and 36% were 70 years or older. According to the Inland Marine Transportation System (IMTS 2010), the average economic service life of a lock structure is 50 years and can be extended up to 75 years through major rehabilitation projects. Poor lock conditions resulted in increased failures, which restricted the transportation of grains via river systems. As reported in a document by the House of Representatives Committee on Transportation and Infrastructure (USHR-CTI 2011), the Ohio River experienced a sharp rise in navigation outages in the last decade, where outages increased from 25,000 hours in 2000 to 80,000 hours in 2011.

1.3 Objectives

This study examined the effects of U.S. biofuel policies and navigation impediments along the Mississippi River system on agricultural transport system usage and market conditions. In particular, two types of impediments were considered: lock failures at selected locks and dams and low water levels due to drought. In pursuing this, the work had two major objectives:

- Investigate the effects of past and projected U.S. biofuel production on the agricultural transportation system, grain prices, consumption, and production levels, and

- Investigate the economic impact of major impediments to barge transportation on major U.S waterways and the implications for grain transportation and markets.

1.4 Outline of the Study

The first section provides an introduction, background, and objectives of the study. Section 2 presents the conceptual structure and empirical specification of the international grain transportation model that is used in the analysis. Section 3 reports on the investigation of the implications of past and projected biofuel production levels for agricultural transportation, markets characteristics, and producers’ welfare. Section 4 reports on an economic investigation of impediments to barge transportation in the form of river lock facilities and low water levels, and their implications for welfare and agricultural transportation. Finally, Section 5 discusses the results and implications found by the study, as well as offering suggestions for additional research.

2. CONCEPTUAL STRUCTURE AND DOCUMENTATION OF THE INTERNATIONAL GRAIN TRANSPORTATION MODEL

This section describes and documents the transport model that will be used in this dissertation. This section was written jointly with Dr. Witsanu Attavanich, who has a similar version in his dissertation. However, this presentation of materials has been updated. The section will a) explain the genesis of the International Grain Transportation Model **(**IGTM); b) present conceptual and algebraic discussions of IGTM's intent and mathematical structure; c) discuss steps and procedures involved in developing the IGTM data set; and d) present validation information regarding the way the IGTM solution replicates observed grain flows.

2.1 Model History

The IGTM is an expanded and updated version of a model developed by Fuller and colleagues (e.g., Fuller, Fellin, and Grant 1999; Fuller, Fellin, and Eriksen 2000; Fellin et al. 2008). The current version originated from one described in Fellin et al. (2008). However, it was completely reprogrammed with data updated to reflect the 2007-2008 crop years (Vedenov et al. 2010). The current data shows recent changes in grain demand reflecting growth in the biofuel market along with the cost effects of higher energy prices. Previous versions have been used in several transportation studies (e.g., Fuller, Fellin, and Grant 1999; Fellin et al. 2001; Fuller, Fellin, and Eriksen 2000; Fuller et al. 2003; Fellin et al. 2008).

2.2 Model Description

IGTM is a price-endogenous, spatial equilibrium, mathematical programming model. It portrays world grain trade in corn and soybeans with an objective to maximize total net welfare, where total net welfare is determined as sum of both producers' and consumers' surplus less the costs associated with transportation, storage, and grain handling activities. The theoretical underpinnings of the model originate from the works of Samuelson (1952), and Takayama and Judge (1971).

Domestic regional excess demands and supplies, transportation, storage, and grain handling rates/charges are modeled at the crop reporting district level in IGTM. Internationally, all foreign trading countries are treated as an excess supply or excess demand region, with the exception of Mexico and Canada. Mexico encompasses five regions (Northwest, Northeast, West, Central, and South), whereas Canada has only two regions (East and West). Regional demand, supply, and shipments are modeled on a quarterly basis. Multiple modes are portrayed, including truck, rail, barge, lake vessels, and ocean-going ships. Transportation flows depict grain flows to and from 303 U.S. domestic regions going through 42 U.S. intermediate shipping points and 118 international exporting and importing countries/regions.

Each region is identified as either an excess supply or an excess demand region; they can also be a transshipment region. Excess supply regions have production and carry-in stocks that exceed consumption, while excess demand regions have consumption that exceeds production and carry-in. The prices for the points where the supply and demand curves pass through for domestic excess supply regions are the average county level country elevator grain prices, while grain prices for foreign excess supply regions are represented by free on board (FOB) ship or rail grain prices. All grain handling, storage, and transportation charges associated with moving grain from country elevators to ports in the domestic portion are included in the model.

Grain supply is generated mainly in the fall quarter in the northern hemisphere, while southern hemisphere locations generate grain in the spring quarter. Grain is then carried forward into subsequent quarters, which incurs storage charges. Grain handling costs are incurred at points of initial supply, grain storage facilities at intermodal transfer facilities (barge loading and unloading facilities, and ports), and at destinations. Interregional trade occurs with the purpose of quarterly regional excess demands, and considers transportation costs and regional price differentials that provide an incentive for trade.

Shipments in the continental U.S. are modeled to link domestic excess supply regions with barge-loading/unloading sites, domestic excess demand regions, and ports in a quarterly and modal dependent transportation network (rail, barge, and truck). Grain handling and storage charges, and quarterly truck, rail, and barge rates are applied across this network. Grain barge loading sites on the inland waterways are linked to barge unloading elevators at Texas Gulf ports and barge unloading elevators on the lower Mississippi River, Cumberland River, and Tennessee River by quarterly barge rates.

The barge unloading points on the Texas Gulf and the lower Mississippi ports incur charges associated with receiving the grain and loading the grain to ocean-going vessels, while barge-unloading facilities on the Cumberland and Tennessee Rivers incur costs of receiving and loading grain to truck and rail cars. Domestic excess supply regions are directly linked to all domestic excess demand regions and all U.S. ports by truck and rail modes with applicable grain loading (at supply region) and unloading charges. Transportation rates are on a quarterly basis. In addition, truck and rail modes connect excess supply regions to river barge loading sites or the river's barge unloading elevators to nearby excess demand regions at quarterly rates. Some selected domestic excess supply regions are also linked to foreign excess demand regions in Mexico and Canada with applicable quarterly rail rates. Mexico may also import grain via the ocean port at Veracruz (Southern part of Mexico), which is linked by truck and rail rates to the other five Mexican excess demand regions.

IGTM versions are created and validated for the marketing years of 2007 and 2010 and are used to investigate the economic and transport implications of RFS1 and RFS2 mandates. The base IGTM represents 2010 marketing year. In the base IGTM, the domestic portion includes 135 corn excess supply regions and 175 soybean excess supply regions. It also contains 168 corn excess demand regions and 42 soybean excess demand regions. Geographic regions in the domestic portion of the model are CRDs, generally including 10 to twenty counties. The foreign component of IGTM includes 33 corn excess supply regions (exporting countries) and 93 corn excess demand regions (importing countries) as shown in Table 2. For soybeans, internationally, IGTM includes 19 soybean excess supply regions (exporting countries) and 52 soybean excess demand regions (importing countries) as shown in Table 2.

Table 1. Foreign Corn Excess Supply and Demand Regions

Regional Status	Region/Country
Excess Supply Regions (Exporting Countries)	Argentina, Australia, Brazil, Bulgaria, Burkina, Burma, Cambodia, Canada West, Canada East, Croatia, Czech Republic, Denmark, Ethiopia, France, Ghana, Hungary, India, Kazakhstan, Laos, Latvia, Malawi, Moldova, Paraguay, Romania, Serbia, Slovakia, Slovenia, South Africa, Sweden, Tanzania, Uganda, Ukraine, Zambia
Excess Demand Regions (Importing Countries)	Albania, Algeria, Angola, Austria, Azerbaijan, Belarus, Belgium, Bolivia, Bosnia Herzegovina, Botswana, Cameroon, Cape Verde, Chad, Chile, China, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, Egypt, El Salvador, Estonia, Georgia, Germany, Greece, Guatemala, Guyana, Honduras, Hong Kong, Indonesia, Iran, Iraq, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kenya, Korea North, Korea South, Kuwait, Lebanon, Lesotho, Libya, Lithuania, Luxembourg, Macedonia, Madagascar, Malaysia, Malta, Mexico NW, Mexico NE, Mexico West, Mexico Central, Mexico South, Morocco, Mozambique, Namibia, Nepal, Netherlands, Nicaragua, Norway, Pakistan, Panama, Peru, Philippines, Poland, Portugal, Russia, Saudi Arabia, Senegal, Singapore, Somalia, Spain, Swaziland, Switzerland, Syria, Taiwan, Tajikistan, Thailand, Togo, Trinidad Tobago, Tunisia, Turkey, United Kingdom, Uruguay, Uzbekistan, Venezuela, Vietnam, Yemen, Zimbabwe

Table 2. Foreign Soybean Excess Supply and Demand Regions

Regional Status	Region/Country
Excess Supply Regions (Exporting Countries)	Argentina, Australia, Bolivia, Brazil, Bulgaria, Canada West, Canada East, Croatia, Czech Republic, Hungary, India, Paraguay, Romania, Serbia, Slovakia, South Africa, Uganda, Ukraine, Uruguay
Excess Demand Regions (Importing Countries)	Bangladesh, Barbados, Belgium, Bosnia Herzegovina, Chile, China, Colombia, Costa Rica, Cuba, Denmark, Ecuador, Egypt, France, Germany, Greece, Guatemala, Indonesia, Iran, Ireland, Israel, Italy, Japan, Korea North, Korea South, Lithuania, Malaysia, Mexico NW, Mexico NE, Mexico West, Mexico Central, Mexico South, Morocco, Netherlands, Nigeria, Norway, Pakistan, Panama, Peru, Philippines, Portugal, Russia, Singapore, Spain, Switzerland, Syria, Taiwan, Thailand, Turkey, United Kingdom, Uzbekistan, Venezuela, Vietnam

The grain is stored in the excess supply region until it is shipped via the transportation/logistic network to other locations. The stored grain can be shipped to barge loading elevators that are linked to barge unloading elevators. Included in the model are 32 barge loading/unloading sites. These include several sites such as the Upper Mississippi (7), Illinois (3), Missouri (6), Arkansas (3), Ohio (4), lower Mississippi (5), Cumberland (1), White (1), and Tennessee (2) rivers. River elevators at these sites are barge-loading facilities with the exception of the two sites on the Tennessee River (Huntsville and Knoxville) and a site on the Cumberland River (Nashville). These sites may both ship and receive grain. In the base model, the Upper Mississippi River elevators are closed above St. Louis during the winter in order to account for river freezing.

Domestic excess supply regions are also linked by quarterly truck and rail rates to the port elevator locations. These locations include the lower Mississippi, Texas Gulf, Atlantic, Pacific Northwest, and the Great Lakes. In the model, these ports (except the Great Lakes ports) can ship directly to foreign excess demand regions at quarterly bulk-grain carrier rates.

The Great Lakes ports can only ship grain to ports at Montreal, Canada, using non-ocean-going vessels known as lakers. The grain is unloaded from lakers in Montreal first, then loaded onto large ocean-going bulk grain carriers that travel to foreign excess demand regions. The Great Lake ports are closed during the winter months due to freezing.

Representative foreign ports associated with foreign corn excess demand regions include Odessa, Ukraine for Ukraine and Moldova corn exports, Durban, South Africa for corn exports from South Africa, Madras, India for corn exports from India, and Bangkok, Thailand for corn exports from Burma, Cambodia, and Thailand. Other foreign ports used include Shanghai, China for corn exports from China, Buenos Aires, Argentina for corn exports from Argentina, and Santos (Sao Paulo), Brazil for exports from Bolivia, Brazil, and Paraguay. In the soybean portion of the model, most of the same ports are used. In addition, Buenos Aires, Argentina, is the representative port for Uruguay. Canada exports corn through Vancouver and St. Lawrence River ports (Quebec) and makes shipments to India via Madras.

Representative foreign ports for foreign corn excess demand regions (importers) in Europe include Rotterdam for the European Union North, Barcelona, Spain for western Europe, Bari, Italy for southeastern Europe, Odessa, Ukraine for eastern Europe, and Haifa for the eastern Mediterranean. Other ports used include Algiers for North Africa, Damman for the Persian Gulf, Singapore for Southeast Asia, Kaohsiung for Taiwan, Ulsan for Korea, and Yokohama for Japan. Ports used in the Americas include Veracruz for Mexico, Callao for western South America, Puerto Cortes for Central America, and Maracaibo for the Caribbean and northern South America.

For soybeans, the primary foreign ports and associated excess demand regions in Europe include Rotterdam for the European Union North, Barcelona, Spain for Western Europe, Bari, Italy for Southeastern Europe, Odessa, Ukraine for Eastern Europe, and Haifa for the eastern Mediterranean. Other ports used for soybeans include Dammam for Persian Gulf, Singapore for Southeast Asia, Kaohsiung for Taiwan, Ulsan for Korea, Yokohama for Japan, Shanghai for China, and Veracruz for Mexico.

2.3 Structure of the Model

IGTM is a spatial equilibrium model that is of the following form:

$$(1)\qquad \mathbf{Max} - \sum_{i\in l,g,q} \int \boldsymbol{\alpha}(\mathbf{S}_{igq})\mathbf{dS}_{igq} + \sum_{j\in l,g,q} \int \varphi(\mathbf{D}_{jgq})\mathbf{dD}_{jgq} - \sum_{i,j,g,q,m} \mathbf{tc}_{ijgqm} * \mathbf{Transport}_{ijgqm}$$

$$- \sum_{l,g,q} \mathbf{s}_{lgq} * \mathbf{I}_{lgq} - \sum_{l,g,q,m} \mathbf{cul}_{lgqm} * \mathbf{Fromtran}_{lgqm} - \sum_{l,g,q,m} \mathbf{cl}_{lgqm} * \mathbf{Totran}_{lgqm}$$

$$- \sum_{l,g,q,m,m1} \mathbf{CMS}_{lgqmm1} * \mathbf{ModeShift}_{lgqmm1}$$

Subject to

$$(2)\qquad \mathbf{D}_{jgq} + \sum_{m} \mathbf{Totran}_{lgqm} + \mathbf{I}_{lgq} \leq \mathbf{S}_{igq} + \sum_{m} \mathbf{Fromtran}_{lgqm} + \mathbf{S}_{igq(-1)} \quad \forall l,g,q$$

$$(3)\qquad \mathbf{Fromtran}_{lgqm} + \sum_{j} \mathbf{Transport}_{ijgqm} + \sum_{m1} \mathbf{ModeShift}_{lgqmm1}$$

$$\leq \mathbf{Totran}_{lgqm} + \sum_{i} \mathbf{Transport}_{ilgqm} + \sum_{m1} \mathbf{Modeshift}_{lgqm1m} \quad \forall l,g,q,m$$

$$(4)\qquad \mathbf{I}_{lgq} \leq \mathbf{storagecap}_{lg} \quad \forall l,g,q$$

where

l	indexes all regions encompassing excess supply and demand regions, barge locations, and ports and is used to identify areas where grain can be transshipped, stored or switch modes;
i	indexes excess supply regions, $i \subset l$;
j	indexes excess demand regions, $j \subset l$;
g	indexes the grains (corn and soybeans);
q	indexes the quarter of the year;
m	indexes the type of transportation modes;

$\mathbf{S}_{igq}$ gives the excess supply in region i of grain g in quarter q;

$\boldsymbol{\alpha}(\mathbf{S}_{igq})$ is the inverse excess supply function in region i of grain g in quarter q;

$\mathbf{D}_{jgq}$ is excess demand in region j of grain g in quarter q;

$\boldsymbol{\varphi}(\mathbf{D}_{jgq})$ is the inverse excess demand function in region j for grain g in quarter q;

$\mathbf{Transport}_{ijgqm}$ is the quantity shipped from excess supply location i to excess demand location j of grain g in quarter q by mode m;

$\mathbf{I}_{lgq}$ is the amount of grain g stored at region l in quarter q;

$\mathbf{Totran}_{lgqm}$ is the amount of grain g entered into transport from storage or local supply in region l in quarter q by mode m;

$\mathbf{Fromtran}_{lgqm}$ is the amount of grain g removed from transport to meet demand or be entered into storage at region l in quarter q by mode m;

$\mathbf{ModeShift}_{lgqmm1}$ is the amount of grain g in region l that changes mode of transportation from mode m to mode $m1$ in quarter q;

$\mathbf{tc}_{ijgqm}$ is transportation costs (\$) per unit of grain shipment from excess supply source i to excess demand destination j of grain g by mode m;

$\mathbf{cul}_{lgqm}$ is the cost of unloading per unit of grain g unloaded at region l in quarter q by mode m;

$\mathbf{cl}_{lgqm}$ is the cost of loading per unit of grain g loaded at region l in quarter q by mode m

$\mathbf{CMS}_{lgqmm1}$ is the cost of mode shift per unit of grain g at region l in quarter q from mode m to mode $m1$;

$\mathbf{s}_{lgq}$ is the storage costs per unit of grain g stored at region l in quarter q;

$\mathbf{storagecap}_{lg}$ is the storage capacity for grain g in region l.

Equation 1 is the objective function. It maximizes the total net welfare, which is determined as the area under the demand curves, minus that under the excess supply curves minus grain transportation costs, loading, unloading, mode shift and storage costs. It is assumed that demand and supply functions in IGTM are linear.

Constraints are imposed when maximizing the objective function. Equation 2 is the regional balance constraint for grain going into and out of the transport system in each region in each time segment. Equation 3 is a balance for the grain in the transport system on a particular mode by location, grain, mode, and quarter. Finally, Equation 4 is the storage capacity constraint for each grain in each region and each time segment.

2.4 Model Data

Specification of IGTM requires data on the international and domestic excess supply and demand functions; truck, railroad, barge, and shipping rates; and grain storage and loading/unloading charges. This section provides details of these data regarding their sources, a description of the individual datasets, and steps involved to obtain the data used for IGTM.

2.4.1 Excess Supply and Demand Equations

Following Shei and Thompson (1977), we estimate the inverse excess supply equation for each region using estimated excess supply elasticity, quantity exported from the region, and representative price. These data were used to estimate the slope and intercept terms of a linear inverse excess supply equation. In a similar manner, inverse excess demand equations were estimated for each region using excess demand elasticity, quantity imported into region, and a representative price.

As shown in Equation 5, we need own-price demand and supply elasticities, prices and quantities produced, consumed, and exported from a region to estimate excess supply elasticity. In Equation 6, information on estimated own-price demand and supply elasticities, quantity consumed, produced, and imported into a region are used to calculate excess demand elasticity.

$$E_{ExS} = E_S(Q_p/Q_e) - E_D(Q_c/Q_e) \tag{5}$$

$$E_{ExD} = E_D(Q_c/Q_i) - E_S(Q_p/Q_i) \tag{6}$$

where

E_{ExS}	is the excess supply elasticity for a region;
E_{ExD}	is the excess demand elasticity for a region;
E_S	is the own-price supply elasticity for a region;
E_D	is the own-price demand elasticity for a region;
Q_p	is the quantity produced for a region;
Q_c	is the quantity consumed for a region;
Q_e	is the quantity exported from a region; and
Q_i	is the quantity imported into a region.

The estimated domestic own-price demand and supply elasticities of corn and soybeans are obtained from the Food and Agricultural Policy Research Institute (FAPRI 2012) at the University of Missouri. The CRD-level domestic corn and soybean production and aggregate national estimates of domestic corn use and soybean crushing are obtained from the databases of the U.S. Department of Agriculture's Economic Research Service (ERS 2008; 2009; 2012a, 2012b) and National Agricultural Statistics Service (NASS 2008a, 2008b; 2009a, 2009b, 2009c, 2009d, 2009e, 2009f, 2009g). CRD-level soybean crush and corn consumption were estimated using data from various sources including the National Oilseed Processors Association, USDA publications, websites of companies located in a particular CRD, industry experts, and FAPRI staff.

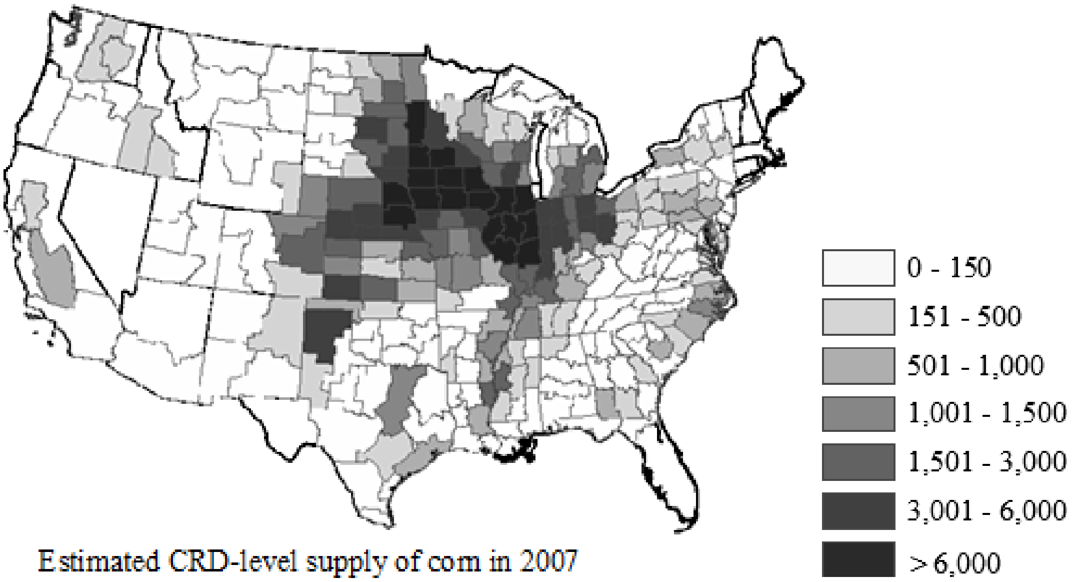
In a similar manner, foreign excess supply and demand elasticities are estimated based on country/region specific own-price demand and supply elasticities obtained from FAPRI. Each country's corn and soybean production, beginning stocks, imports, exports, feed, total disappearance, and ending stocks by crop year are drawn from the Production, Supply and Distribution (PS&D) database compiled by the USDA Foreign Agricultural Service (USDA-FAS 2008b). Foreign trade in terms of monthly/quarterly exports and imports of corn and soybean for selected countries is obtained from the FAS Global Agricultural Trade database (USDA-FAS 2008c) and Global Agricultural Information Network (formerly Attaché Reports) database (USDA-FAS 2008a).

Next, regional production and estimated consumption are used to calculate regional corn and soybean export and import quantities. The above-mentioned data are then used to quantify regional excess supply and demand elasticities. Finally, the regional excess supply and demand equations are derived using calculated regional excess supply and demand elasticities together with regional excess supply and demand quantities and prices for corn and soybeans, which will be discussed in the following subsections.

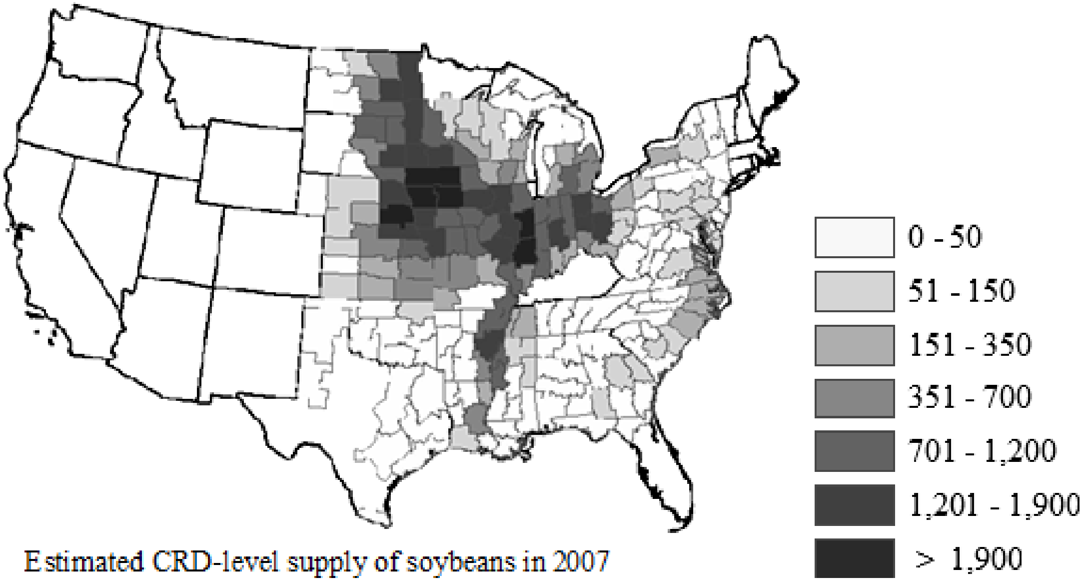
2.4.2 Corn and Soybean Excess Supply and Demand

Domestic excess supply (surplus) and demand (deficit) crop reporting districts (CRDs) for each commodity are identified by subtracting total usage and ending stocks (in bushels) from the production plus initial stocks of a particular commodity. The data are formed for the 2010–2011 marketing year (September 1, 2010 to August 31, 2011). Estimated CRD-level supply of corn and soybeans in 2010 are shown in Figure 1.. Supply regions of corn and soybeans tend to be concentrated in the Corn Belt (Illinois, Iowa, Indiana, Ohio, and Missouri), Great Plains (Nebraska, Dakotas, and Kansas), and Lake States (Minnesota, Michigan, and Wisconsin) regions.

Total consumption is comprised of three categories: seed, feed for livestock, and consumption for food, alcohol, and industrial use (use for crushing purposes in case of soybeans). Finally, the ending stock is the grain on hand in the end of 2010/2011 marketing year (August 31, 2011). The CRD level beginning and ending stocks are obtained by multiplying CRD's share in the total national corn or soybean production with the total national beginning and ending stocks published by USDA. Seed used by each CRD is also obtained in similar fashion by multiplying each CRD's share in the total national planted acreage of corn or soybeans with the total national seed use during the same planting season.



Estimated CRD-level supply of corn in 2007



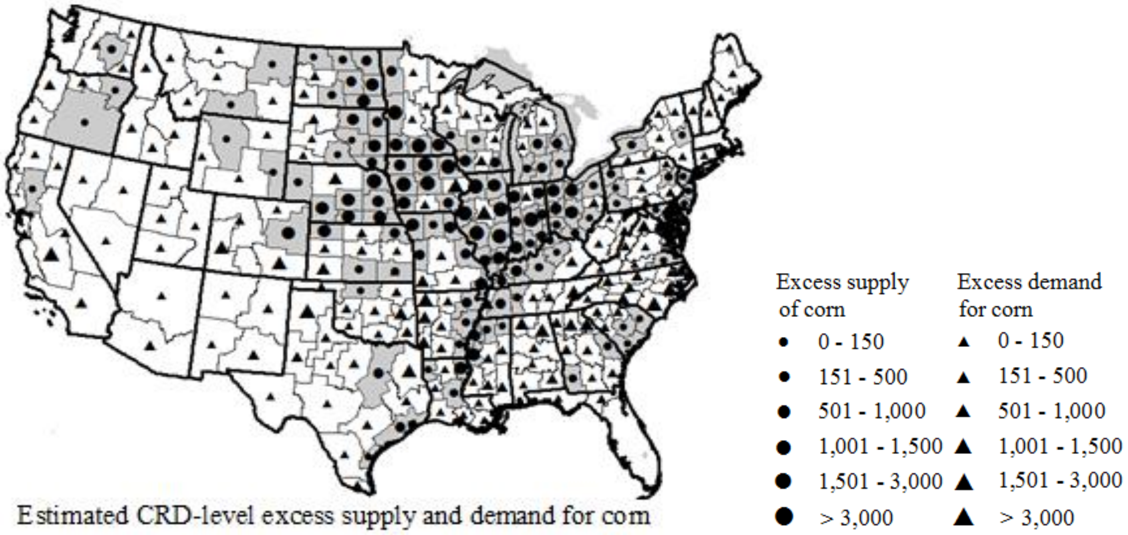
Estimated CRD-level supply of soybeans in 2007

Figure 1. Estimated CRD-level supply of corn and soybeans in 2007 (1,000 tons)

Corn consumption for food, alcohol, and industrial use in each CRD represents the aggregate consumption of wet and dry corn millers (for food, alcohol, and ethanol production) within each CRD drawn from the websites of the company with a facility located in a particular CRD, other publicly available data and by industry experts. For soybean, consumption by soybean crushers in each CRD is obtained by multiplying CRD's share in total state crushing with state crush estimates. NOPA publishes soybean crush estimates in terms of seven geographic regions where each region includes an individual state (such as Iowa and Illinois) or groups of states. The state's crushing share within a NOPA region and CRD's share within a state were unchanged from the 2003-2004 year model (Fellin et al. 2008).

Estimates of corn consumption for feed purposes are based on per animal consumption of corn for each type of animal and number of animals in each CRD. The corn consumption for animal feed (livestock, poultry, and dairy) is estimated based on information on population data and representative rations for the 2007/2008 crop year. Information on livestock and poultry population was obtained from Dr. Edward Yu, the University of Tennessee, and several USDA publications (USDA-NASS 2008a, 2008b; 2009a, 2009b, 2009c, 2009d, 2009e, 2009f, 2009g; USDA-AMS 2008a, 2008b; 2012).

Figure 2 shows the distribution of excess supply and demand regions across the U.S. regions. Excess corn supply regions tend to be concentrated in the Corn Belt region even though this area has the largest consumption of corn for feed, food, alcohol, and industrial uses in the U.S. Other important excess demand regions for corn are in the East-Central U.S. (largely in North Carolina), South-Eastern U.S. (primarily Alabama, Georgia, Mississippi, and Arkansas), Texas, and California.



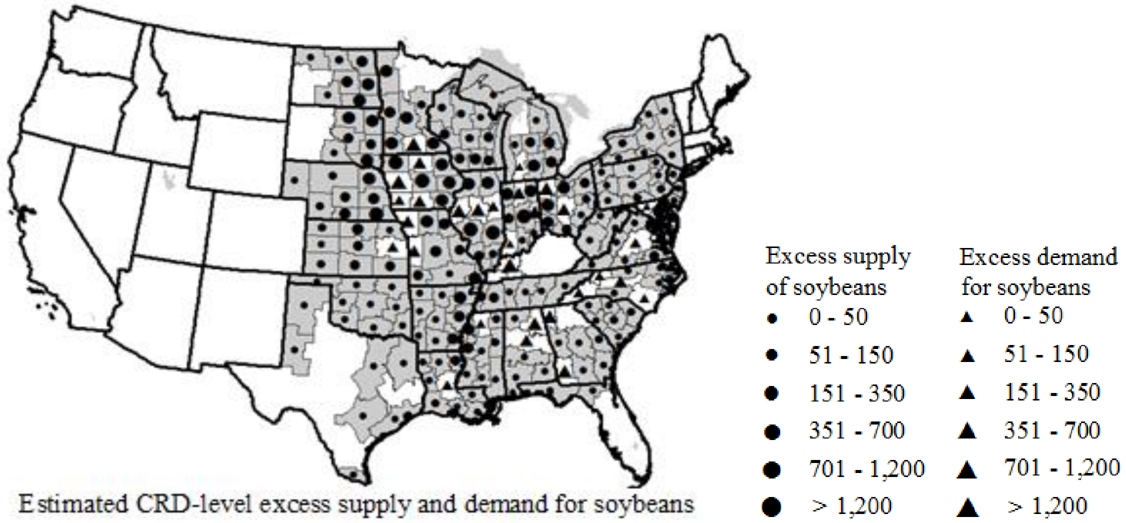


Figure 2. Estimated CRD-level excess supply and demand for corn and soybeans in the 2007/2008 marketing year (1,000 tons)

Excess soybean supply regions tend to be located in the Great Plains (primarily Dakotas and Nebraska), Lake States (largely in Minnesota), and Corn Belt. Excess soybean demand regions are generally located in the Corn Belt, and southeastern states.

2.4.3 Corn and Soybean Prices

For domestic regions, CRD level quarterly corn and soybean prices are collected from the daily county level Posted County Prices (PCP) from archived datasets of the USDA Farm Service Agency (USDA-FSA 2009). These quarterly prices are quarterly averages of three representative county level daily prices in each CRD. Average crop reporting districts contain 10 or more counties. The daily PCP rates from only two or three representative counties are chosen to obtain quarterly prices in each CRD due to the extensive manual labor requirement for obtaining data for each individual county. For example, Alabama CRD 30 contains 16 counties and only three interspersed counties, Jefferson, Pickens, and Tallapoosa, are chosen as a representative sample.

For foreign countries, the FOB ship grain prices were obtained from public information sources as detailed below with the remainder estimated from available price data and shipping rates.[1] For Argentina and Brazil, quarterly FOB prices are used for corn and soybeans. Argentinean corn and soybean quarterly FOB prices are obtained from the official website of the Argentinean Ministry of Agriculture. The USDA-AMS report (USDA-AMS 2012) provides information on soybean prices (in $US/MT) at major exporting regions in Brazil and transportation costs to the major exporting ports of the country. Brazilian quarterly FOB port soybean prices are calculated as the weighted average of regional soybean prices times the weighted average transportation charges to

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[1] In order to avoid a possible discrepancy between actual and estimated values of grain handling charges, FOB prices were used whenever possible because they already reflect grain-handling charges.

ports. Finally, the quarterly FOB corn prices (USD/MT) are represented by average monthly corn prices after converting them into U.S. dollars and the data is obtained from the Foreign Agricultural Service reports (USDA-FAS 2008a).

2.4.4 Elasticities

By using own-price elasticities obtained from FAPRI, the long-run excess supply and demand are estimated for both domestic and foreign excess supply and demand regions. Estimated domestic elasticities for 2004–2005 were employed in the model due to abrupt fluctuations in prices in 2007-2008 in order to avoid poorly represented long-run elasticities. Current foreign elasticities obtained from FAPRI are used in the 2010 IGTM model (FAPRI 2012). Domestic corn and soybean elasticity estimates are calculated for each major excess supply and demand CRD regions and for groups of CRDs if they are insignificant players. Similarly, foreign elasticity estimates are calculated for a specific country if it is a major importing or exporting country otherwise adjacent small players are grouped together. For example, major corn importing countries like Japan, Korea, and Mexico have country-specific elasticity estimates and non-major importing/ exporting countries are pooled into broader geographic region.

2.4.5 Distance Data

The distance data is comprised of three separate distance matrices for truck/rail, barge, and ship transportation modes. These include: (1) distances (in miles) between domestic, Canadian, and Mexican regions via truck and railroad, (2) barge distances between barge loading locations with exporting ports, and (3) inter-port travel distances (in nautical miles) between domestic and international ports plus those between international ports. The distances between each CRD is represented by truck/rail distance matrix and provided by Texas Transportation Institute (TTI). The trucking alternative for grain is limited to hauls of 300 miles or less, because trucking beyond that mileage is not practical or economically feasible for large shipments. Overland shipments to Mexico from the U.S. are linked to three of the five major corn and soybeans excess demand regions and over-the-ocean shipments are linked to the Veracruz port. An internal Mexican distance matrix connects all five major Mexican corn and soybeans excess demand regions with each other and Veracruz.

Separate inter-port distance matrices are constructed for corn and soybeans due to different trade flows between the international regions. For example, in the corn-port-distance matrix, all major grain exporting U.S. ports are linked to representative foreign ports, which in turn are connected to other international excess demand and supply regions. Data from portworld.com website was used as the primary source (PortWorld 2013) for obtaining port distances. The distance between the representative barge locations is based on Upper Mississippi River Navigation Charts published by U.S. Army Corps of Engineers and other online mapping resources (USACE 2009).

2.4.6 Handling and Storage Charges

The model requires grain storage charges at county elevators and loading/unloading costs associated with each type of transportation mode in each CRD and as well as at domestic intermodal transfer locations. Similar charges are also needed in the international portion of the model. The data on handling and storage charges (in

USD/MT) is obtained from publicly available sources such as USACE publications and industry expert estimates from the National Grain and Feed Association. Whenever available, port FOB grain prices are used in the estimation of excess supply equations for exporting regions, which eliminates the need for explicitly including handling and transportation charges of these regions.

2.4.7 Rail and Truck Rates

In obtaining the domestic rail rates for grain shipments the annual public waybill data for 2010 and 2011 published by Surface Transportation Board (STB) were used as primary data set (USDOT-STB 2010; 2011). STB's annual public waybill data contains detailed information (such as mileage, volume, cost, date and time, etc.) on the shipment of many different agricultural and non-agricultural commodities between Business Economic Areas (BEA). Because the model requires CRD level data, the BEA level rail rates are converted into CRD level rates in order to maintain the spatial consistency of the data explained below.

Based on the waybill data, corridors with high volume of shipments for each commodity are identified in order to obtain representative rail-transport charges. In particular, corn waybill data is broken into eight geographic regions where first seven represent seven railroad corridors with high volume of shipments between two (origin-destination) BEA regions or groups of such regions. The last group includes all other corn shipments between regions that are not reflected in any of the seven corridors. The soybean shipments are categorized in a similar fashion, including the Pacific Northwest and Gulf of Mexico corridors and a group for all other shipments.

The rail rate per ton-mile for each individual shipment in each of these regions is found by dividing total revenue from the shipment (both with and without miscellaneous charges) by the number of tons and miles of the haul. Then, the quarterly rates (USD/short ton-mile) were calculated as the arithmetic average of rail rates (USD/short ton-mile) within each corridor for each quarter. Quarterly rates for unit train shipments (for shipments equal to or greater than 50 rail cars) were also calculated in a similar fashion. The unit train rates are typically lower than non-unit-train shipment rates. All other rail shipments that are not represented by any corridor are pooled into single general group and the quarterly average rates are calculated for three distinct distance categories. These categories include rail shipments with distances 100 to 500 miles, 501 to 1000 miles, and over 1000 miles. Finally, the obtained rail rates are used for shipments between CRDs, barge locations, and ports by applying the rates from appropriate corridors.

In obtaining the estimates of truck rates for the domestic hauls of 300 miles or less, the quarterly data from the USDA's *Grain Transportation Report* (USDA-AMS 2008a) is used as the primary data source. The per-ton-mile truck rates are estimated by regression analysis. This is applied to the trucking distance matrix to get rates for shipments.

2.4.8 Barge Rates

The barge rates (USD/ Metric ton) are developed for 32 barge loading/unloading locations (mostly along the Mississippi River system) to seven major barge destination locations. These include Baton Rouge, LA; Glasgow, MO; Huntsville, AL; Knoxville, TN; Memphis, TN; Nashville, TN; and Louisville, KY. The data for barge rates are weekly per ton spot-barge tariff rates per short ton published by the USDA (USDA-AMS 2008b). The quarterly barge rates represent average weekly rates within a given quarter at a given barge location. Because the original weekly spot-barge tariff rates from AMS do not cover low-volume, small river origin and destination points, the rates for such routes are obtained from the estimates of industry experts and private consultants.

International grain ship rates are estimated using data obtained from the USDA-AMS and the International Grain Council (IGC).[2] The quarterly ship rates are then estimated based on regression using above datasets from these sources and the corresponding distances. Individual rates are estimated for two trading countries if they fall into the list of major grain exporting or importing countries. Otherwise, the rates are estimated for broader geographic regions that represent a group of countries with a representative port city. For example, for most northern EU and Scandinavian countries, Rotterdam, Netherlands is used as a representative port.

2.4.9 Comparison of Historical and Model-Projected Flows

As a way to validate IGTM, this section provides a comparison of historical and model-projected transportation flows. Available historical data used to compare with the model-projected results are collected from various sources including the U.S. Army

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[2] The IGC database provides reasonable coverage of international grain freight rates between major export and import regions. For example, the data set includes freight rates between U.S. Gulf Coast and Japan, China, Brazil, South Korea, Morocco, and Egypt. However, the IGTM requires more comprehensive data set for estimating ship rates. The rates obtained from USDA-AMS, for important trade routes such as Gulf Coast to Japan and Pacific Northwest to Japan, are also used to complement the IGC data.

Corps of Engineering, the USDA-AMS, the USDA-FAS, and previous transportation studies in particular recent studies from Marathon and Denicoff (2011) and Denicoff et al. (2010). Because the analysis in Section 3 focuses on the long-term climate change impacts on the transportation system, IGTM is developed and validated in such a way that the model can replicate the general pattern of grain transportation flows in the real world. To represent the general pattern of the flows, model-projected results were compared with the range of historical flows during a period mostly in recent years depending on the availability of the data instead of choosing a particular year. Overall, model-projected quantities of corn and soybeans transportation flows were within the range of their actual quantities of transportation flows, as shown in Tables 3-6.

Table 3 shows that model-projected quantities and shares of corn and soybeans for export classified by modes of transportation are in their historic ranges for IGTM 2007 during 2005-2007 and for IGTM 2010 during 2008-2010. Overall, barges play an important role in the export of corn and soybeans, which is followed by the rail and truck systems, respectively.

Table 3. Historic and Model-Projected Quantities and Shares of Corn and Soybeans for Export Classified by Modes of Transportation

	CORN		SOYBEANS	
Mode	Model-Projected Quantities (1000 tons)	Range of Historic Quantities (1000 tons)	Model-Projected Quantities (1000 tons)	Range of Historic Quantities (1000 tons)
	2007	2005-2007	2007	2005-2007
Truck	5,588	3,457-8,252	1,716	1,725-6,381
	(9)	(7-13)	(6)	(6-19)
Rail	22,934	18,380-24,735	11,530	10,676-13,541
	(37)	(32-39)	(42)	(34-44)
Barge	32,677	28,778-34,689	14,355	15,030-15,242
	(53)	(50-57)	(52)	(45-50)
Total	61,200	58,875-63,420	27,602	30,506-34,147
	(100)	(100)	(100)	(100)
	2010	2008-2010	2010	2008-2010
Truck	4,184	1,692-6,803	2,430	3,895-7,757
	(8)	(3-12)	(6)	(8-21)
Rail	23,739	19,801-24,615	19,259	14,492-20,484
	(43)	(38-42)	(49)	(39-44)
Barge	27,205	27,457-31,174	17,917	15,089-21,864
	(49)	(47-57)	(45)	(40-47)
Total	55,129	52,752-58,875	39,606	37,338-46,243
	(100)	(100)	(100)	(100)

Note: 1) Shares of corn and soybeans for export are in parenthesis. 2) Ranges of historic data of corn and soybeans are from 2005 to 2007 collected from Marathon and Denicoff (2011).

Table 4 shows domestic flows classified by modes of transportation. The simulated results of corn and soybeans shipped via rail and barge are in their historic ranges except for corn shipped via barge where model-projected quantities are significantly lower than actual quantities. However, barge transportation accounts for 1% of total domestic corn transportation volume (Marathon and Sparger 2012). As expected, model-projected shipments of corn and soybeans via truck are lower than their historic ranges estimated by Marathon and Denicoff (2011) because shipments within CRD, mainly accomplished by truck, are not modeled.

Table 4. Historic and Model-Projected Quantities (1,000 tons) and Shares of Corn and Soybeans Exiting via U.S. Port Areas

Port Areas	CORN		SOYBEANS	
	Model-Projected Quantities (1000 tons)	Range of Historical Quantities (1000 tons)	Model-Projected Quantities(1000 tons)	Range of Historical Quantities (1000 tons)
	2007	2006-2008	2007	2006-2008
Lower Miss	35,366	27,829-34,873	15,086	15,139-16,925
	(57.8)	(54.7-64.0)	(54.7)	(52.2-57.6)
Texas Gulf	1,430	1,308-2,925	131	108-176
	(2.3)	(2.6-5.3)	(0.5)	(0.4-0.5)
PNW	13,649	9,274-12,724	8,625	6,042-9,451
	(22.3)	(17.2-25.0)	(31.2)	(21.6-29.2)
Great Lakes	1,650	280-1,706	742	334-1,111
	(2.7)	(0.6-3.1)	(2.7)	(1.0-4.0)
Atlantic	183	584-769	213	565-587
	(0.3)	(1.1-1.4)	(0.8)	(1.8-2.0)
Overland	8,923	4,275-7,265	2,804	3,458-4,580
	(14.6)	(7.8-14.3)	(10.2)	(12.3-15.7)
Total	61,200	50,857-54,861	27,602	28,026-32,333
	(100)	(100)	(100)	(100)
	2010	2009-2011	2010	2009-2011
Lower Miss	30,090	25,955-29,382	21,403	19,375-22,569
	(54.6)	(59.2-63.6)	(54.0)	(54.5-56.9)
Texas Gulf	4,603	792-1,702	405	925-2,399
	(8.4)	(1.8-3.8)	(1.0)	(2.7-6.1)
PNW	12,293	8,478-9,983	11,360	7,309-10,298
	(22.3)	(19.1-21.2)	(28.7)	(21.5-24.9)
Great Lakes	766	122-352	804	385-780
	(1.4)	(0.3-0.8)	(2.0)	(1.1-2.0)
Atlantic	2,294	302-471	1,731	1,077-1,388
	(4.2)	(0.7-1.1)	(4.4)	(3.0-3.4)
Overland	5,082	5,057-7,307	3,902	3,040-4,293
	(9.2)	(11.4-16.7)	(9.9)	(7.7-12.6)
Total	55,129	43,880-47,948	39,606	34,062-41,411
	(100)	(100)	(100)	(100)

Note: 1) Share of corn and soybeans for export are in parenthesis. 2) Ranges of historic data of corn and soybeans are from 2006 to 2010 collected from Marathon and Denicoff (2011) and Grain National Reports from the USDA-AMS (USDA-AMS 2007; 2008b; 2009c; 2010; 2011a).

In Table 5, model-projected quantities and/or shares of corn and soybeans exiting via U.S. port areas are generally in the range of their historic quantities and share. The lower Mississippi River ports and the Pacific Northwest ports are the major destinations for corn and soybean export from the U.S. to the rest of the world.

Table 6 contrasts model-projected shares of corn and soybeans exiting at the lower Mississippi River ports classified by modes of transportation with their ranges of historic shares from 2005-2009. Projections are comparatively close to their historic ranges and the table reveals that almost all corn and soybean are shipped via barge to these ports. Projected quantities are deemed to be reasonably close to historical data. However, further refinement or re-specification may result in a different set of quantities.

Table 5. Historic and Model-Projected Shares of Corn and Soybeans Exiting at the Lower Mississippi River Ports Classified by Mode of Transportation

Modes	CORN		SOYBEANS	
	Model-projected share (%)	Historical share (%)	Model-projected share (%)	Historical share (%)
	2007	2005-2009	2007	2005-2009
Barge	92	87-91	95	87-89
Truck & Rail	8	9-13	5	11-13
Total	100	100	100	100
	2010	2005-2009	2010	2005-2009
Barge	90	87-91	84	87-89
Truck & Rail	10	9-13	16	11-13
Total	100	100	100	100

Note: Ranges of historic data of corn and soybeans are from 2005 to 2009 collected from Marathon and Denicoff (2011) and the USDA-AMS (2011a).

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	CORN		SOYBEANS	
Modes	Model-projected share (%)	Historical share (%)	Model-projected share (%)	Historical share (%)
	2007	2005-2009	2007	2005-2009
Barge	92	87-91	95	87-89
Truck & Rail	8	9-13	5	11-13
Total	100	100	100	100
	2010	2005-2009	2010	2005-2009
Barge	90	87-91	84	87-89
Truck & Rail	10	9-13	16	11-13
Total	100	100	100	100

Note: Ranges of historic data of corn and soybeans are from 2005 to 2009 collected from Marathon and Denicoff (2011) and the USDA-AMS (2011a).

Any decision based on the model's adequacy depends on whether the model yields the correct amount of modal transportation volume and modal share within historical ranges. In addition, the model should have the correct grain flows from grain supply regions to major grain destinations such as port locations and to regions with large livestock operations. Based on these comparisons, the model was deemed adequate for the studies conducted in Sections 3 and 4.

3. U.S. BIOFUEL PRODUCTION AND IMPLICATIONS FOR AGRICULTURAL TRANSPORTATION AND MARKETS

Production of biofuels in the U.S. grew by almost a factor of 10 between 2000 and 2012 (RFA 2012). Biofuel production prospects and market penetration has been influenced by policies and energy prices. One influential policy involves developments under the Clean Air Act involving the oxygenate requirement for gasoline. Ethanol is one such oxygenate and its usage has been promoted by bans placed on alternative oxygenates. Another significant factor in biofuel growth in the United States is the dive toward renewable energy, as required by the Renewable Fuel Standards (RFS) of Renewable Fuel Provisions of the Energy Bills in 2005 (H.R.6-2005) and 2007 (H.R.6-2007). Energy prices have also been influential. Ethanol producers experienced high growth during the period from 2000-2010. The production of ethanol reached 1.6 billion gallons in 2000, which required 630 million bushels of corn (RFA 2012 and USDA-ERS 2012a) while, production of ethanol increased to 3.9 billion gallons in 2005 and 13.2 billion gallons in 2010, which required 1.6 and 5 billion bushels of corn respectively.

This unprecedented explosion in usage of grain for fuel production strengthened the linkages between agricultural and energy commodities (McPhail and Babcock 2012). Corn and soybean prices increased and rising energy prices also played a major role. Corn and soybean prices increased from $2 and $5.66 per bushel in 2005 to $5.18 and $11.30 in 2010 respectively (USDA-ERS 2012a; USDA-ERS 2012b).

Agricultural transportation is affected by supply and demand dynamics, which is in turn influenced by domestic biofuels production and policies. Regional grain transportation volumes and modal shares have been affected (Marathon and Sparger 2012). A six-year average volume of corn transportation via rail increased from 71.3 million tons per year during 1999-2004 to 76.9 million tons per year during 2005-2010 and rail modal share decreased from 30% to 26% respectively. Barge shipments decreased from 38.8 to 33.2 million tons and barge modal share decreased from 17% to 11%. Finally, volume of corn transport via truck increased from 124 to 186.9 million tons and its modal share increased from 53% to 63% (Marathon and Sparger 2012).

This essay has the main objective of understanding the implications of U.S. biofuel production, mandated by Renewable Fuel Provisions of the Energy Bills in 2005 and 2007, for transportation system use, grain prices, the welfare of consumers and producers, and agricultural transportation.

3.1 Biofuel Basics

Basic knowledge of how biofuels are produced and used is useful in carrying out the proposed research. Brief descriptions of important terms and concepts are given below.

3.1.1 Ethanol

Ethanol is the major biofuel produced in terms of volume. The Renewable Fuels Association defines ethanol and its production process, as “Ethanol, or ethyl alcohol, is a renewable alcohol fuel made from agricultural resources. In the U.S. ethanol is primarily produced from the starch contained in grains such as corn, grain sorghum, and wheat through a fermentation and distillation process that converts starch to sugar and then to alcohol" (RFA 2009a). Currently in the United States, the main feedstock for ethanol production is corn accounting for 97% (USDA 2008a). As of 2010, domestic ethanol production topped 13.2 billion gallons, which accounted for about 10% of nation's gasoline consumption. Sugar cane is another main feedstock, although it is mainly used in Brazil for ethanol production. Brazil satisfied more than half of its needs for gasoline with sugarcane ethanol in 2010 (SugarCane.org 2013).

Conventional corn-based ethanol is produced by two production processes: wet and dry milling, with dry milling being the most common. Dry milling also yields byproducts such as condensed distiller's solubles (CDS), dried distillers grains (DDGs), and carbon dioxide. Wet milling yields byproducts of corn oil, corn gluten meal, and carbon dioxide. DDGs and corn gluten meal are used as livestock feed while corn oil and carbon dioxide are used for other industrial purposes (RFA 2009b).

The U.S. Department of Energy's Energy Information Agency (EIA) reports that nearly all U.S. ethanol is blended into gasoline at ratios up to 10 % by volume to produce a fuel called E10 or "gasohol." All cars built after 1970 can run on the ethanol blend E10, however, high-level ethanol blends from E60 to E85 requires a "flex-fuel" vehicle (EIA 2009a).

3.1.2 Biodiesel

Biodiesel is defined by EIA (2009c) as follows. "Biodiesel is a fuel typically made from soybean, canola, or other vegetable oils; animal fats; and recycled grease. It can serve as a substitute for petroleum-derived diesel or distillate fuel." A biodiesel produced from these sources through transesterification is known by the acronym FAME (Fatty Acid Methyl Ester). Glycerin is a biodiesel by-product that is used in soaps and other products. The primary sources of U.S. biodiesel production are soybean oil and yellow grease, primarily recycled cooking oil (Radich 2004). According to the National Renewable Energy Laboratory (NREL 2005), biodiesel blends of B20 (20% biodiesel and 80% petroleum diesel) or lower can be used in any diesel engine with proper fuel tank maintenance and fuel blending.

Soybean oil, the most common feedstock for biodiesel production, is produced by crushing soybeans. According to the National Biodiesel Board (2011), during the crushing process a bushel (60 pounds) of soybeans yields 48 pounds of soybean meal and 11 pounds of crude soybean oil. The crude soybean oil is the item that is converted into biodiesel. In addition, biodiesel reduces lifecycle carbon emissions by 60-80%, relative to regular petroleum based diesel.

3.2 Overview of United States Biofuel Policies

Biofuel production prospects and market penetration have been influenced by a number of policies. One influential policy involves the Clean Air Act (Clean Air Act 1990) oxygenate requirement for gasoline. Ethanol is one such oxygenate and its usage has been promoted by bans placed on alternative oxygenates. By the end of 1990s, states banned Methyl Tertiary Butyl Ether (MTBE) for use as a gasoline oxygenate, after discovering its negative effects on health and the environment. In 2000, the Environmental Protection Agency (EPA) recommended that MTBE be banned nationally.

By 2004, 18 states including California, had banned the use of MTBE and began switching to ethanol as a gasoline oxygenate. Consequently, as these states began switching to ethanol, demand for fuel ethanol increased steadily.

Policies related to clean air and energy, along with the energy prices and economic incentives have accelerated the U.S. adoption of biofuels. The U.S. Congress revised and expanded the Clean Air Act with a major amendment in 1990. The 1990 Amendment encourages the development and sale of alternative fuels, including ethanol and biodiesel. It gave the EPA a broader authority to implement and enforce regulations to reduce air pollutants. Specifically, the 1990 Amendment required the EPA to establish a national renewable fuel program to increase the amount of biofuels.

Biofuels are also encouraged by legislated minimum requirements for blending in transportation fuels. The Energy Policy Act of 1992 (H.R.776) encouraged the use of alternative fuels and defined biodiesel as an “alternative fuel.” Subsequent biofuel related policies such as the Energy Policy Act of 2005 (H.R.6-2005) and the Energy Independence and Security Act of 2007, also known as EISA 2007, (H.R.6-2007) required that transport fuels contained minimum amounts of renewable fuel.

The Renewable Fuel Standard Program, under the Energy Policy Act of 2005, established the first of the renewable fuel volume mandates, known as RFS1. RFS1 stipulated that a minimum amount of renewable fuels be blended into gasoline. Namely, it required that 7.5 billion gallons of the national fuel supply be provided by renewable fuels by 2012 (EIA 2009b). The act also offered incentives for the production of cellulosic biofuels, any fuel produced from cellulosic feedstock, with the goal of producing 1 billion gallons of such fuel by 2015.

The Energy Independence and Security Act of 2007 further expanded the biofuel requirements mandating that 36 billion gallons of renewable fuels be blended into gasoline and diesel by 2022. These provisions are known as RFS2. RFS2 categorizes renewable fuels into conventional biofuels (corn ethanol) mandating blending of no more than 15 billion gallons (BG, and advanced biofuels (cellulosic biofuel and biomass-based biodiesel) mandating blending of a minimum of 21 BG (EIA 2009b). Cellulosic biofuel and biomass-based biodiesel are allocated separate requirements within the advanced biofuels category. One hundred million gallons of cellulosic biofuel is required in 2010 rising up to 16 BG in 2022. The requirement for biomass-based biodiesel starts from 0.5 BG in 2009 and ends up reaching 1BG in 2012. These specific requirements on advanced biofuels result in a cap on the conventional, corn-starch-based, ethanol production. Under RFS2, corn-based ethanol rises from 10.5 BG in 2009 to 15 BG in 2015 and stays at that level until 2022 (see Table A2). It is also important to note that the biofuels industry's ability to produce cellulosic ethanol has been lagging the RFS2 mandated levels and the EPA has reduced these mandates.

In addition to above policies, federal and state governments provided several tax credits, subsidies, grants, loan guarantees and other types of incentives to encourage biofuels production and consumption. All federal tax incentives expired on December 31, 2011. The following are the examples of expired tax credits. Major federal tax incentives for biofuel blenders included Volumetric Ethanol Excise Tax Credit (VEETC) and

Biodiesel Mixture Excise Tax Credit. Under VEETC, an ethanol blender was eligible for a tax incentive for 45 cents per gallon of pure ethanol blended with gasoline. This tax credit was first applied against the blender's fuel tax liability and any remaining credit could be refunded from IRS (Reference H.R. 4853, 2010, Section 708; and 26 U.S. Code 6426). Under the Biodiesel Mixture Excise Tax Credit, a blender who blends pure biodiesel, agri-biodiesel, or renewable biodiesel is eligible for $1.00 per gallon of pure biodiesel blended into petroleum diesel (Reference H.R. 4853, 2010, Section 701; and 26 U.S. Code 6426). Small-scale biofuel producers were eligible for a Federal Small Ethanol and Agri-Biodiesel Producer Tax Credit. Under this program, small ethanol and biodiesel producers were eligible for small producer credit of 10 cents for every gallon produced up to 15 MG a year. A small producer is one who has less than 60 MG of productive capacity at any given time throughout the tax year (H.R. 4853 and 26 U.S. Code 40, 40A).

The federal government provides other incentives to encourage biofuel production and consumption. For example, the federal government provides the Alternative Fuel Infrastructure Tax Credit that offsets the 30% cost of alternative fueling equipment up to $30,000 on equipment installed after December 31, 2005. The Advanced Biofuel Production Grants and Loan Guarantees Bio-refinery Assistance Program provides loan guarantees for commercial bio-refineries up to 50% of a project, not exceeding $250 million, to develop, construct new bio-refineries, or to retrofit existing ones (U.S. Code 8103).

At the state level, almost all governments have implemented state-level incentive programs and regulations. Most states implemented Alternative Fuel Vehicle (AFV) and Fueling Infrastructure Loans programs that provide rebates on purchased biofuels, low cost loans or rebates up to certain amount to replace conventional vehicles with AFVs or convert vehicles to operate on alternative fuels. In addition, many state governments provide grants to biofuel producers for each gallon of biofuels produced through Ethanol and Biodiesel Production Grants programs. For example, the state of Kansas offers a biodiesel production incentive of 30 cents per gallon sold (Kansas Statues). The state of Iowa provides a tax credit for retailers of 6.5 cents per gallon of ethanol through the Ethanol Blend Retailer Tax Credit program if the retailer meets a certain percentage of ethanol mix. Another example is Iowa. This state requires ethanol to be at least 12% of total gasoline sales in order for a retailer to be eligible (Iowa Code 422.110). Finally, it is also important to note incentives for energy prices. Figure 3 shows the weekly real petroleum, gasoline, diesel, and ethanol prices for 2000 through 2012. The large increase in prices also contributed greatly to industry expansion. It shows an increase in the price of ethanol in 2005, the year when the RFS1 biofuel mandates became effective. In general, the variability in the price of ethanol reflected a similar variability in the price of other energy commodities.

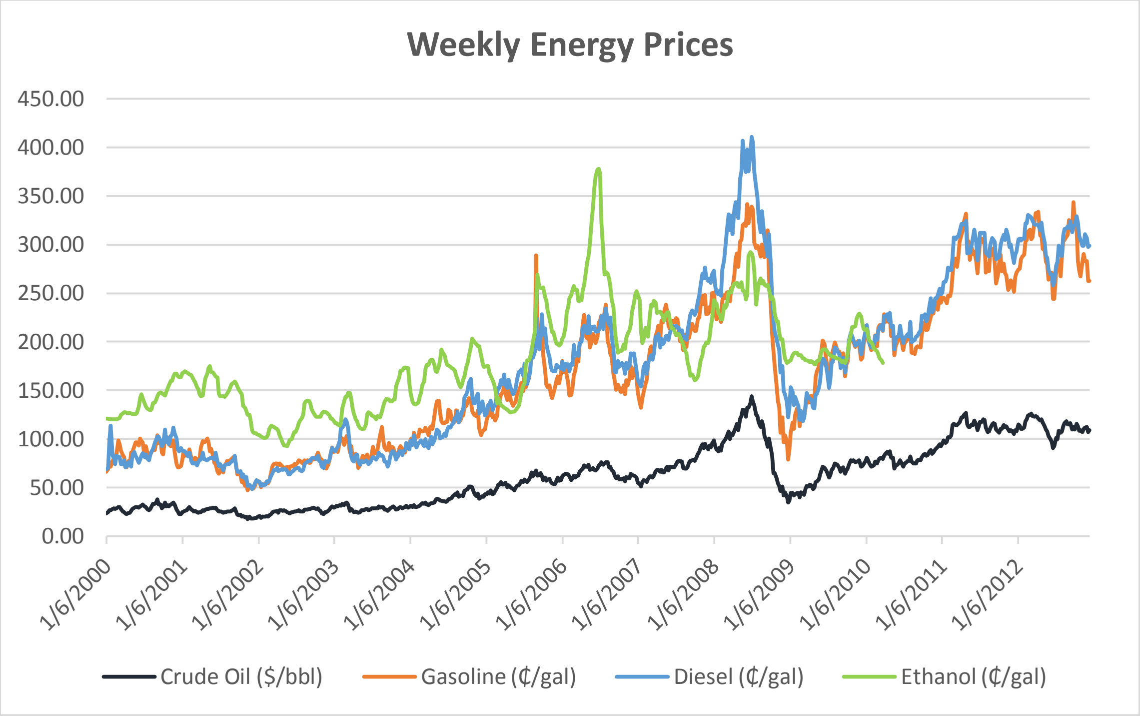

Figure 1. Historical petroleum, gasoline, diesel, and ethanol prices
Source: Datastream (except ethanol); Hart Energy (for ethanol)
Note: The crude oil price represents the price of Brent crude oil in USD per barrel, gasoline and diesel prices represent FOB prices at New York Harbor in cents per gallon, and ethanol price represents the national average in cents per gallon. Ethanol price is not available after 3/25/2010

3.3 Previous Economic Studies

Effects of recent U.S. biofuels policies on the biofuels industry, grain transportation flows, and on agriculture as whole have been researched by a number of investigators (Babcock 2008; Hayes et al 2009; Tokgoz et al 2007; Wilson et al. 2008). Babcock investigated the distributional implications of U.S. ethanol subsidies finding that the welfare losses outweigh the welfare gains including greenhouse gas benefits. He concludes that the ethanol subsidies transferred to corn growers are not efficient. Closely related research by Tokgoz et al. investigated the effects of U.S. biofuels policies on ethanol production, crop acreages, prices, and trade. They found that expansion of U.S. ethanol production leads to higher long-run crop prices, which in turn lead to higher meat, egg, and dairy prices at retail level. They also found that permanently higher oil prices cause U.S. ethanol production to expand significantly.

Hayes et al. (2009) investigated the implications of high-energy prices and biofuel policies including RFS mandates and tax incentives, for agricultural markets. They found that the linkages between the agricultural and energy sectors become increasingly strong in the presence of biofuel policies and higher energy prices, where high-energy prices raise the prices of most agricultural commodities. They also found that biofuels production expands in response to two factors: 1) RFS mandates when energy prices are low, or 2) higher energy prices when RFS mandates are exceeded. McPhail and Babcock (2012) used a stochastic partial equilibrium model to investigate the effects of RFS mandates and the blend wall on commodity price variability. Their findings indicate that RFS mandates and the blend wall increase the price variability of corn and gasoline when supply shocks occur in markets.

Sarica and Tyner (2013) used the U.S. EPA MARKAL model to evaluate the impacts and costs of U.S. biofuel policies. The model represents the entire spectrum of energy supply from various sources, including traditional energy technologies (e.g. oil, natural gas, hydro, coal, etc.), corn, and corn stover. Their findings indicate that ethanol production from corn reaches 15 billion gallons and thermochemical biofuel reaches 13 billion gallons by 2030 under a reference case of no government intervention. Production of thermochemical biofuels becomes profitable after 2020. However, in the presence of

RFS mandates ethanol production reaches 15 billion gallons in 2015 and remains at that level afterwards. They estimate that the cost of the binding RFS mandates is 33 cents/gal in 2015 and 12 cents/gal afterwards.

3.4 Modeling Procedures and Data

In this analysis, different scenarios are used to characterize the effects of biofuel production on grain transport, grain prices, and producers' and consumer's welfare. Simulated results will be compared with a baseline model to quantify the effects of biofuel production with and without the RFS1 and RFS2 mandates. Calibrated IGTM models for 2007 and 2010, developed in Section 2, are used to form the baselines. Two types of scenarios are formulated. The first pre-RFS1 and pre-RFS2 simulate the effects of biofuel production for 2007 and 2010 respectively, if the biofuel production levels associated with RFS1 and RFS2 do not occur. The second simulates the future effects of biofuel production for crop year 2021 in a forward-looking manner and uses IGTM 2010 with technology and demand projections as the baseline.

3.4.1 International Grain Transportation Model (IGTM)

The IGTM model will be used to examine the transportation implications of U.S. biofuel production. This model (IGTM) is explained in Section 2. Briefly, IGTM simulates quarterly grain production, consumption, prices, and storage. It also predicts quarterly transportation flows by mode (trucks, rail, barges, lake vessels, and ocean-going ships) to and from 303 U.S. regions (largely crop reporting districts) going through 42 intermediate shipping points. In addition, it indicates where modes can be changed and depicts world trade. World trade is modeled on a quarterly basis with 118 foreign exporting and importing countries/regions.

3.4.2 Developing Retrospective Scenarios

Scenarios are used to characterize the effect of biofuel production on grain transport. Scenarios are reflective of the production environment as of 2001, as of 2007 mandates and as of 2012.

3.4.2.1 Pre-RFS1 scenario. The pre-RFS1-scenario simulates production as of 2001 and is compared with production after the RFS1 mandates as of 2007. As discussed in the previous section, the model uses the excess demand or excess supply quantities by region. That balance reflects the difference between total regional grain supply and regional demand for grain and includes grain used: 1) for in-region biofuel production and 2) in-region non-biofuel consumption. In the pre-RFS1 scenario, 2007 levels of grain supply capability and non-biofuel grain demand levels plus 2000 levels of grain use for biofuel production were used. That scenario looks at pre-biofuel boom feedstock usage. Consequently, more corn and soybeans become available for non-biofuel consumption due to lower grain demand for biofuel production. Because the adjusted demand for ethanol changes the local consumption, it alters the excess demand or supply quantities of grain in the region. In addition, the excess demand and supply curves were also recalculated for each CRD, because excess demand and supply elasticities use regional excess demand and excess supply quantities as input.

3.4.2.2 Pre-RFS2 scenario. The pre-RFS2-scenario simulates the biofuel production levels and associated production of 2007, which is compared with 2010 as the reference year. The baseline IGTM 2010 model is adjusted by replacing the 2010 corn and soybean biofuel feedstock demand with 2007 data in order to develop a solution without the effects of RFS2 and 2007-2010 energy price rises. The lower grain usage for ethanol changes the excess demand or supply quantities of grains in the region. The excess demand and supply elasticities were also recalculated for each CRD.

3.4.2.3 Data for the pre-RFS1 and pre-RFS2 scenarios. The USDA's Feed Grains Yearbook provides detailed corn use for different purposes including biofuel production (USDA-ERS 2012a). In marketing year (MY) 2000, nearly 630 million bushels of corn were used for making ethanol. Corn demand for ethanol reached 3 billion bushels in MY 2007. Therefore, under the pre-RFS1 scenario, corn demand for ethanol was decreased from 3 billion to 630 million bushels. By 2010, 5 billion bushels of corn was used to produce ethanol. Similarly, the 2010 biofuel corn requirement was decreased by 2 billion bushels to reflect corn use in 2007 for ethanol under the pre-RFS2 scenario.

Soybean requirements for biodiesel production in MGY 2000 were very small with 1.640 billion bushels of soybeans crushed to produce soybean oil (USDA-ERS 2012b), producing 8.4 million metric tons of oil. In 2000, 2 million gallons of biodiesel were produced (NBB 2012). This represents 2.9 million bushels of soybean demand for biodiesel production. In 2007, 450 million gallons of biodiesel were produced (NBB 2012) and this represents the use of 434 million bushels of soybeans for biodiesel production. Therefore, 2007 soybean demand for biodiesel production decreased from 434 million bushels to 2.9 million bushels in the pre-RFS1 scenario

Biodiesel production declined to 315 MGY in 2010 (NBB 2012), with an approximate production level of 904 million gallons of biodiesel. In MGY 2010, 1,648 million bushels of soybeans were crushed with an estimated 617 million bushels for biodiesel production (USDA-ERS 2012b). In 2010 the soybean requirement for biodiesel production increased by about 182 million bushels relative to 2007. To reflect this change, 2010 soybean demand for biodiesel production is decreased by 182 million bushels in the pre-pre-RFS2 scenario.

3.4.3 Developing Forward-Looking Scenarios

Comparisons between the 2007 scenario and the pre-RFS1 scenario and between the 2010 base scenario and the pre-RFS2 scenario help us understand the past effects of increases in biofuel production. Because the RFS2 mandates are expected to continue, forward-looking scenarios were developed in order to understand the likely effects of future biofuel production. In particular, forward-looking scenarios will be used in the IGTM based on future biofuel production volumes projected by the USDA and Energy Information Administration of the US Department of Energy (EIA) for the year 2021.

Three scenarios are considered, namely, USDA_2021, EIA_2021, and Base_USDA_2021. All other details of the forward-looking scenarios are based on USDA’s long-term agricultural projections (USDA 2012). The projections include the supply and disposition of all major agricultural commodities, including corn and soybeans, their respective farm prices, and agricultural trade between the countries. These projections are based on certain assumptions on macroeconomic conditions for the near future and do not assume major shocks to global agricultural markets. The Energy

Information Administration publishes an Annual Energy Outlook report that includes long-term projections for future energy supply and demand. The EIA scenario assumptions are based on EIA's Annual Energy Outlook 2012 projections (EIA 2012) for ethanol and biodiesel reflected in the reference case.

The USDA_2021 scenario reflects USDA projections for supply and disposition of corn and soybeans in 2021. The EIA_2021 scenario uses the same assumptions from USDA projections with the exception that corn and soybean use for biofuel production reflects the volumes from the EIA projections. Finally, the Base_USDA_2021 scenario is identical to the USDA_2021 scenario with the exception that biofuel production stays at 2010 levels. Hence, corn and soybean demand for biofuel production stays the same. Although somewhat unrealistic, the Base_USDA_2021 scenario simulates higher production and consumption of grains and no growth in biofuel production from 2010 levels. Table 7 shows supply and disposition of grains for each scenario.

The supply and demand for corn and soybeans are projected to rise in all scenarios. Corn and soybean consumption for biofuel production purposes in the USDA_2021 scenario are projected to be 5,475 and 854 million bushels respectively. These consumption levels represent 15 billion gallons of domestic corn based ethanol production and 854 million gallons of domestic biodiesel production. The EIA projects that 17 billion gallons of ethanol will be blended into gasoline. Biodiesel consumption is projected to reach 1,849 million gallons in 2021 crop year, which requires 1,258 million bushels of soybeans. All 17 billion gallons of ethanol and 1.8 billion gallons of biodiesel are assumed to come from domestic production in the EIA_2021 scenario.

Table 7. Corn and Soybean Supply and Disposition under Each Future Scenario

Supply & Disposition	2016	2021
Corn (million bushels)		
Beginning stocks	1,508	1,468
Production	14,330	15,435
Total Supply	15,838	16,903
Demand		
Feed & residual	5,575	6,000
Food	1,431	1,476
Seed	24	24
Ethanol	5,100	5,475
Ethanol_EIA	5,441	6,145
Ethanol_Base	5,021	5,021
Ending Stock	1,473	1,518
Soybeans (million bushels)		
Beginning stocks	208	204
Production	3,440	3,610
Total Supply	3,648	3,814
Demand		
crush: Food[3]	1,031	1,031
crush: Biodiesel	724	854
crush: Biodiesel_EIA	1,060	1,258
crush: Biodiesel_Base	617	617
Seed and residual	140	142
Ending Stock	208	207

Corn and soybeans are bulk commodities. The transportation cost of bulk commodities makes up a significant portion of the delivered price of a commodity. The total estimated transportation costs of U.S corn and soybean exports were as high as 23% and 15% of the commodity farm price respectively in 2010. Therefore, it is important to have correct estimates of future transportation rates for the forward-looking scenarios. Two types of econometric models were used in making transportation rate forecasts.

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[3] Only one overall soybean crush estimate is given in USDA projections. The crush estimates for biodiesel production deduced from the 2010 biodiesel production. Soybean crush estimates for food purposes are kept the same for all years. Therefore, changes in overall soybean crush estimates are only due to changes in soybean crush for biodiesel production.

Structural regression models are used to forecast truck and rail rates and time series models are used to forecast barge and ocean rates. Detailed discussion of modeling procedures and model results are provided in Appendix C.

3.5 Results

The scenarios were all simulated with IGTM and the results of each scenario were compared. The pre-RFS1 scenario results are compared to the 2007 IGTM baseline model results and the pre-RFS2 scenario results are compared to the 2010 IGTM baseline model results. The forward-looking scenario results are compared to the 2010 baseline IGTM model results. Each scenario's effect on agricultural transportation and grain markets is discussed.

3.5.1 Pre-RFS1 Scenario Results

Table 8 shows the change in grain market indicators under the increased biofuels production between the pre-RFS1 scenario and the 2007 baseline. In the 2007 baseline model, total worldwide consumption (excess demand quantity) of corn was 176 million metric tons, where 82.9 million metric tons (3,264 million bushels) consumed by the U.S. consumers and 93.1 million metric tons by foreign consumers. The total world excess supply quantity of corn was 177 million tons where 146 million tons was provided by U.S. producers. The pre-RFS1 scenario results indicate that, had the corn use for ethanol production stayed at the 2000 levels that domestic and foreign consumers would have consumed more corn for food purposes because of net increase in available corn supply. In particular, domestic net corn supply available to non-ethanol consumption would increase by 7.6% (11.1 million tons) and foreign net corn supply would decrease by 7% (2.2 million tons). This finding indicates that domestic and foreign consumers could have consumed 1.6% (1.3 million tons) and 8.2% (7.6 million tons) of more corn respectively without RFS1 production levels in 2007.

Table 8. **Changes in Prices, Regional Excess Demand, and Supply Quantities under RFS1**

	Base 2007 Corn	Change for Corn	Base 2007 Soybeans	Change for Soybeans
		1000 metric tons		
Domestic Excess Demand	82,932	1,306	18,285	-8,550
Foreign Excess Demand	93,126	7,630	73,135	4,626
Total Excess Demand	176,058	8,936	91,420	-3,924
Domestic Excess Supply	146,106	11,130	46,868	-199
Foreign Excess Supply	30,917	-2,195	43,334	-3,726
Total Excess Supply	177,023	8,935	90,202	-3,925
		USD/metric ton		
U.S. Consumer Price	188	-37	437	-54
U.S. Producer Price	130	-37	334	-53
Foreign Consumer Price	247	-36	452	-52
Foreign Producer Price	178	-30	407	-51

In the case of soybeans, domestic and foreign consumers' aggregate net consumption were 18.3 and 73.1 million metric tons respectively, and aggregate net supply by domestic and foreign producers were 46.9 and 43.3 million tons respectively under the 2007 baseline scenario. The comparison with the pre-RFS1 scenario results indicates that without the biofuel production as of the RFS1 mandates that total net soybean exports would decrease by 4.4% (3.9 million tons), where U.S. producers' net exports decreases by 0.4% (0.2 million tons) and foreign producers' net exports decreases by 8.6% (3.7 million tons). Net soybean consumption also decreases by the same amount under the pre-RFS1 scenario. This suggests that, total U.S. soybean consumption (for food and biodiesel purposes) would decrease by 46.8% (8.5 million tons) and foreign soybean consumption would increase by 6.3% (8.5 million tons) without the RFS1 production levels.

The results show the net changes in domestic supply and demand quantities for grains. Regional consumption of corn and soybeans comes from two *Sources:* 1) food and animal feed related sources, and 2) biofuel production feedstock use. Similarly, net grain exports from a region reflect the difference between region's total grain production and regional grain use for food and biofuel purposes. Therefore, regional excess supply quantity of grain changes depending on the level of biofuel production.

Close inspection of the scenario results reveals that grain production would fall with consumption increasing by less than the volume diverted from biofuel production. For example, 61.5 million tons of corn and 11.8 million tons of soybeans that would have been supplied for biofuel production are now available for food and feed consumption under the pre-RFS1 scenario. However, consumption increases by only 19.7 million tons of corn and 8.3 million tons of soybeans. The remaining 39.9 million tons corn and 1.5 million tons of soybeans would not be supplied. These 19.7 million tons of corn would come from former deficit (8.6 million tons) and surplus (11.1 million tons) locations (CRDs), and 9.9 million tons would be consumed in the domestic market and 9.8 million tons would be consumed in the foreign markets. This finding suggests that observed 2007 levels of corn and soybean production would be lower by 39.9 and 1.5 million tons in the absence of RFS1 production levels. In other words, producers would reduce production accordingly without the RFS1 production levels.

The 9.8 million tons of domestic grain exported to foreign consumers offsets the net increase in foreign corn deficit (7.6 million tons) and net decrease in foreign corn surplus (2.2 million tons). For soybeans, 8.3 million tons of export quantity comes from domestic formerly deficit (8.5 million tons) and surplus (-0.2 million tons) regions and all is consumed in the foreign markets to offset 4.6 million tons of net foreign deficit and 3.7 million tons of foreign supply shortage under pre-RFS1 scenario. All 8.5 million tons of soybeans that are diverted from biodiesel production at deficit regions are not consumed locally and therefore reflected as net decrease in domestic aggregate deficit. Even though 3.3 million tons of extra soybeans would be available at surplus locations, some other surplus regions decrease their supply which results in 0.2 million tons of reduction in net soybean supply. The findings suggest that ethanol production diverted 19.7 million tons (775 million bushels) of corn and biodiesel production diverted 8.3 million tons (303 million bushels) of soybeans from non-biofuel consumption purposes.

The 2007 baseline corn prices averaged \$188 and \$247 per metric ton for U.S. and foreign consumers and \$130 and \$178 for domestic and foreign producers respectively. The average prices of soybean were \$437 and \$452 per metric ton for U.S. and foreign consumers and \$334 and \$407 for domestic and foreign producers. The pre-RFS1 scenario result comparison shows that those production levels affect corn and soybean prices in both domestic and international markets. Without the RFS1 level of production, corn and soybean prices would have been lower by 12% to 30% depending on commodity and market. For example, corn prices are 20% ($37/ton or 94 cents/bushel) lower for domestic consumers and 28.5% lower for domestic producers. Corn prices would be 14.6% ($36/ton) lower for average foreign consumers and 16.8% ($30/ton) lower for average foreign producers under the pre-RFS1 scenario. However, soybean prices are 12.4% ($54/ton) lower for the average domestic consumer, 15.9% ($53/ton) lower for average domestic producers, 11.5% ($52/ton) lower for average foreign consumers, and 12.5% ($51/ton) lower for average foreign producers.

Figure 4 shows the spatial distribution of the changes to average domestic prices and quantities supplied and demanded under the pre-RFS1 scenario. It also shows the direction and magnitude of changes in each CRD. Demand quantity decreases in some CRDs represent reductions due to diverting grains from local biofuel production to food consumption and animal feed.

Individual countries are differentially affected under the pre-RFS1 scenario. The quantity of corn supplied by Argentina and Brazil declines by 1.5 and 0.7 million tons and the corn prices go down by $29.08 and $30.78 per ton respectively. Brazil is affected the most in the soybeans market where its soybeans supply quantity declines by 2.5 million tons and Argentinian supply quantity goes down by 1.1 million tons. Brazilian and Argentinian soybean prices decrease by $50.18 and $51.86 per ton respectively. Some other importing countries decrease their consumption due to higher supply and lower prices. Mexico, Spain, and China benefit the most by consuming 2.9 and 2.3 million tons of more corn and 1.1 million tons of more soybeans respectively under RFS1 scenario.

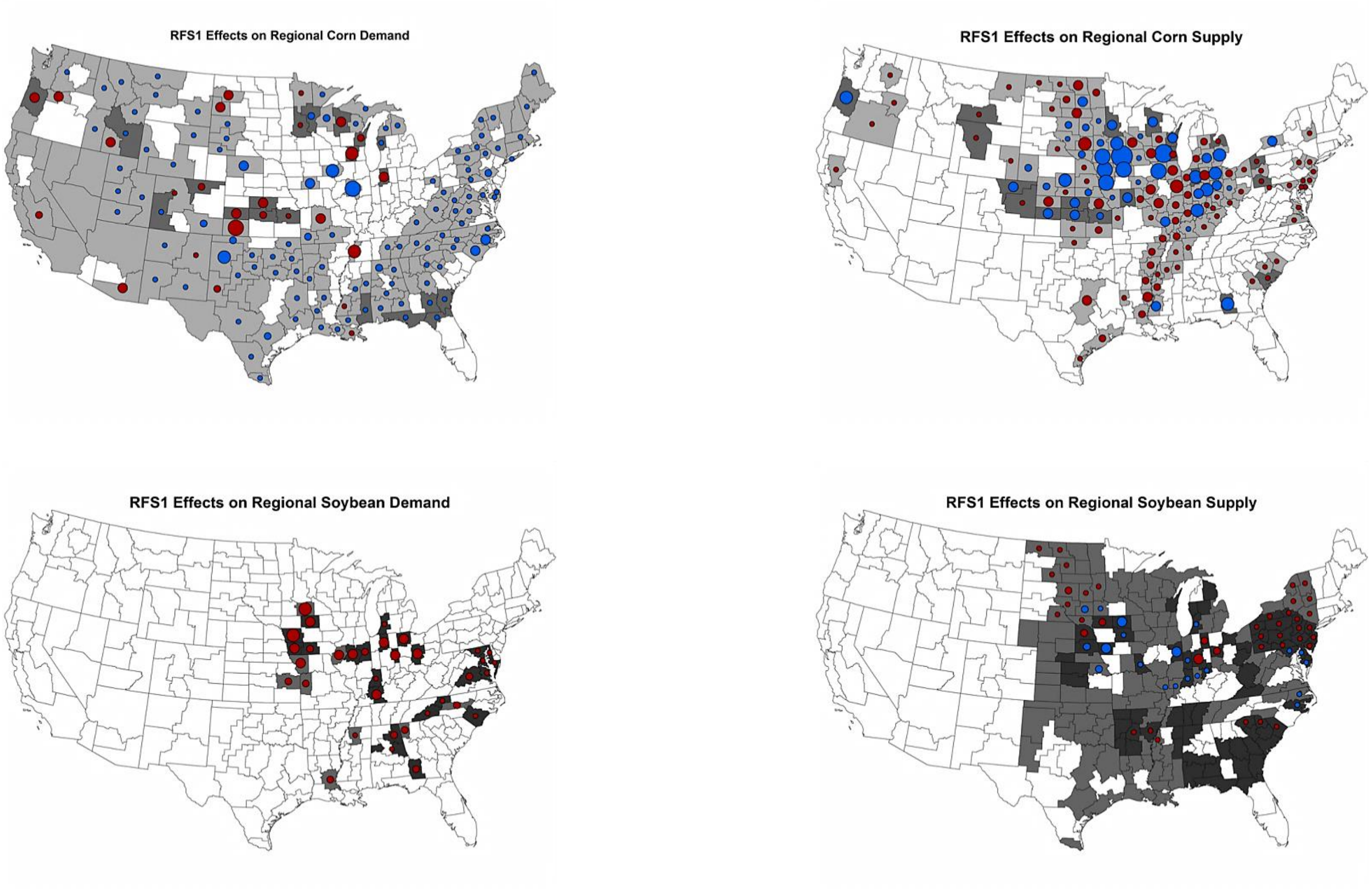


Figure 4. Changes in prices and excess supply and demand quantity under RFS1 production levels
Note: Blue dots indicate quantity increase and red indicates quantity decrease. Light to dark colors represent a continuum of small to large changes in the price. Prices are measured in $/bushel and the quantity is measured in million bushels.

The largest increases in corn excess supply quantity occur in the ethanol-producing CRDs such as CRDs 10, 20, 40, 50, and 70 in Iowa, CRDs 20 and 60 in Indiana, CRD 80 in Wisconsin, and CRD 10 in Illinois. The largest demand quantity increases occur in CRDs with large livestock operations such as CRD 11 in Texas and CRD 20 in Nebraska, which both have large-scale cattle feedlots, and CRD 90 in North Carolina, which has large-scale hog operations. Increases in soybean supply quantity also correspond to biodiesel-producing CRDs and some of the largest decreases in soybean demand quantity occur in CRDs 20 and 70 in Iowa. The list of top 10 countries with highest increases in consumption is provided in Table 9.

Table 9. Countries with Highest Increases in Consumption under Pre-RFS1 Scenario

CORN			SOYBEANS		
Country	Demand Change	Price Change	Country	Demand Change	Price Change
Mexico	2,853	-36.15	China	1,070	-51.92
Spain	2,305	-30.59	Taiwan	460	-52.13
Portugal	599	-30.59	Japan	405	-51.93
Netherlands	357	-30.59	Mexico	350	-52.98
Italy	244	-30.59	Spain	318	-51.67
Malaysia	187	-33.17	Thailand	279	-52.03
Colombia	160	-36.06	Italy	247	-53.30
Zimbabwe	150	-30.56	South Korea	188	-52.44
Denmark	61	-30.59	Indonesia	180	-51.71
Vietnam	53	-32.30	Iran	158	-49.46
Others	661	-35.73	Others	972	-52.17
TOTAL	7,630	-35.73	TOTAL	4,626	-52.17

Note: 1) quantity is in 1000 metric tons and 2) price is in $/ton.

Biofuel production mandates under RFS1 change the regional supply and demand dynamics and grain price levels. As a result, inter-regional and intra-regional transportation volumes and modal share are affected under the pre-RFS1 scenario. Table 10 provides information regarding changes in U.S. corn and soybean export volumes from each port location via ship and rail. A total of 88.8 million tons of corn and soybeans were exported in 2007 baseline model. Gulf and PNW ports exported 59% and 25% of the total corn and soybeans. Great Lakes ports were relatively small players. Overland corn and soybean exports to Mexico and Canada via rail are estimated at 9.3 and 2.4 million tons.

Table 10. Breakdown of Total U.S. Corn and Soybean Exports by Ports

Export Locations	Baseline 2007	pre-RFS1 2007	Change	Change (%)
Gulf Ports	52,012	59,064	7,052	14%
Great Lakes Ports	2,392	4,759	2,368	99%
PNW Ports	22,274	28,323	6,049	27%
Atlantic Ports	397	992	595	150%
To Mexico	9,304	11,375	2,071	22%
To Canada	2,424	2,464	41	2%
Total Exports	88,802	106,978	18,176	20%

Note: Quantity is measured in 1000 metric tons.

The results show that corn and soybean export volumes increase by 20% under the pre-RFS1 scenario. Exports from all ports increase, with the biggest export increases taking place at the Gulf and PNW ports. For example, exports from the Gulf and PNW ports increase by 14% and 27% respectively in the absence of RFS1 production levels.

Export volumes of Great lakes and Atlantic ports also increase by 99% and 150% respectively under the pre-RFS1 scenario. In terms of overland exports, Mexico imports 22% more corn and soybeans from the United States. Modal transport usage also changes. Table 11 provides information on the volume of corn and soybeans shipments by mode on a tonnage and ton-mile basis. On a tonnage basis, most of the corn and soybeans are transported by truck, then by rail and barge, as shown in the 2007 baseline model. However, when the distance of the shipment is also considered, rail transportation accounted for 54%, barge accounted for 39%, and truck accounted for the remaining 8% of the domestic transportation volume on a ton-mile basis in the baseline scenario. Under the pre-RFS1 scenario, demand for all transportation modes increased and rail leads other modes.

Table 11. Total Volume of Corn and Soybean Shipments by Mode of Transportation

Transport Mode	Baseline 2007	pre-RFS1 2007	Change	Change (%)
	Transportation volume (1000 tons)			
Truck	100,079	102,069	1,990	2%
Rail	99,920	109,169	9,250	9%
Barge	50,190	55,037	4,847	10%
Small Ship	2,392	4,759	2,368	99%
Big Ship	77,074	93,139	16,065	21%
	Transportation volume (billion ton-miles)			
Truck	8,935	9,191	256	3%
Rail	63,174	72,759	9,586	15%
Barge	45,401	50,511	5,110	11%

Note: Ton-miles = tonnage x mileage of the shipment.

The pre-RFS1 increases traded volumes. Nearly 2 million tons of additional corn and soybeans are transported by truck, a 2% increase on a tonnage basis and 6% increase on a ton-mile basis from the 2007 baseline. The largest increase occurs with rail with 9% and 15% more tonnage and ton-mile travel respectively. Volume shipped by barge also increases by 10% from the 2007 base scenario. Higher volumes of incoming shipments to all port locations increases export movements by ocean vessels by 21%.

Effects of increased biofuel production levels under RFS1 production conditions differentially affect inter-regional transportation flows and volumes. Analyzing the model results on a CRD or state level is beyond the scope of this study and is omitted here. Rather, the CRDs are grouped geographically to facilitate the analysis. The Agricultural Sector Model (Adams et al., 2005) regions are used for the purposes of this study and the descriptions of the regions are given in Appendix B.

Table 12 presents model results for inter-regional and intra-regional grain movements for corn and soybeans for the 2007 base model and for the pre-RFS1 scenario. The Corn Belt, Great Plains, and Lake States are the major corn- and soybean-producing regions of the United States and most (88%) shipments originate from these regions. The Corn Belt share was 54%, Great Plains share 21%, and Lake States share 13%.

Total corn and soybean shipments from the Corn Belt region increase by 12.2 million tons or 11% under the pre-RFS1 scenario. Intra-regional grain shipments and shipments from the Corn Belt to the Great Plains region decline by 7% and 87% respectively. The Corn Belt ships 58%, 113%, and 13% more grains to the Southwest, Great Lakes, and Gulf ports respectively. The Corn Belt ships 2.2 and 1.3 million tons of grain to PNW ports and Mexico under the pre-RFS1 scenario.

Total volume of corn shipments originating from the Great Plains is not significantly affected by the shift from RFS1 production levels to the pre-RFS1 scenario. However, the intra-regional shipments and shipments from the Great Plains to the Corn Belt, South Central, and Southwest regions decrease by 17%, 49%, 41%, and 12% respectively in the absence of RFS1 production levels. Gulf and PNW ports and Mexico respectively receive 47%, 8%, and 9% more corn and soybeans from the Great Plains region.

Table 12. Inter-regional and Intra-regional Grain Shipments

Origin	Destination	Base 2007	pre-RFS1	Change	Change (%)
Corn Belt	Corn Belt	21,857	20,403	-1,455	-7%
	Great Plains	2,192	284	-1,908	-87%
	Lake States	-	243	243	-
	Northeast	1,984	2,373	388	20%
	Pacific	5,392	5,722	330	6%
	Rocky Mountains	1,439	1,476	37	3%
	South Central	9,253	8,920	-333	-4%
	Southeast	16,077	16,762	685	4%
	Southwest	5,777	9,126	3,349	58%
	Great Lakes Ports	1,929	4,102	2,174	113%
	Gulf Ports	40,903	46,081	5,178	13%
	PNW Ports	-	2,207	2,207	-
	Mexico	-	1,342	1,342	-
	TOTAL	106,803	119,040	12,237	11%
Great Plains	Corn Belt	1,108	566	-542	-49%
	Great Plains	3,911	3,229	-682	-17%
	Pacific	1,145	1,448	303	27%
	Rocky Mountains	2,512	2,549	37	1%
	South Central	1,192	704	-488	-41%
	Southwest	4,313	3,798	-514	-12%
	Gulf Ports	1,023	1,499	476	47%
	PNW Ports	17,872	19,322	1,450	8%
	Canada	166	316	150	91%
	Mexico	9,227	10,033	806	9%
	TOTAL	42,469	43,465	997	2%

Table 12 Continued

Origin	Destination	Base 2007	pre-RFS1	Change	Change (%)
Lake States	Corn Belt	3,511	2,804	-707	-20%
	Great Plains	1,657	3,612	1,955	118%
	Lake States	6,936	5,906	-1,030	-15%
	Northeast	677	1,021	344	51%
	Pacific	1,340	290	-1,050	-78%
	Rocky Mountains	1,590	886	-704	-44%
	South Central	-	1,143	1,143	-
	Southeast	2,601	2,904	303	12%
	Southwest	322	369	47	15%
	Atlantic Ports	-	606	606	-
	Great Lakes Ports	463	657	194	42%
	PNW Ports	4,078	5,745	1,668	41%
	Canada	1,763	1,133	-630	-36%
	TOTAL	24,938	27,077	2,139	9%
Northeast	Northeast	1,081	1,241	160	15%
	Southeast	914	697	-217	-24%
	Atlantic Ports	9	35	26	288%
	Canada	495	837	342	69%
Northeast	TOTAL	2,498	2,810	311	12%
Pacific	Pacific	86	51	-34	-40%
	Rocky Mountains	189	229	40	21%
	PNW Ports	324	561	237	73%
	TOTAL	598	840	242	41%
Rocky Mountains	Rocky Mountains	1,731	1,943	211	12%
	TOTAL	1,731	1,943	211	12%
South Central	South Central	11,844	10,551	-1,293	-11%
	Southeast	1,168	273	-895	-77%
	Gulf Ports	2,718	3,280	562	21%
	TOTAL	15,730	14,104	-1,626	-10%
Southeast	Northeast	87	150	63	72%
	South Central	-	320	320	-
	Southeast	1,362	1,781	420	31%
	Atlantic Ports	388	351	-37	-9%
	TOTAL	1,837	2,603	766	42%
Southwest	Southwest	723	333	-390	-54%
	Gulf Ports	1,498	1,243	-255	-17%
	Mexico	77	-	-77	-100%
	TOTAL	2,298	1,576	-723	-31%

Note: Quantity is in 1000 metric tons.

The Lake States' total shipments increased by 2.1 million tons (9%) under the pre-RFS1 scenario, but intra-regional shipments decreased by 15%. The volume of grain shipments between the Lake States and the Corn Belt, Pacific, and Canadian regions is reduced by 20%, 78%, and 36% under the pre-RFS1 scenario. The largest increase in grain shipments from the Lake States occurs between the Great Plains (118%), and the South Central regions and the PNW ports (41%). The South Central region's total grain shipments decrease by 10%, but other regions are not significantly affected by RFS1 production levels under the pre-RFS1 scenario.

3.5.2 Pre-RFS2 Scenario Results

The effects of higher corn and soybean use under RFS2 in 2010, as opposed to 2007 levels, are summarized in Table 13. In the 2010 baseline model, the total worldwide excess demand quantity of corn was 184.9 million metric tons, but domestic net imports from other domestic surplus regions accounted for 85.3 million metric tons (3,358 million bushels) and foreign imports accounted for 99.6 million metric tons.

Table 13. Changes in Prices, Consumer Demand, and Producer Supply under RFS2

	Base2010 Corn	Change for Corn	Base2010 Soybeans	Change for Soybeans
	1000 metric tons			
Domestic Excess Demand	85,310	-8,177	12,898	-2,001
Foreign Excess Demand	99,566	13,539	88,075	6,530
Total Excess Demand	184,876	5,362	100,973	4,529
Domestic Excess Supply	130,216	10,500	53,335	11,434
Foreign Excess Supply	52,546	-5,138	51,441	-6,905
Total Excess Supply	182,762	5,362	104,776	4,529
	USD / metric ton			
U.S. Consumer Price	228	-50	470	-63
U.S. Producer Price	170	-51	381	-62
Foreign Consumer Price	313	-49	602	-60
Foreign Producer Price	211	-45	383	-58

In the 2010 baseline model, the total worldwide excess demand quantity of corn was 184.9 million metric tons where domestic net imports from other domestic surplus regions accounted for 85.3 million metric tons (3,358 million bushels) and the foreign imports accounted for 99.6 million metric tons. The total worldwide excess supply quantity of corn was 182.8 million tons where 130.2 million tons (5,125 million bushels) was provided by U.S. producers in the 2010 baseline model. The pre-RFS2 scenario results suggest that domestic corn and soybean exportable supply would increase, foreign corn and soybean exportable supply would decrease, domestic corn and soybean aggregate (biofuel and non-biofuel) consumption would decrease, and foreign corn and soybean consumption would increase without the RFS2 production levels. In particular, in the absence of RFS2 production levels, domestic net corn excess supply quantity would increase by 8% (10.5 million tons) and the foreign net corn excess supply quantity would decrease by 9.8% (5.1 million tons). Domestic net corn consumption would decrease by 9.6% (8.2 million tons) and foreign consumers' net corn consumption would increase by 13.6% (13.5 million tons) under pre-RFS2 scenario due to smaller ethanol production volumes and commodity use.

With soybeans, excess demand quantity by domestic and foreign consumers was 12.9 million tons (474 million bushels) and 88 million tons, and excess supply quantity for soybeans by domestic and foreign producers was 53.3 MMT (1,959 million bushels) and 51.4 million tons respectively in the 2010 baseline model. The pre-RFS2 scenario results indicate that total net soybean supply would increase by 4.3% (4.5 million tons) with a net increase of 21.4% (11.4 million tons) by domestic producers and a net decrease of 13.4% (6.9 million tons) by foreign producers in the absence of RFS2 production levels. Under this scenario, domestic consumers' net soybean consumption decreases by 15.5% (2 million tons) and foreign consumers' net soybean consumption increases by 7.4% (6.5 million tons). The net increase in the total excess soybean supply results in an equal amount of net increase in the total excess demand for soybeans under the pre-RFS2 scenario.

Similar to the pre-RFS1 scenario, the pre-RFS2 scenario resulted in 23.7 million tons of net excess corn supply. The reduction in biofuel production diverts 50 million tons of corn and 5 million tons of soybeans to food and feed consumption under pre-RFS2 scenario. Given the model's supply and demand schedule, only 26.3 million tons of corn is actually consumed and the remaining 23.7 million tons of corn would not be supplied. These 26.3 million tons of excess corn supply quantity would come from what were previously excess demand regions (15.8 million tons) and the rest from traditional excess supply regions (10.5 million tons) while 7.6 million tons would be consumed in the domestic market and 18.7 million tons in foreign markets. The findings suggest that ethanol production diverted 26.3 million tons (1,035 million bushels) of corn from food and animal feed and that 23.7 million tons of corn is produced only to support ethanol production in 2010.

Observed average prices of corn were \$228 and \$313 for domestic and foreign consumers, and \$170 and \$211 for domestic and foreign producers respectively on a metric ton basis. The average prices of soybean were \$470 and \$602 for domestic and foreign consumers, and \$381 and \$383 for domestic and foreign producers respectively.

The results show that RFS2 production levels affected the corn and soybean prices in both domestic and international markets. Without the higher biofuels production volumes under RFS2 production levels, corn and soybean prices would have been lower than the 2007 price levels by 10% to 30% depending on commodity and market. For example, corn prices would be 21.9% ($50/ton or $1.27/bushel) and 30% ($51/ton or $1.30/bushel) lower for domestic consumers and producers, 15.6% ($49/ton) and 21.3% ($45/ton) lower for foreign consumers and producers respectively. Soybean prices would be 13.4% ($63/ton) lower for domestic consumers, 16.3% ($62/ton) lower for domestic producers, 10% ($60/ton) lower for foreign consumers, and 15.1% ($58/ton) lower for foreign producers without the RFS2 production levels.

Figure 5 shows the changes to domestic prices, quantity supply and demand under the pre-RFS2 scenario. It also shows the direction and magnitude of changes by CRD. Grain consumption decreases in some CRDs due to the reduction in biofuel production. As expected, largest increases in corn excess supply quantity comes from ethanol producing CRDs such as CRD 60 in Nebraska, CRDs 70 and 80 in Minnesota, CRDs 10, 20, and 40 in Iowa, CRDs 20 and 90 in South Dakota. The largest consumption increases occur in CRDs with large livestock feeding operations.

Individual supplier and consumer countries would be affected under the pre-RFS2 scenario. The list of top 10 countries with highest increases in consumption is provided in Table 14. Corn supply quantity from Argentina and Brazil declines by 1.6 and 3.0 million tons and corn prices go down by $44.77 and $43.99 per ton respectively.

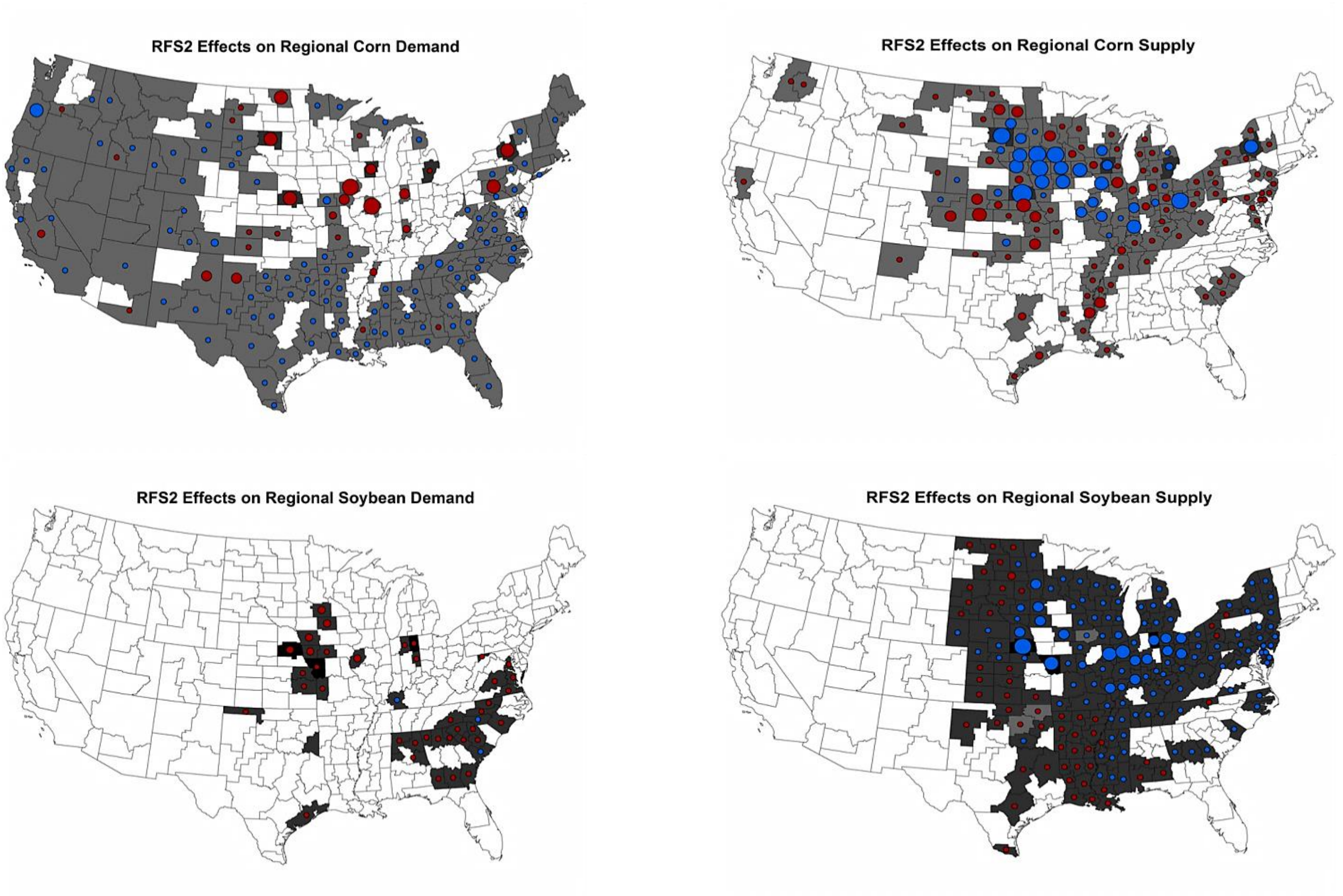
Table 14. Countries with Highest Increases in Consumption under the Pre-RFS2 Scenario

CORN			SOYBEANS		
Country	Consumption Change	Price Change	Country	Consumption Change	Price Change
Mexico	1,743	-50.59	China	3,977	-60.36
Korea, South	1,621	-49.67	Mexico	394	-63.30
Italy	1,241	-49.50	Indonesia	380	-58.06
Egypt	1,158	-49.87	Turkey	270	-61.19
Spain	912	-47.27	Taiwan	239	-61.57
Taiwan	837	-51.10	Thailand	214	-58.53
Colombia	701	-49.81	Egypt	206	-60.71
Germany	606	-46.51	Russia	200	-61.56
Indonesia	606	-48.12	Vietnam	185	-58.53
Japan	391	-50.90	Japan	146	-61.65
Other countries	3,723	-49.36	Other countries	321	-60.16
TOTAL	13,539	-49.36	TOTAL	6,530	-60.16

Note: Quantity is in 1000 metric tons.

Brazilian soybean supply quantity declines by 6.0 million tons and Argentinian supply by 0.9 million tons. Brazilian soybean prices decrease by $57.91 and Argentinian prices decrease by $57.72 per ton. Other net deficit countries increase consumption due to higher supply and lower prices. China, Mexico, South Korea, Italy, and Egypt benefit from such conditions under the pre-RFS2 scenario.

The RFS2 biofuel production levels changed regional supply and demand conditions and grain price levels. Inter-regional and intra-regional transportation volumes and modal shares were also affected.



RFS2 Effects on Regional Corn Demand

RFS2 Effects on Regional Corn Supply

RFS2 Effects on Regional Soybean Demand

RFS2 Effects on Regional Soybean Supply

Figure 5. Changes in prices and excess supply and demand quantities due to RFS2 production levels
Note: Blue dots represent quantity increase and red dots represent quantity decrease. Light to dark colors represent the small to large changes in the price. Prices are measured in $/bushel and the quantity is measured by million bushels.

The RFS2 biofuel production levels changed regional supply and demand conditions and grain price levels. As a result, inter-regional and intra-regional transportation volumes and modal shares were also affected. Table 15 provides information on changes in U.S. export volumes via ship and rail. A total of 94.7 million tons of corn and soybeans are exported to foreign markets by U.S. producers in the 2010 baseline model. Gulf and PNW ports exported 60% and 25% of the total corn and soybeans. Great Lakes and Atlantic ports are relatively small players. Overland corn and soybean exports to Mexico and Canada via rail are 5.6 and 3.3 million tons in the 2010 baseline model.

The results suggest that overall export volumes increase by 34% under the pre-RFS2 scenario. Exports from all ports increase, with the biggest increases at the Gulf and PNW ports. For example, exports from the Gulf and PNW ports increase by 38% and 28% respectively in the absence of RFS2 production levels. Export volumes of Great lakes and Atlantic ports also increase by 85% and 40% respectively. In terms of overland exports, Mexico imports 23% more corn and soybeans from the United States.

Table 15. Breakdown of Total Domestic Corn and Soybean Exports by Ports

Export Locations	Baseline 2010	pre-RFS2 2010	Change	Change (%)
Gulf Ports	56,502	77,755	21,253	38%
Great Lakes Ports	1,570	2,912	1,342	85%
PNW Ports	23,653	30,382	6,729	28%
Atlantic Ports	4,026	5,639	1,614	40%
To Mexico	5,660	6,939	1,280	23%
To Canada	3,325	3,219	-106	-3%
Total Exports	94,735	126,846	32,112	34%

Note: Quantity is in 1000 metric tons.

As shown in Table 16, the need for transportation modes also changes. On a tonnage basis, the largest volumes are transported by rail, followed by truck and barge in the 2010 baseline model. However, when the distance of the shipment is also considered, rail transportation accounts for 56%, barge 37%, and truck 7%. Under the pre-RFS2 scenario, usage of all transportation modes increases and rail leads other modes. Nearly 5.4 million tons of additional corn and soybeans are transported by truck, a 6% increase on a tonnage basis and a 5% increase on a ton-mile basis. Rail increases by 17% and 31% on a tonnage and ton-mile basis respectively. Barge volume increases by 26% and 29% on a tonnage and ton-mile basis. Higher export volumes increase overall usage of ocean vessels by 36%. In contrast to the pre-RFS1 scenario, RFS2 production levels resulted in higher volumes of overall and mode-specific demand for transportation than does RFS1 production levels.

Table 17 presents model results for inter-regional and intra-regional grain movement. In the 2010 base model, about 86% of all corn and soybean shipments originated from the Corn Belt, Great Plains, and Lake States regions, where the Corn Belt's share was 46%, Great Plains 24%, and Lake States 16%.

Table 16. Total Volume of Corn and Soybean Shipments by Mode of Transportation

Transport Mode	Baseline 2010	pre-RFS2 2010	Change	Change (%)
		Transportation volume (1000 tons)		
Truck	93,699	99,088	5,389	6%
Rail	103,961	121,847	17,886	17%
Barge	46,594	58,811	12,217	26%
Small Ship	1,570	2,912	1,342	85%
Big Ship	85,750	116,688	30,938	36%
		Transportation volume (billion ton-miles)		
Truck	8,350	8,752	402	5%
Rail	66,181	86,676	20,495	31%
Barge	43,492	56,093	12,601	29%

Note: Ton-miles = tonnage x mileage of the shipment.

Table 17. Inter-regional and Intra-regional Grain Shipments

Origin	Destination	Base2010	pre-RFS2	Change	Change (%)
Corn Belt	Corn Belt	17,436	11,064	-6,372	-37%
	Great Plains	82	445	363	446%
	Lake States	771	1,114	343	44%
	Northeast	2,612	1,181	-1,431	-55%
	Rocky Mountains	354	1,212	858	242%
	South Central	7,749	12,675	4,926	64%
	Southeast	13,054	13,669	615	5%
	Southwest	2,393	3,525	1,131	47%
	Atlantic Ports	959	1,530	571	60%
	Great Lakes Ports	1,570	2,912	1,342	85%
	Gulf Ports	38,772	51,144	12,372	32%
	PNW Ports	4,177	7,422	3,245	78%
	Mexico	-	303	303	-
	TOTAL	89,930	108,196	18,266	20%
Great Plains	Corn Belt	608	-	-608	-100%
	Great Plains	7,030	5,666	-1,364	-19%
	Pacific	6,546	8,369	1,823	28%
	Rocky Mountains	1,773	1,644	-129	-7%
	South Central	1,374	1,356	-18	-1%
	Southwest	7,805	7,561	-244	-3%
	Gulf Ports	2,334	7,430	5,096	218%
	PNW Ports	10,437	8,218	-2,219	-21%
	Canada	3,325	3,219	-106	-3%
	Mexico	5,604	6,636	1,032	18%
	TOTAL	46,836	50,100	3,263	7%
Lake States	Corn Belt	3,308	2,543	-765	-23%
	Great Plains	2,607	1,416	-1,191	-46%
	Lake States	9,491	11,085	1,594	17%
	Northeast	444	79	-365	-82%
	Pacific	4,437	6,952	2,515	57%
	Rocky Mountains	4,222	4,155	-67	-2%
	South Central	574	854	280	49%
	Southeast	2,666	2,746	80	3%
	Atlantic Ports	2,464	3,145	681	28%
	PNW Ports	1,776	3,454	1,677	94%
	TOTAL	31,990	36,428	4,438	14%

Table 17 Continued

Origin	Destination	Base2010	pre-RFS2	Change	Change (%)
Northeast	Northeast	1,526	1,638	112	7%
	Southeast	1,318	994	-324	-25%
	Atlantic Ports	360	653	294	82%
	TOTAL	3,204	3,286	82	3%
Pacific	Pacific	298	213	-85	-29%
	PNW Ports	472	353	-119	-25%
	TOTAL	769	566	-204	-26%
Rocky Mountains	Rocky Mountains	2,815	2,496	-319	-11%
	TOTAL	2,815	2,496	-319	-11%
South Central	South Central	10,857	10,962	105	1%
	Southeast	1,518	1,187	-331	-22%
	Gulf Ports	5,029	4,836	-193	-4%
	TOTAL	17,404	16,986	-418	-2%
Southeast	Southeast	512	623	112	22%
	Atlantic Ports	243	311	67	28%
	TOTAL	755	934	179	24%
Southwest	Southwest	352	327	-25	-7%
	Gulf Ports	2,736	2,368	-368	-13%
	Mexico	55	-	-55	-100%
	TOTAL	3,144	2,695	-449	-14%

Note: Quantity is in 1000 metric tons.

Without the conditions surrounding the RFS2, total corn and soybean shipments from the Corn Belt region increase by 18.3 million tons or 20%. Corn Belt intra-regional grain shipments decrease by 6.4 million tons (-37%) and shipments from the Corn Belt to the Northeast region decline by 1.4 million tons (-55%). In contrast, the South Central and Southwest regions and major grain exporting ports are affected positively by removing biofuel production involved with RFS2 production levels. For example, the Corn Belt ships 64% and 47% more grain to the South Central and Southwest regions under the pre-RFS2 scenario. The Great Lakes, Gulf, and PNW ports receive 85%, 32%, and 78% more grain from the Corn Belt region respectively.

Total volume of corn shipments originating from the Great Plains is increased by 3.3 million tons or 7% under the pre-RFS2 scenario. Intra-regional grain shipments and shipments between the Great Plains, Corn Belt, and PNW ports are affected negatively by the RFS2 production levels. The Great Plains intra-regional grain shipments declined by 1.4 million tons (-19%). In addition, shipments to the PNW ports decline by 2.2 million tons (-21%). The Pacific region, Gulf ports, and Mexico are positively affected, where grain shipments from the Great Plains to the Pacific region increase by 28%, shipments to the Gulf ports by 218%, and shipments to Mexico by 18%.

Total grain shipments from the Lake States region increased by 4.4 million tons or 14% due to a retreat from RFS2 to RFS1 biofuel levels. Unlike the Corn Belt and Great Plains regions, intra-regional grain shipments from the Lake States increase by 17%. The volume of grain shipments from Lake States to Corn Belt and Great Plains regions are reduced by 23% and 46% respectively. The largest increase in grain shipments from Lake States involves Pacific (57%) and PNW ports (94%). Other regions are not significantly affected.

3.5.3 Forward-Looking Scenario Results

Projected corn and soybean excess supply and demand volumes increase in all forward-looking scenarios due to projected technical progress resulting in higher quantities of grain supply and grain consumption levels. Given the assumption of no major policy changes and no exogenous economic shocks to global agricultural markets, grain prices are projected to decline by a small amount. Table 18 provides information on projected grain prices, the quantity that will be supplied and consumed in the domestic and international markets in 2021, and a comparison with the 2010 base model results.

Table 18. Domestic and Foreign Grain Supply and Demand Quantities and Equilibrium Grain Prices under Baseline and Forward-Looking Scenarios

	Base2010	BaseUSDA	USDA2021	EIA2021
	CORN (1000 metric tons)			
Domestic Excess Demand	85,310	102,146	104,738	109,779
Foreign Excess Demand	99,566	130,789	127,642	124,882
Total Excess Demand	184,876	232,935	232,380	234,661
Domestic Excess Supply	130,216	167,663	166,489	163,137
Foreign Excess Supply	52,546	67,367	67,985	73,618
Total Excess Supply	182,762	235,030	234,474	236,755
U.S. Available Corn Surplus for Export	44,906	65,517	61,751	53,358
	Price changes from base ($/metric ton)			
U.S. Consumer Price	228	-30	-20	-12
U.S. Producer Price	170	-31	-21	-12
Foreign Consumer Price	313	-14	-4	2
Foreign Producer Price	211	-22	-15	-8
	SOYBEANS (1000 metric tons)			
Domestic Excess Demand	12,898	13,594	18,669	26,650
Foreign Excess Demand	88,075	134,318	134,261	133,092
Total Excess Demand	100,973	147,912	152,930	159,742
Domestic Excess Supply	53,335	60,527	58,476	57,266
Foreign Excess Supply	51,441	87,610	94,679	102,701
Total Excess Supply	104,776	148,137	153,155	159,967
U.S. Available Soybean Surplus for Export	40,437	46,933	39,807	30,616
	Price changes from base ($/metric ton)			
U.S. Consumer Price	470	-27	-23	2
U.S. Producer Price	381	-22	-18	7
Foreign Consumer Price	602	2	4	28
Foreign Producer Price	383	-13	-8	17

As stated in the previous sections, the BaseUSDA scenario represents USDA-projected grain supply and demand levels for 2021 except where the USDA's projected grain demand for biofuel production is replaced with grain demand for biofuels that represents 2010 production levels. USDA2021 is the USDA's grain supply and demand projections for 2021 where the grain demand for biofuel is 15 billion gallons of ethanol production. The EIA2021 scenario assumes higher levels of grain demand for biofuel production, including an additional 1.5 billion gallons of ethanol production.

Total excess supply quantity of corn is projected to increase by 29% under the BaseUSDA scenario, by 28% under the USDA2021 scenario, and by 30% under the EIA2021 scenario. Corresponding total projected excess demand quantity for corn increases by 26% under the BaseUSDA and USDA2021 scenarios and by 27% under EIA2021 scenario. If the corn-based ethanol production stays at 2010 levels, projected domestic aggregate corn deficit increases by 19.7% to 102.1 million tons and the domestic corn excess demand quantity increases by 28.8% to 167.7 million tons that will result in an export increase of 65.5 million tons in 2021 under the BaseUSDA scenario. The USDA2021 and EIA2021 scenarios require 11.5 and 28.6 million tons more corn for ethanol production. This increases the net domestic excess demand quantity of corn and decreases the domestic excess supply quantity of corn. As a result, the net domestic corn available for export decreases by 5.7% (61.8 MT) and 18.6% (53.4 MT). Foreign countries respond by decreasing their corn consumption and increasing their corn production.

Similar trends are projected in the soybean market, with the exception that foreign soybean consumers do not lower their consumption levels when there is increased demand for soybeans for domestic biodiesel production. Baseline and projected net supply of domestic corn and soybeans and net demand by foreign consumers for 2021 under each scenario is shown in Table 19. Projected domestic grain exports decrease as more grains are diverted for biofuel production, thus decreasing foreign consumption of U.S. grains.

Table 19. Projected Net U.S. Exports of Corn and Soybeans in 2021

	Base2010	BaseUSDA	USDA2021	EIA2021
		CORN		
Net U.S. Foreign Supply	44,907	65,517	61,751	53,358
Net Foreign Demand	-47,020	-63,422	-59,657	-51,264
		SOYBEANS		
Net U.S. Foreign Supply	40,437	46,933	39,807	30,616
Net Foreign Demand	-36,634	-46,708	-39,582	-30,391

Note: Quantity is in 1000 tons.

Domestic corn consumer and producer prices are projected to decrease. At 2010 levels of corn based ethanol production, domestic consumer and producer prices for corn will decrease by 13.2% ($30/ton or $0.76/bushel) and 18.2% ($31/ton or $0.80/bushel) respectively under the BaseUSDA scenario. Under the same scenario domestic soybean prices for consumers decrease by 5.7% ($27/ton or $0.74/bushel) and prices for producers decrease by 5.8% ($22/ton or $0.60/bushel). However, the projected prices for foreign consumers and producers decrease by a small amount under the BaseUSDA scenario and the price changes are insignificant, with the exception that soybean prices increase under the EIA2021 scenario. Corn and soybean prices are similar to USDA projected prices. The 2021 USDA projected farm prices for corn and soybeans are $4.65 and $11.35 per bushel and the model-projected corn and soybean prices are $4.73 and $10.70 respectively. The projected corn and soybean requirements for biofuel production change the regional supply and demand characteristics. As a result, total domestic corn and soybean exports (see Table 18) and regional equilibrium prices are affected, as are volumes by transportation mode and export levels by port.

Table 20 provides information on projected export changes by port. A total of 85.3 million tons of corn and soybeans are exported in the 2010 base. Nearly 63% of the total corn and 21% of the total soybean exports are accounted for by the Gulf and PNW ports respectively. The Great Lakes ports and East Coast ports are relatively small players. In 2010, the overland corn and soybean exports to Mexico and Canada via rail are estimated to be 5.7 and 5.0 million tons respectively.

Table 20. Breakdown of Total U.S. Corn and Soybean Exports by Ports

Export Locations	Base2010	BaseUSDA	USDA2021	EIA2021
Gulf Ports	56,502	85,445	76,357	64,064
Great Lakes Ports	1,570	7,138	5,910	4,386
PNW Ports	23,653	4,708	5,703	2,338
Atlantic Ports	4,026	6,995	5,416	5,185
To Mexico	5,660	6,791	6,791	6,669
To Canada	5,017	1,371	1,381	1,333
Total Exports	85,344	112,449	101,559	83,974

Note: Quantity is in 1000 metric tons.

The results suggest that the overall export volumes increase under all scenarios with the exception of the EIA2021 scenario. The dominance of the Gulf ports in grain exports is projected to increase, while that of the PNW ports is projected to decrease. The importance of the Great Lakes and Atlantic ports is likely to increase. For example, the Gulf ports are projected to export 13-51% (7.6-28.9 million tons) more grain, but the PNW ports are projected to export 76-90% (17.9-21.3 million tons) less grain relative to 2010 levels. However, the Great Lakes and Atlantic ports are expected to increase grain exports by 179-355% and 29-74% (3-6 and 1-3 million tons) respectively. In terms of overland exports, Mexico is projected to increase imports by 1 million tons while Canada is projected to import 73% (3.6 million tons) less grain.

Demand for transportation modes is also projected to change. Table 21 provides information on projected volumes. On a tonnage basis, most of the corn and soybeans were transported by rail followed by truck and barge in 2010. However, when the distance of the shipment is also considered, rail transportation accounted for 56%, barges accounted for 37%, and trucks accounted for the remaining 7% of the domestic transportation volume on ton-mile basis. The total volume of corn and soybeans transported by truck is projected to decrease by 25-41% (23-38 million tons), whereas rail transportation is projected to increase by 57-60% (59-62 million tons).

Table 21. Total Volume of Corn and Soybean Shipments by Mode of Transportation

Export Locations	**Base2010**	**BaseUSDA**	**USDA2021**	**EIA2021**
	Transportation volume (1000 tons)			
Truck	93,699	70,564	65,134	55,214
Rail	103,961	163,350	162,996	166,445
Barge	46,594	74,264	65,757	54,649
Small Ship	1,570	7,138	5,910	4,386
Big Ship	85,750	104,287	93,386	75,972
	Transportation volume (billion ton-miles)			
Truck	8,350	4,382	4,089	3,336
Rail	66,181	59,824	59,419	56,462
Barge	43,492	72,356	63,199	51,331

Note: Ton-miles = tonnage x mileage of the shipment.

Although the volume of rail deliveries increases significantly under all scenarios, both truck and rail volumes decrease on a ton-mile basis. This suggests that grains will be transported over shorter distances in larger quantities in 2021 compared to 2010 shipments. However, barge shipments are expected to increase on both a tonnage and ton-mile basis. Thus, model results suggest that by 2021 demand for truck and rail transportation will decrease by 48%-60% and 10%-15% respectively, while demand for barge transportation will increase by 18%-66%. Corn and soybean transportation shipments via ocean vessels are projected to increase by 22% and 9% (18.5 and 7.7 million tons) under the BaseUSDA and USDA2021 scenarios, but are projected to decrease by 11% (9.8 million tons) under the EIA2021 scenario.

Tables 22 and 23 present the results for inter-regional and intra-regional grain movements. Nearly 88% of all corn shipments originate from the Corn Belt (48%), the Great Plains, (23%), and the Lake States (16%) regions. Total corn shipments from the Corn Belt region are expected to increase from 68.2 million tons to 83.3, 87.9 million tons under the forward-looking scenarios. Intra-regional corn transportation volume will remain the same under the current biofuel production levels (BaseUSDA scenario), but it is expected to increase under the alternative scenarios. For example, under the USDA2021 and EIA2021 scenarios, intra-regional corn flows are 18% and 42% (2.3 and 5.6 million tons) higher than under the BaseUSDA scenario.

Table 22. Inter-regional and Intra-regional Corn Shipments under Forward-Looking Scenarios

Origin	Destination	Base2010	BaseUSDA	USDA2021	EIA2021
Corn Belt	Corn Belt	13,277	13,102	15,611	18,850
	Great Plains	82	-	629	507
	Northeast	2,612	4,504	4,588	4,582
	Rocky Mountains	354	-	-	-
	South Central	6,776	14,535	13,821	12,345
	Southeast	12,422	11,715	11,720	12,326
	Southwest	1,685	411	-	-
	Atlantic Ports	845	4,590	4,086	4,763
	Great Lakes Ports	766	-	-	-
	Gulf Ports	25,197	39,039	34,880	29,903
	PNW Ports	4,177	-	-	-
	TOTAL	68,192	87,896	85,335	83,277
Great Plains	Great Plains	5,580	18,962	20,067	19,345
	Pacific Northwest	461	80	80	78
	Pacific Southwest	4,446	4,629	4,532	4,873
	Rocky Mountains	1,773	6,740	7,234	6,321
	South Central	1,374	219	944	1,923
	Southwest	7,206	9,944	9,421	8,826
	Gulf Ports	2,139	-	-	-
	PNW Ports	4,892	-	-	-
	Canada	1,299	-	-	-
	Mexico	3,783	-	-	-
	TOTAL	32,954	40,574	42,278	41,365
Lake States	Corn Belt	1,691	9,549	9,811	9,907
	Great Plains	2,607	1,611	2,130	2,993
	Lake States	7,171	4,053	2,842	2,813
	Northeast	444	3,592	3,291	3,293
	Pacific Northwest	2,567	-	-	-
	Rocky Mountains	2,032	-	-	-
	South Central	574	-	-	-
	Southeast	2,218	-	-	-
	Atlantic Ports	1,375	274	109	-
	Great Lakes Ports	-	4,529	4,504	3,912
Lake States	PNW Ports	1,661	-	-	-
	Mexico	-	4,755	4,755	4,755
	TOTAL	22,340	28,363	27,441	27,673
Northeast	Northeast	1,416	1,883	1,865	2,031
	Southeast	471	238	238	242
	Atlantic Ports	0.2	-	-	-
	Canada	-	583	592	389
	TOTAL	1,887	2,704	2,695	2,662
Pacific Northwest	Pacific Northwest	-	469	563	563
	PNW Ports	472	1	1	1
	TOTAL	472	470	564	564

Table 22 continued

Origin	Destination	Base2010	BaseUSDA	USDA2021	EIA2021
Pacific Southwest	Pacific Northwest	-	127	119	119
	Pacific Southwest	298	230	289	289
	TOTAL	298	357	408	408
Rocky Mountains	Pacific Northwest	-	37	37	44
	Pacific Southwest	-	545	545	521
	Rocky Mountains	2,815	3,042	2,986	2,817
	TOTAL	2,815	3,624	3,568	3,381
South Central	South Central	3,634	7,785	7,671	7,752
	Southeast	524	4,313	4,347	3,772
	Gulf Ports	4,967	5,744	5,895	6,274
	TOTAL	9,125	17,843	17,913	17,798
Southeast	Southeast	290	415	443	458
	Atlantic Ports	75	-	-	-
	TOTAL	364	415	443	458
Southwest	Southwest	148	-	26	571
	Gulf Ports	2,483	2,567	2,612	2,042
	TOTAL	2,631	2,567	2,612	2,612

Note: Quantity is in 1000 metric tons.

Table 23. Inter-regional and Intra-regional Soybean Shipments under Forward-Looking Scenarios

Origin	Destination	Base2010	BaseUSDA	USDA2021	EIA2021
Corn Belt	Corn Belt	4,159	3,335	2,850	2,405
	Great Plains	-	-	-	592
	Lake States	771	-	-	-
	Northeast	-	1,197	722	680
	South Central	973	1,001	1,374	1,662
	Southeast	632	1,541	1,798	2,143
	Southwest	708	-	-	-
	Atlantic Ports	114	503	352	-
	Great Lakes Ports	804	721	630	474
	Gulf Ports	13,576	20,540	17,359	14,553
	TOTAL	21,738	28,838	25,085	22,508
Great Plains	Corn Belt	608	1,728	2,107	3,797
	Great Plains	1,451	4,883	5,648	4,858
	Lake States	-	2,159	1,440	2,016
	Pacific Northwest	1,639	242	20	5
	Rocky Mountains	-	1,686	1,470	550
	Southwest	599	1,905	1,695	1,228
	Gulf Ports	195	1,459	1,457	1,457
	PNW Ports	5,545	-	-	-
	Canada	2,026	529	529	635
	Mexico	1,821	-	-	-
	TOTAL	13,883	14,592	14,364	14,546

Table 23 continued

Origin	Destination	Base2010	BaseUSDA	USDA2021	EIA2021
Lake States	Corn Belt	1,617	3,824	4,427	6,428
	Lake States	2,320	3,140	3,428	2,323
	Pacific Northwest	1,870	-	-	-
	Rocky Mountains	2,191	-	-	-
	Southeast	448	-	-	-
	Atlantic Ports	1,089	-	-	-
	Great Lakes Ports	-	1,888	777	-
	PNW Ports	115	-	-	-
	Mexico	-	2,036	2,036	1,914
	TOTAL	9,650	10,888	10,667	10,665
Northeast	Northeast	111	176	143	209
	Southeast	847	819	979	1,345
	Atlantic Ports	359	1,434	822	381
	Canada	-	259	259	309
	TOTAL	1,317	2,688	2,204	2,245
South Central	South Central	806	1,830	1,981	2,047
	Southeast	994	454	595	710
	Southwest	-	-	-	101
	Gulf Ports	7,505	8,578	8,423	8,048
	TOTAL	9,305	10,862	10,999	10,906
Southeast	Southeast	222	336	356	294
	Atlantic Ports	169	148	47	-
	TOTAL	390	484	403	294
Southwest	Southwest	16	331	472	444
	Gulf Ports	441	1,170	780	176
	Mexico	55	-	-	-
	TOTAL	513	1,501	1,252	620

Note: Quantity is in 1000 metric tons.

No significant changes are expected in corn flows from the Corn Belt region to the Southeast region (VA, NC, SC, GA, and FL) and it remains the single largest supplier to this region under all scenarios. Under all scenarios, corn shipments from the Corn Belt to the Northeast and South Central regions nearly double by 2021. Corn shipments to the Atlantic ports increase from 0.8 million tons to over 4 million tons while shipments to the PNW ports discontinue under all scenarios. The Gulf Ports receive 19-55% (4.8, 14 million tons) more corn shipments from the Corn Belt.

Total volume of corn shipments originating from the Great Plains increased by 23%-28% from 2010 levels. The largest increase is in intra-regional corn transportation volume within the Great Plains. In particular, intra-regional corn shipments will increase by 240% (13.4 million tons) under the BaseUSDA scenario, 260% (14.5 million tons) under the BaseUSDA scenario, and 247% (13.8 million tons) under the EIA2021 scenario. The shipments from the Great Plains region to the Pacific Southwest remain the same under all cases. The Rocky Mountains region becomes a significant destination for corn originating from the Great Plains region. The Southwest regions also see some moderate increase in corn shipments from the Great Plains. One surprising finding is that the Great Plains region ships 12.1 million tons of corn to all port locations, Canada, and Mexico under the base model, but it no longer ships any corn under any of the scenarios.

The Lake States' total shipments increase by 25% on average. Three types of distinct patterns are observed in the scenario results. In the first pattern, corn shipments from the Lake States to the Corn Belt and Northeast regions increase significantly under all cases. Shipments from the Lake States to the Corn Belt increase from 1.7 to over 9.5 million tons. Overall, the differences in transportation volumes between the scenarios are relatively small. The second pattern is observed in corn intra-regional shipments, where the changes between the base and scenario results are large and differ across scenarios. For example, intra-regional shipments decrease by 43% in the BaseUSDA scenario and by 60% under the USDA2021 and EIA2021 scenarios. In the third pattern, some routes between the Lake States and other regions disappear and other new linkages emerge. The Lake States no longer ship to the Pacific Northwest, Rocky Mountains, South

Central, Southeast, Atlantic Ports, and PNW ports. In addition, new routes are established between Great Lakes Ports and Mexico under alternative scenarios.

No significant changes are expected in transportation flows in the remaining regions with the exception of the South Central region where the volume of corn shipments nearly doubles under all scenarios. The most significant changes there occur in intraregional shipments and flows to the Southeastern region. Intraregional shipments are expected to double under all scenarios. The volume of corn shipments from the South Central region to the Southeast region increases from 0.5 to 4.3 million tons under the BaseUSDA and USDA2021 scenarios and to 3.8 million tons under the EIA2021 scenario. Shipments to the Gulf ports are also expected to increase under all scenarios.

Similar to corn shipments, soybean shipments originating from the Corn Belt, Great Plains, and Lake States account for 80% of the total soybean shipments in the 2010 base model. Total soybean shipments from the Corn Belt region are expected to increase by 4-33% by 2021. Intra-regional soybean transport volume declines by 20% (0.8 million tons) at the 2010 biodiesel production level under the BaseUSDA scenario. Furthermore, at higher biodiesel production levels under the USDA2021 and EIA2021 models, it decreases by 31% (1.3 million tons) and 42% (1.7 million tons) respectively. Soybean shipments from the Corn Belt region to the Gulf ports accounted for 62% of the region's total shipments in the base model and this remains the single largest route under all scenarios. However, the soybean movements to the Gulf ports decline depending on the level of biodiesel production. For example, the Corn Belt region's soybean shipments to the Gulf ports will increase by 51% (7 million tons) under the BaseUSDA scenario but the increase is only 28% (3.8 million tons) and 7% (1 million tons) under the USDA2021 and EIA2021 scenarios respectively. Soybean shipments to the South Central and Southeast regions increase under all cases and the volume of shipments increases under the higher levels of biodiesel production in the USDA2021 and EIA2021 scenarios.

Overall volume of soybean shipments originating from the Great Plains does not increase significantly from its 2010 levels. However, significant regional-specific changes occur. Intra-regional soybean shipments and shipments to the Corn Belt, Southwest, and Gulf ports significantly increase under all scenarios. Soybean shipments to the Pacific Northwest and Canada significantly decrease and the Great Plains no longer ships to PNW ports and Mexico under all forward-looking scenarios. New routes emerge between the Great Plains and other regions. The new destinations include the Lake States and Rocky Mountains regions.

Total soybean shipments from the Lake States are projected to increase by about 11-13% (1-1.2 million tons) by 2021. The Corn Belt region is projected to become a major receiver of soybeans from the Lake States. The Corn Belt will receive more and more soybeans from the Lake States under the scenarios with higher levels of biodiesel production. In particular, soybean shipments from the Lake States to the Corn Belt increase by 136% (2.2 million tons), 174% (2.8 million tons), and 297% (4.8 million tons) under the BaseUSDA, USDA2021, and EIA2021 scenarios respectively. The Lake States increase soybean shipments to Mexico by nearly 2 million tons a year under all scenarios. In contrast, soybean shipments to the Pacific Northwest, Rocky Mountains, and Southeast regions and Atlantic ports are projected to decrease by 2021 under all forward-looking scenarios. No major changes are projected in the volume of soybean shipments in other remaining regions.

3.6 Conclusions

U.S. biofuel production levels have altered grain prices, non-biofuel grain consumption, and agricultural transportation system usage. This study yielded several key findings and implications about the situation.

- Had the RFS1-associated biofuel production levels not been in place, domestic and foreign consumers would have consumed 11.9% (9.9 million tons) and 10.5% (9.8 million tons) more corn in 2007. Prevailing market prices of corn would have been lower by 20% ($37/ton or $0.97/bushel) for domestic consumers and 15% ($36/ton) for foreign consumers.
- The RFS1-associated production levels did not have very large effects on the domestic soybean market in terms of consumption for food purposes. However, foreign consumers' consumption would have increased by 11% (8.3 million tons). In addition, soybean prices would have been 12% ($54/ton or $1.37/bushel) and 11% ($52/ton) lower for domestic and foreign consumers respectively.
- Had biofuel production stayed at 2007 levels as opposed to increasing to 2010 RFS2 levels, domestic and foreign consumers would have consumed 9% (7.6 million tons) and 19% (18.7 million tons) more corn in 2010. Prevailing market

prices of corn would have been lower by 22% ($50/ton or $1.27/bushel) for domestic consumers and 16% ($49/ton) for foreign consumers.

- In the absence of RFS1 production levels, total U.S. corn and soybean exports would have been 20% higher than 2007 levels. Without the RFS2 production levels, U.S. corn and soybean exports would have been 34% higher than 2010 levels. In particular, grain exports from the Gulf and PNW ports to international markets would increase by 14% and 27% without RFS1 production levels and by 38% and 28% without RFS2 production levels.
- Relative to other modes, transportation volume by truck was not significantly affected by higher volumes of biofuel production. Volume of truck deliveries would have increased only by 2% and 6% in the absence of RFS1 and RFS2 production levels.
- Volume of rail freight would have increased by 9% and 17% on a tonnage basis and 15% and 31% on a ton-mile basis if the RFS1 and RFS2 levels of biofuel production had not occurred.
- Barge use would have increased by 10% and 26% in the absence of RFS1 and RFS2 production levels due to higher export volumes to international markets. As a result, volume of shipments via big ships would increase by 21% and 36%.

Results under forward looking scenarios for 2021 indicate that exports are expected to go up and that a small decline in prices is expected, especially in the domestic market. This is mostly due to technological progress and a static, largely capped, level of corn-based biofuel production. This in turn affects domestic and international grain flows, demand for grain transportation, and U.S. grain exports to foreign markets. As a result, several key findings were noted.

- Net U.S. corn exports increase under all forward-looking scenarios and net U.S. soybean exports decrease under the EIA2021 scenario. This is largely due to technological progress. In addition, the corn share in the ethanol market is limited to 15 billion gallons. Changes in the volume of exports are expected at major grain-exporting ports. Grain exports from the Gulf ports are expected to increase by 41% under the USDA2021 scenario. Pacific Northwest ports are expected to lose some of their market share to the Great Lakes and Atlantic ports. This expected increase in grain exports from the Gulf ports would create a need for increasing a port's grain receiving and handling capacity, and for maintaining other infrastructure that can handle higher volumes of freight.
- Inter crop reporting district movements by truck decline by 30%-40% under the 2021 scenarios.
- The use of rail transportation increases by 57%-60%. Despite the larger volumes of grain movements, rail deliveries will be used for shorter distances and the average distance of grain shipment will decline by 42%-47%. This may be due to the upward trend in the rail rates.
- Use of barge transportation is expected to increase under all scenarios due to higher volumes of supply available in the Corn Belt region.

- Demand for ocean transportation is expected to increase under the BaseUSDA and USDA2021 scenarios and decline under the EIA2021 scenario. The EIA2021 decline in the volume of ocean transportation is due to higher projected biofuel production levels, which cause available corn and soybean supply for export to decline.
- Scenario results indicate that the volume of rail freight will increase by as much as 60% on a tonnage basis by 2021. This projected increase in rail volume would necessitate developing or maintaining tracks and a fleet of rail cars to handle higher freight capacity in regions between the Corn Belt and other major grain destinations. One alternative may be to replace old rail cars with smaller capacity with newer hopper cars with larger cargo capacity.

4. MISSISSIPPI RIVER SYSTEM NAVIGATION IMPEDIMENTS AND IMPLICATIONS FOR AGRICULTURAL TRANSPORTATION

A well-developed and competitive Mississippi River System (MRS) water transportation system provides agricultural shippers with a highly efficient and low-cost system of transportation (Marathon and Sparger, 2012). Barges, railroads, and trucks are partners in grain transport. Any major river disruption affects other modes and consequently may lead to imbalance and inefficiency in the entire transportation system. In particular, water transportation plays an important role in U.S. agriculture's ability to compete in world markets. For example, the five-year average (2005-2010) modal shares of rail and barge delivery to point of grain exports are 48% and 44% respectively. In domestic grain transportation, rail and truck dominated with modal shares of 26% and 73% respectively.

Most of the corn and soybeans that originate in the Midwest travel by barge and pass through one or more MRS locks on their way to market. If segments of the river are closed due to lock failures, U.S. producers' cost advantages are reduced as grain is diverted to modes that are more expensive. Barge dominates as a supply source for Gulf Coast exports providing 87–91% of corn and 87–89% of soybeans exported through Mississippi Gulf ports during 2005 and 2009 (Marathon and Denicoff 2011). Impediments to barge transportation due to the deteriorating condition of the MRS lock and dam infrastructure and persistent severe drought conditions would directly affect U.S. grain producers, the barge industry, and ultimately, the consumers.

4.1 Objective

The main objective of this section is to investigate the economic impact of select impediments to the Mississippi River system barge transportation and its implications for grain transportation and market conditions. Two types of impediments to barge transportation are considered. The first impediment involves failures of varying duration at selected MRS locks and dams. The second impediment involves decreased water levels caused by persistent drought. The IGTM model from the second section will be used to assess these impacts.

This study is an updated and expanded version of a 2011 study by Kruse et al. (2011) entitled "America's Locks and Dams: A Ticking Time Bomb for Agriculture? Final Report to the United Soybean Board, 2011." The author of the current study played a major role in the model setup and analysis used in the 2011 study. The extensions herein involve the introduction of the drought/water level analysis, recalculation of some barge shipment routes and costs, updated data, and a correction regarding southern hemisphere supply availability to the spring quarter.

4.2 Background on River Impediments

This section provides background information on the condition of river locks and identifies the most vulnerable locks. It also provides background information on the impact of droughts on barge navigation and barge freight capacity.

4.2.1 Lock Condition and Identification of High-Priority Locks

As of 2010, 54% of the Inland Marine Transportation System's lock structures were over 50 years old and 36% of all lock structures were 70 years or older. The average economic service life of a lock structure is 50 years, but it be extended up to 75 years through major rehabilitation projects. Poor lock conditions have caused an increase in frequent lock failures, which has restricted the transportation of grains via the river systems (USHR-CTI 2011). For example, the Ohio River experienced a sharp rise in navigation outages where the navigation outages increased from 25,000 hours in 2000 to 80,000 hours in 2011.

The IMTS Capital Investment Strategy (CIS) Team developed criteria for assessing and prioritizing work for maintenance and rehabilitation of locks and published its report in 2010 (IMTS 2010). Next, each district belonging to the U.S. Army Corps of Engineers (USACE 2010) identified high priority construction or major rehabilitation projects using structural/operational risk and reliability and economic return criteria developed by the IMTS CIS team. Five locks were chosen from the USACE list of high priority locks to assess the economic impact of impediments. The following locks were selected for detailed analysis:

- LaGrange Lock and Dam on the Illinois River;
- Lock and Dam 20 on the Upper Mississippi River;
- Lock and Dam 25 on the Upper Mississippi River;
- Lock and Dam 52 on the Ohio River; and
- Markland Lock and Dam on the Ohio River.

4.2.2 Impact of Persistent Droughts on the U.S. River System

Record low-water levels in 2012 on the Mississippi river system due to abnormal climate conditions had severe adverse effects on grain shippers. Shippers had to reduce the tow size and use light-load barges in order to navigate through the shallow segments of the river (BusinessWeek 2012). In some cases, barge freight was forced to stop due to boat groundings. Shallow conditions also added to transit time for barge transportation. Articles in BusinessWeek and the Los Angeles Times (Cart 2012) reported that a number of shippers and stakeholders in the barge industry reacted to the low water levels by loading barges with less tonnage to reduce draft to 8.5-9 feet (three feet less than the normal 11-12 ft. draft). In addition, the number of barges pushed by a towboat was reduced from 30-40 to 20-30 barges.

On July 20, 2012, The American Waterways Operators, the national trade association for the U.S. tugboat, towboat, and barge industry, published a news release stating that barge-carrying capacity had been reduced by 17 tons for every one-inch loss of draft. This translates to 204 tons of lost cargo capacity per barge because of the one-foot decrease in barge draft. The AWO release further stated that the one-foot loss of draft resulted in 3,000 tons of lost cargo capacity for a typical 15-barge tow and over 9,000 tons on a 30-45 barge tow. Marty Hettel, a senior manager at the AEP River Operations, stated that it was taking 3-6 extra days transit time for a barge to transport cargo from Cairo, IL, to New Orleans, LA (USA Today, September 19, 2012).

4.3 Previous Economic Studies

Numerous research studies have investigated the economic impact of impediments to barge navigation. Most studies investigated the effects of congestion and delays at locks and their impact on barge freight volume and barge rates. Fuller and Grant (1993) investigated the effect of lock delays on the cost and efficiency of marketing U.S. corn and soybeans via the Upper Mississippi and Illinois rivers by using a multi-commodity least-cost network flow model. They found that lock delays affected the barge transport costs and caused grain to be redirected to less efficient modes.

Spatial equilibrium models have been used to evaluate the grain transportation infrastructure. Fuller et al. (2001) evaluate the improvements in transportation infrastructure in South America as it influences region’s competitiveness in world grain markets by using quadratic spatial equilibrium model of international corn and soybean economies. Their findings indicate that improvements increase South American annual grain exports by more than three million tons and annual producer revenues by $1 billion. In 2000, Fuller, Fellin, and Ericksen investigated the implications of Panama Canal closure and an increase in Canal toll for U.S grain exports and producers’ revenue by using a similar model. Yu et al. (2007) employed time-series analysis to evaluate the effects of lock congestion and delays on grain barge rates. They find that accumulated lock delays increase barge rates in the Upper Mississippi River.

Climate induced changes in modal split and transportation volume have been researched, although there are not many studies specifically address low water levels on waterways (Koetse and Rietveld 2009). Modal-split effects of low water levels, due to climate change, on inland waterway transport in the river Rhine area was evaluated by Jonkeren, Jourquin, and Rietveld (2011) using NODUS model, a GIS-based software. Their findings indicate that the effect of climate change on modal split is not significant and even under an extreme drought scenario, similar to the 2003 drought in Europe, European inland waterway transport volume declines by 5.4%. Olsen, Zepp, and Dager (2005) evaluated the low water levels from 1933-2002 on the middle Mississippi River and its effects to barge transportation. They estimated that the average losses to shippers amounted to $77 million a year during this period. Under the three global circulation models (GCMs) forward-looking scenarios for the year 2100, the expected losses to barge shippers due to low water levels are estimated to range between $10-118 million a year. Millerd (2005) investigates the effects of low water levels on the Great Lakes and St. Lawrence River due to climate change under several GCM scenarios for 2030-2050. Their finding indicates that the average annual cost of grain shipments through Great Lakes increase by 6-26%. Attavanich et al. (2013) evaluated the climate induced regional shifts in crop production, crop-mix, and transportation volumes in North America under different GCM scenarios using the IGTM model. Their findings indicate that aggregate and regional agricultural transportation volumes and modal shares change due to climate change.

4.4 Modeling Procedures

In order to carry out the analysis needed to achieve the objectives of this study, lock failures and decreased water levels were simulated. The lock failure scenarios were simulated for durations of two weeks, one month, three months, and one year. 1-foot, 2-

foot, 3-foot decreases in barge draft (a barge's depth in the water) were considered for each drought scenario. In addition, the drought scenarios incorporated barge rate increases by 10%, 20%, and 30%. In all, this analysis considered 65 scenarios of lock failure consisting of 13 failure scenarios in different quarters of the year, plus one-year scenarios for each of five locks (LaGrange Lock on the Illinois River; Lock 20 and 25 on the Upper Mississippi River; Lock 52 and Markland on the Ohio River) and six scenarios under drought conditions. Table 24 illustrates these scenarios. For example, the "LaGrange_Fall_2weeks" scenario models the situation where the LaGrange Lock and Dam on the Illinois River fail for two weeks in the fall quarter, resulting in no barge shipments through the lock during this period. In the "Lock25_annual" scenario, Lock and Dam 25 on the Upper Mississippi River is closed for an entire year and no barge traffic is allowed to go through during this period. If there is a lock between two barge locations, then that route is broken into two parts, from upstream origin barge locations to the lock and from the lock to downstream destination barge locations, in order to accommodate the lock failure scenarios. With this setup, no barge shipment that originates from the upstream end of the lock can reach the destination at the downstream end of the lock during the lock failure. For example, a barge shipment originating from St. Paul, MN, to St. Louis, MO, has to go through locks 20 and 25 on the Upper Mississippi River and if any one of the locks fails, the freight cannot reach its destination.

Table 24. Scenarios under Consideration

Lock Failure Scenarios			
Fall_2weeks	Winter_2weeks	Spring_2weeks	Summer_2weeks
Fall_1month	Winter_1month	Spring_1month	Summer_1month
Fall_1quarter	Winter_1quarter	Spring_1quarter	Summer_1quarter
Annual			
Drought Scenarios			
1-foot	2-foot	3-foot	
1-footRI*	2-footRI	3-footRI	

Note: RI denotes rate increase.

In modeling drought scenarios, the 1-foot, 2-foot, 3-foot scenarios represent situations where barge draft, a barge's depth in the water, is decreased by one foot, two feet, and three feet respectively, due to low water levels on the river. The 1-footRI, 2-footRI, and 3-footRI scenarios represent situations in which persistent drought results in both a rate increase and a draft decrease. For example, "1-footRI" contains a 1-foot draft decrease and a 10% barge rate increase. The scenario "2-footRI" has a 2-foot decrease in barge draft and a 20% increase in barge rates. The scenario "3-footRI" has a 3-foot decrease in barge draft and 30% increase in barge rates. Therefore, the assumption of higher barge rates under drought conditions is reasonable given the increase in barge delivery time and decrease in barge freight capacity due to low water levels on the river.

Imposing the barge rate increase is straightforward. All barge rates are increased by the relevant percentage for all quarters of the year. In order to impose reduction in river water levels, the maximum barge traffic volume at key segments of the river system is reduced by a certain percentage. Specific reduction rates for each scenario are presented and explained in the next paragraph. Because most of the barge grain supply has to go through LaGrange Lock on the Illinois River and Lock 25 on the Upper Mississippi River, and the primary barge freight destination is Port Baton Rouge, these three locations are chosen to impose the volume restrictions. Maximum barge freight capacity of these three locations is identified by using 10-year historical grain freight volume data obtained from USACE (2010). Table 25 shows the maximum barge freight volume for grains and the reduced volume under each scenario.

Table 25. Maximum Barge Freight Volume and Reduced Volume under Each Scenario

Location	Maximum capacity	Reduction 1 foot in draft or 14%	Reduction 2 feet in draft or 27%	Reduction 3 feet in draft or 41%
LaGrange	6,112	5,256	4,462	3,606
Lock25	9,087	7,815	6,634	5,362
Baton Rouge	13,138	11,299	9,591	7,752

Note: Capacity is measured in 1000 metric tons.

These scenario-specific reductions in grain handling capacity were identified based on barge industry experts' observations during drought. Following statements by Thomas A. Allegretti, president and CEO of AWO, (AWO 2012, BusinessWeek 2012) it is assumed that the carrying capacity of a single barge is reduced by 17 tons for each 1-inch loss of water. Thus if the typical carrying capacity of a barge is 1,500 tons, then each 1-foot decrease in barge draft results in a 204 ton reduction or -14% in overall carrying capacity of a barge. Similarly, a 2-feet and 3-feet decrease in barge draft corresponds to 27% and 41% reduction in maximum quarterly barge freight capacity.

The implicit assumption here is that the number of barges in a tow stays the same. The typical tow contains 15-20 barges on the Upper Mississippi River and 30-40 barges on the Lower Mississippi River. As discussed in the previous section, the number of barges in a tow is reduced due to navigability when the water level on river is low. If a reduction in the number of barges in a single tow were incorporated in the analysis, then 1-foot, 2-foot, and 3-foot reductions in barge draft would result in 26%, 48%, and 66% reductions in overall barge freight volume. However, this possibility is not considered in this analysis.

4.5 Results

Sixty-five failure-related scenarios and six drought-related scenarios were simulated after imposing the necessary restrictions on lock availability, barge traffic volume, and barge rates. Simulated results were compared with IGTM baseline results for 2010 to identify the impediments' implications for supply and demand, agricultural transportation, and welfare.

Some general results were observed. Simulated model results indicated that aggregate domestic and international supply and demand quantities did not change more than 1% under any scenario. Lock failures at Markland Lock and Lock 52 did not alter domestic regional grain flows significantly. Therefore, in most cases, scenario results from Markland and Lock 52 are not presented if the scenario did not yield significant changes from the baseline scenario. Locks 20 and 25 are both located on the Upper Mississippi River and often result in almost identical results. For this reason, only the Lock 25 scenario results were presented. Two types of results were presented, transport and welfare implications. Quarterly results were also presented, but only for the most costly quarter.

4.5.1 Lock Failure Scenario Results

Changes in the volume of incoming shipments to port locations by each mode of transportation due to lock failures are summarized in Tables 26, 27, 28, and 29. Combined shipments to all port locations decreased by 2% on average due to lock failures. Gulf ports were adversely affected and PNW and Atlantic ports were positively affected.

A closure of the LaGrange lock will have the most adverse effect on Gulf ports under a partial year closure when the lock closure occurs in the fall. If the LaGrange lock is closed for a month during the fall, then it decreases total barge shipments to the Gulf ports by 4% and increases rail shipments by 12%. Of the diverted traffic, only 0.8 million tons of grain are delivered to the Gulf ports via rail and the remaining 1 million tons are delivered to the PNW and Atlantic ports via rail. If the LaGrange lock is closed during the entire fall quarter or an entire year, then it reduces total barge shipments to the Gulf ports by 10% and 14% and increases rail shipments to the Gulf by 29% and 50% respectively. Similarly, lost barge volume not delivered to the Gulf ports is transported to other port locations via rail.

Table 26. Changes in Incoming Shipments to Port Locations by Each Mode of Transportation Due to Lock Failures at the LaGrange Lock on the Illinois River

Port Locations	Mode	Baseline	Fall 2 weeks	Fall 1 month	Fall 1 quarter	Annual
Gulf Ports	Barge	45,122	-436	-1,829	-4,551	-6,508
	Rail	7,007	175	837	2,040	3,528
	Truck	4,372	0	0	190	59
	Total	56,502	-262	-992	-2,321	-2,921
PNW Ports	Rail	23,181	64	580	1,210	1,072
	Truck	472	0	0	0	0
	Total	23,653	64	580	1,210	1,072
Atlantic Ports	Rail	3,825	176	389	506	752
	Truck	200	0	0	0	0
	Total	4,026	176	389	506	752
Great Lakes	Truck	1,570	0	0	0	158
ALL PORTS	TOTAL	85,750	-1,592	-1,593	-2,175	-2,509

Note: Quantity is measured in 1000 metric tons

Table 27. Changes in Incoming Shipments to Port Locations Due to Lock Failures at Locks 20 or 25 on the Upper Mississippi River

Port Locations	Mode	Baseline 2010	Fall 1 quarter	Summer 2 weeks	Summer 1 month	Summer 1 quarter	Annual
Gulf Ports	Barge	45,122	-446	-753	-1,186	-1,320	-5,976
	Rail	7,007	127	470	447	477	3,867
	Truck	4,372	15	0	0	0	93
	Total	56,502	-305	-284	-739	-843	-2,019
PNW Ports	Rail	23,181	353	208	663	767	1,408
	Truck	472	0	0	0	0	0
	Total	23,653	353	208	663	767	1,408
Atlantic Ports	Rail	3,825	-47	54	54	54	199
	Truck	200	0	0	0	0	0
	Total	4,026	-48	53	53	53	198
Great Lakes	Truck	1,570	0	0	0	0	0
ALL PORTS	TOTAL	85,750	-1,569	-1,592	-1,592	-1,592	-1,982

Note: Quantity is measured in 1000 metric tons

Table 28. Changes in the Total Volume of Grain Shipments by Mode of Transportation Due to Lock Failures at LaGrange Lock on the Illinois River

Transport Mode	Baseline 2010	Fall 2 weeks	Fall 1 month	Fall 1 quarter	Annual
	Transportation volume (1000 tons)				
Truck	93,699	-584	-1,565	-3,714	-5,923
Rail	103,961	565	1,643	2,958	5,642
Barge	46,594	-436	-1,737	-4,932	-6,888
Small Ship	1,570	0	0	0	158
Big Ship	85,750	-22	-23	-605	-939
	Transportation volume (billion ton-miles)				
Truck	8,350	-88	-255	-281	-286
Rail	66,181	237	1,679	3,730	4,806
Barge	43,492	-376	-1,942	-5,331	-7,168
Small Ship	829	0	0	0	83
Big Ship	756,433	455	7,828	13,877	14,495

Note: ton-miles = tonnage x mileage of the shipment

Table 29. Changes in the Total Volume of Grain Shipments by Each Mode of Transport Due to Lock Failures at Locks 20 and 25 on the Upper Mississippi River

Transport Mode	Baseline 2010	Fall 1 quarter	Summer 2 weeks	Summer 1 month	Summer 1 quarter	Annual
	Transportation volume (1000 tons)					
Truck	93,699	-276	-332	-856	-886	-7,137
Rail	103,961	290	310	834	864	6,747
Barge	46,594	-1,448	-753	-1,025	-1,159	-6,979
Small Ship	1,570	0	0	0	0	0
Big Ship	85,750	0	-22	-22	-22	-412
	Transportation volume (billion ton-miles)					
Truck	8,350	44	-36	-55	-34	-331
Rail	66,181	446	757	1,382	1,563	6,577
Barge	43,492	-525	-1,067	-1,722	-1,948	-8,187
Small Ship	829	0	0	0	0	0
Big Ship	756,433	1,162	5,699	6,511	327	9,233

Note: Ton-miles = tonnage x mileage of the shipment

Unlike the LaGrange lock, lock failures on the Upper Mississippi River have negative effects on incoming shipments to the Gulf ports if they are closed during the summer quarter or throughout the year. One- or three-month lock failures at Locks 20 or

25 reduced barge deliveries by 3%, whereas a one-year lock failure reduced the barge deliveries to the Gulf ports by 13%. One-year lock failures on the Upper Mississippi River increased rail deliveries to the Gulf ports by 55%. However, the negative impact of lock failures along the Upper Mississippi River is not as severe as that of the LaGrange lock on the Illinois River.

Demand for each type of transportation changes in response to lock failures. Results indicate that demand for truck and barge transportation declines and demand for rail increases. Lock failures at LaGrange have a greater effect on transportation volume than do lock failures at Locks 20 and 25 in all scenarios with the exception of annual lock failures on the Upper Mississippi River. For example, one-month and three-month lock failures at LaGrange reduced demand for truck transportation by 2% and 4%, for barge transportation by 4% and 11%, and increased use of rail transportation by 2% and 3% respectively, based on tonnage. Annual lock closure at Lagrange has the most impact on transportation volume because it reduces usage of truck and barge transportation by 6% and 15% respectively, and increases rail volume by 5% based on tonnage. Volume transported by big ship increases by 2% under three-month and annual lock failures, while volume transported by small ship increases by 10% under annual lock closure at LaGrange based on ton-miles.

Lock failures of up to three months at Locks 20 and 25 do not change modal use significantly. Annual lock failures at these locks reduce truck volume by 8% based on tonnage and by 4% based on ton-miles, while reducing barge by 15% based on tonnage and 19% on a ton-mile basis. They also increase rail volume by 6% on a tonnage basis and by 10% based on ton-miles. Volume moving by big ship also increases by 1% on a based on ton-miles under the annual lock closures at Locks 20 and 25.

Lock failures also affect modal transportation costs. Table 30 summarizes the changes in average cost of modal transportation per ton due to lock failures for various lengths of time. Cost of truck transportation is affected only by one-year and winter-quarter lock failures. For example, annual lock failures increase cost of truck transportation by 2-3% and winter lock failures increase cost of truck transportation by 1%. Cost of rail transportation increases by 1% under all scenarios with the exception of LaGrange in the fall and Locks 20 and 25 in the summer quarter, where the cost increases by 2%. Increase in the cost of barge transportation ranges between 9% and 13% depending on the scenario. Average transportation costs of grain shipments via small ship increase by 2-3% and via big ship by 5-7%.

Although lock failures do not change aggregate domestic supply and demand balances or exports significantly, they do change domestic interregional and intraregional grain flows. Tables 31 and 32 summarize changes in interregional and intraregional corn and soybean shipments due to failures at LaGrange and Locks 20 and 25. In most cases, total corn shipments originating from a given region do not change significantly and the changes take place between destination regions. Corn shipments from the Corn Belt to the Corn Belt and South Central regions increase, but shipments from the Corn Belt to the Southwest region and the Gulf ports decrease because of lock failures.

Table 30. Changes in the Transportation Costs Due to Lock Failures ($/ton)

Lock	Quarter	Duration	Truck	Rail	Barge	Small Ship	Big Ship
LaGrange	Fall	2weeks	0%	1%	13%	5%	7%
		1month	-1%	2%	13%	-2%	5%
		1quarter	1%	2%	12%	0%	3%
	Annual	annual	2%	1%	13%	3%	0%
Lock 20	Fall	2weeks	0%	1%	12%	3%	6%
		1month	0%	1%	13%	3%	5%
		1quarter	1%	1%	13%	-2%	5%
	Winter	2weeks	1%	1%	12%		7%
		1month	1%	1%	12%		7%
		1quarter	1%	1%	12%		7%
	Spring	2weeks	0%	1%	12%	3%	7%
		1month	0%	1%	12%	3%	7%
		1quarter	0%	1%	12%	3%	7%
	Summer	2weeks	1%	2%	10%	-1%	5%
		1month	1%	2%	9%	2%	6%
		1quarter	0%	2%	7%	3%	5%
	Annual	annual	3%	3%	-2%	-2%	3%
Lock 25	Fall	2weeks	0%	1%	12%	2%	6%
		1month	0%	1%	12%	2%	6%
		1quarter	1%	1%	13%	2%	5%
	Winter	2weeks	1%	1%	12%		7%
		1month	1%	1%	12%		7%
		1quarter	1%	1%	12%		7%
	Spring	2weeks	0%	1%	12%	2%	7%
		1month	0%	1%	12%	2%	7%
		1quarter	0%	1%	12%	2%	7%
	Summer	2weeks	0%	2%	11%	2%	6%
		1month	1%	2%	10%	5%	5%
		1quarter	0%	2%	11%	-2%	6%
	Annual	annual	3%	3%	4%	-2%	5%
Markland Lock	Fall	2weeks	0%	1%	12%	3%	7%
		1month	0%	1%	12%	3%	7%
		1quarter	0%	1%	12%	3%	7%
	Winter	2weeks	1%	1%	12%		7%
		1month	1%	1%	12%		7%
		1quarter	1%	1%	12%		7%
	Spring	2weeks	0%	1%	10%	3%	6%
		1month	0%	1%	10%	3%	6%
		1quarter	0%	1%	10%	3%	6%
	Summer	2weeks	0%	1%	12%	2%	6%
		1month	0%	1%	12%	2%	6%
		1quarter	0%	1%	12%	2%	6%
	Annual	annual	0%	1%	12%	2%	6%
Lock 52	Fall	2weeks	0%	1%	9%	3%	6%
		1month	0%	1%	9%	3%	6%
		1quarter	0%	1%	9%	3%	6%
	Winter	2weeks	0%	1%	9%	3%	6%
		1month	0%	1%	9%	3%	6%
		1quarter	0%	1%	9%	3%	6%
	Spring	2weeks	0%	1%	12%	2%	6%
		1month	0%	1%	12%	2%	6%
		1quarter	0%	1%	12%	2%	6%
	Summer	2weeks	0%	1%	12%	2%	7%
		1month	0%	1%	12%	2%	7%
		1quarter	0%	1%	12%	2%	7%
	Annual	annual	0%	1%	12%	2%	7%

Note: Transportation costs are measured in $/ton

Table 31. Changes in Inter-regional and Intra-regional Corn Shipments Due to Lock Failures at LaGrange Lock on the Illinois River, and Locks 20 and 25 on the Mississippi River

Origin	Destination	Baseline 2010	LaGrange Fall 2 weeks	LaGrange Fall 1 month	LaGrange Fall 1quarter	LaGrange Annual	Lock20/25 Fall 1 quarter	Lock20/25 Summer 2 weeks	Lock20/25 Summer 1 month	Lock20/25 Summer 1 quarter	Lock20/25 Annual
Corn Belt	Corn Belt	11,839	-96	451	1,073	554	-267	817	1,216	1,246	4,990
	Great Plains	82	0	0	0	-32	0	0	0	0	0
	Northeast	2,613	-2	-6	8	-134	0	0	0	0	0
	Rocky Mts	354	0	0	13	13	0	0	0	0	13
	South Central	8,212	141	549	1,424	2,299	141	73	95	127	192
	Southeast	12,425	0	43	-43	179	0	-2	-1	-1	37
	Southwest	1,684	-19	-165	-764	-311	0	-399	-420	-420	-392
	Atlantic Ports	845	1	18	-353	295	0	-72	-50	-79	-182
	Great Lakes Ports	766	0	0	0	157	0	0	0	0	0
	Gulf Ports	25,197	-46	-906	-2,314	-4,232	127	-440	-865	-895	-4,981
	PNW Ports	4,178	-1	-1	634	887	0	-1	-1	-1	-1
	Total	68,195	-22	-17	-322	-325	1	-24	-26	-23	-324
Great Plains	Great Plains	5,580	0	0	0	-40	0	0	0	0	-355
	Pacific	4,907	-19	-164	-419	-295	0	-420	-419	-419	-419
	Rocky Mts	1,774	-8	-8	-5	-31	0	0	0	0	-23
	South Central	1,374	0	0	-242	-344	0	0	0	0	-103
	Southwest	7,205	19	164	284	296	0	399	420	420	389
	Gulf Ports	2,139	0	0	355	368	0	21	0	0	347
	PNW Ports	4,893	8	8	4	48	0	0	0	0	312
	Canada	1,299	0	0	0	0	0	0	0	0	0
	Mexico	3,783	0	-1	22	-1	0	0	0	0	-1
	Total	32,954	0	-1	-1	1	0	0	1	1	147
Lake States	Corn Belt	1,751	-45	-45	-105	-50	0	-18	176	146	1,141
	Great Plains	2,608	0	0	0	0	0	0	0	0	500
	Lake States	7,110	143	-403	-795	175	268	-798	-1,391	-1,391	-6,093

Table 31 continued

Origin	Destination	Baseline 2010	LaGrange Fall 2 weeks	LaGrange Fall 1 month	LaGrange Fall 1 quarter	LaGrange Annual	Lock20/25 Fall 1 quarter	Lock20/25 Summer 2 weeks	Lock20/25 Summer 1 month	Lock20/25 Summer 1 quarter	Lock20/25 Annual
Lake States	Northeast	444	-24	-20	-81	-98	0	-13	-26	-26	-26
	Pacific	2,568	76	434	702	211	-141	689	1,112	1,112	980
	Rocky Mts	2,032	7	7	-10	-6	0	-1	-1	-1	37
	South Central	574	0	0	0	-96	0	0	0	0	1,932
	Southeast	2,218	26	37	115	107	0	14	26	26	43
	Atlantic Ports	1,374	-182	-11	173	-242	-127	126	103	133	236
	Gulf Ports	0	0	0	0	0	0	0	0	0	1,249
	PNW Ports	1,661	0	0	0	0	0	0	0	0	0
	Total	22,340	1	-1	-1	1	0	-1	-1	-1	-1
Northeast	Northeast	1,415	27	27	73	232	0	14	26	26	26
	Southeast	471	-26	-26	-73	-232	0	-14	-26	-26	-26
	Atlantic Ports	0	0	0	0	0	0	0	0	0	0
	Total	1,886	1	1	0	0	0	0	0	0	0
Pacific	Pacific	298	-1	-1	-1	-1	0	0	-1	-1	-1
	PNW Ports	472	0	0	0	0	0	0	0	0	0
	Total	770	-1	-1	-1	-1	0	0	-1	-1	-1
Rocky Mts	Rocky Mts	2,815	0	0	0	44	0	0	0	0	0
South Central	South Central	4,946	0	55	-52	50	0	0	-47	-47	-315
	Southeast	523	0	-54	48	-54	0	0	48	48	-54
	Gulf Ports	3,656	0	0	4	4	0	0	0	0	369
	Total	9,125	0	1	0	0	0	0	1	1	0
Southeast	Southeast	290	0	0	0	0	0	0	0	0	0
	Atlantic Ports	75	0	0	0	0	0	0	0	0	0
	Total	365	0	0	0	0	0	0	0	0	0
Southwest	Southwest	239	0	0	0	12	0	0	0	0	1
	Gulf Ports	2,390	0	0	-480	-11	0	0	0	0	0
	Total	2,629	0	0	-480	1	0	0	0	0	1

Corn Belt intraregional shipments are affected most by failures at Locks 20 and 25; i.e., one-month, one-quarter, and annual failures at Locks 20 or 25 during summer quarters increase Corn Belt intraregional corn shipments by 10%, 11%, and 42% respectively. Lock failures during fall quarters at LaGrange increase Corn Belt intraregional shipments by 4%, 9%, and 5% under one-month, one-quarter, and annual lock closures respectively.

Lock failures at LaGrange induce the most changes in corn shipments from the Corn Belt to South Central region. One-quarter and one-year lock failures at LaGrange induced 17% and 28% increases in corn shipments from the Corn Belt to the South Central region. The largest decrease in corn shipments from the Corn Belt occurs between the Gulf ports. Three-month and one-year lock closures in the fall quarter at LaGrange reduce corn shipments from the Corn Belt to the Gulf by 2.3 million tons (9%) and 4.2 million tons (-17%) respectively. Annual failures at Locks 20 or 25 decrease corn shipments from the Corn Belt to the South Central region by 20%.

Corn shipments from the Great Plains to the Pacific and South Central regions decrease, while those to the Southwest and the Gulf port regions increase due to lock failures. However, overall volume of corn shipments from the Great Plains does not change. The shipments from the Great Plains to the Pacific region decline by 3-9% under lock closures at LaGrange and by 9% under all scenarios at Locks 20 and 25. Unshipped Pacific-bound corn is diverted almost entirely to the Southwest region. As a result, corn shipments from the Great Plains to the Southwest region increases by 2-4% under LaGrange lock closure scenarios and by 5-6% under Lock20/25 scenarios. Gulf ports receive 17% more corn from the Great Plains if LaGrange is closed for three months or a year. One-year closures at Locks 20/25 increase corn shipments coming into the Gulf ports from the Great Plains by 347,000 tons (16%), which is attributed to rail shipments.

Corn shipments from the Lake States are influenced primarily because of lock failures on the Upper Mississippi River. Most significant change in corn transportation volume occurs in shipments within the region. If Locks 20 and 25 fail, the Lake States' intraregional corn shipments decline by 1.3 million tons (-20%) under one-month and three-month lock failures, and by 6.1 million tons (-86%) under one-year lock closure. Lake States corn shipments to the Pacific region increase by 38-43% when Locks 20 or 25 are closed for a month or longer. Corn shipments from the Lake States to the Corn Belt, South Central, and Gulf ports increase by 1.1 million tons (65%), 1.9 million tons (337%), and 1.2 million tons respectively if the Upper Mississippi locks are closed for a year. The other regions are not affected significantly under all lock failure scenarios.

Inter- and intra-regional soybean shipments under lock failure are summarized in Table 32. Unlike corn, total soybean shipments from the Corn Belt region are affected by lock failures. In general, total soybean shipments from the Corn Belt decline in response to lock failures at LaGrange and increase in response to lock failures at locks 20 and 25. For example, lock failures at LaGrange reduce total soybean shipments from the Corn Belt by 4% under one- to three-month lock failures and by 5% under one-year closures. One-year failures at Upper Mississippi River locks increase total soybean shipments from the Corn Belt by 6%. In addition to aggregate changes, freight volume within the Corn Belt and to the Gulf ports changes due to lock failures. For example, annual lock closures at Locks 20 or 25 increase soybean shipments within the Corn Belt by 2.3 million tons, equivalent to a 75% increase in volume. Soybean shipments from the Corn Belt to the Gulf ports decrease under all cases. The largest reduction in freight volume (-8%) occurs with a three-month lock closure at LaGrange in the fall and under annual lock failures at LaGrange and Locks 20 and 25. Only annual failures at Upper Mississippi River locks affect soybean shipments from the Great Plains region significantly. Under one-year lock closures, soybean shipments from the Great Plains to the Corn Belt decline by 0.42 million tons (-69%) and shipments to the Gulf ports increase by 0.35 million tons (179%).

When lock failures occur at LaGrange, soybean shipments from the Lake States to the Corn Belt decline by 17% under two-week lock closures, 32% under one-month lock closures, and 40% under three-month and annual lock closure scenarios. The Lake States' intraregional soybean shipments are affected most by three-month failures in the fall (-26%) and annual lock failures (-29%) on the Upper Mississippi River locks. Volume of soybean shipments from the Lake States to Atlantic ports increases by 33% to 53% with lock closures at LaGrange. Other regions are not affected significantly by lock failures.

Table 32. Changes in Inter-regional and Intra-regional Soybean Shipments Due to Lock Failures at LaGrange Lock on the Illinois River, and Locks 20 and 25 on the Upper Mississippi River

Origin	Destination	Baseline 2010	LaGrange Fall 2 weeks	LaGrange Fall 1 month	LaGrange Fall 1 quarter	LaGrange Annual	Lock20/25 Fall 1 quarter	Lock20/25 Summer 2 weeks	Lock20/25 Summer 1 month	Lock20/25 Summer 1 quarter	Lock20/25 Annual
Corn Belt	Corn Belt	3,133	298	-87	-12	-55	429	0	32	375	2,338
	Lake States	771	0	0	60	-55	133	0	0	0	77
	South Central	1,997	0	26	26	26	0	0	0	0	0
	Southeast	632	0	0	34	45	0	0	0	0	1
	Southwest	709	0	0	0	0	15	0	0	0	6
	Atlantic Ports	115	0	0	117	117	0	0	0	0	0
	Great Lakes Ports	804	0	0	0	0	0	0	0	0	0
	Gulf Ports	13,576	-357	-777	-1,127	-1,138	-472	0	-33	-137	-1,116
	Total	21,737	-59	-838	-902	-1,060	105	0	-1	238	1,306
Great Plains	Corn Belt	608	0	0	60	-56	103	0	0	0	-417
	Great Plains	1,451	0	0	0	0	0	0	0	0	0
	Pacific	1,639	0	0	0	0	14	-63	-63	-63	14
	Southwest	599	0	0	0	0	0	0	0	0	0
	Gulf Ports	195	0	0	-116	0	-116	62	62	62	348
	PNW Ports	5,543	-1	-1	-75	-75	-1	-1	-1	-1	-74
	Canada	2,026	0	0	0	0	0	0	0	0	0
	Mexico	1,820	0	0	56	56	0	0	0	0	56
	Total	13,881	-1	-1	-75	-75	0	-2	-2	-2	-73
Lake States	Corn Belt	2,062	-357	-659	-830	-830	-79	0	0	0	-146
	Lake States	1,875	0	0	-60	280	-481	0	-33	-137	-547
	Pacific	1,870	0	0	61	-55	344	0	0	0	411
	Rocky Mts	2,191	0	302	241	241	0	0	0	0	-61
	Southeast	448	0	-25	-43	-54	0	0	0	0	0
	Atlantic Ports	1,088	357	383	571	582	79	0	0	0	146
	PNW Ports	115	0	0	61	61	137	0	33	137	198
	Total	9,649	0	1	1	225	0	0	0	0	1
Northeast	Northeast	111	0	0	0	0	0	0	0	0	0
	Southeast	847	0	0	-2	-2	0	0	0	-1	-1
	Atlantic Ports	358	0	1	1	1	0	1	0	1	0
	Total	1,316	0	1	-1	-1	0	1	0	0	-1
South Central	South Central	806	0	0	0	0	0	0	0	0	0
	Southeast	993	0	26	27	27	0	0	0	0	0
	Gulf Ports	7,504	0	92	121	121	0	0	0	0	0
	Total	9,303	0	118	148	148	0	0	0	0	0
Southeast	Southeast	222	0	0	0	0	0	0	0	0	0
	Atlantic Ports	168	0	0	0	0	0	0	0	0	0
	Total	390	0	0	0	0	0	0	0	0	0
Southwest	Southwest	112	0	0	55	55	15	62	62	62	62
	Gulf Ports	344	0	0	0	0	-14	-62	-62	-62	-7
	Mexico	55	0	0	-55	-55	0	0	0	0	-55
	Total	511	0	0	0	0	1	0	0	0	0

In addition to changes in the volume of inter-regional corn and soybean shipments, regional modal shipments also change. Regional changes in modal transportation volume due to lock failures are presented in Table 33. The baseline column represents annual modal transportation volume. Percentage changes under lock closure scenarios represent changes in annual modal volume, regardless of the duration of lock closure. The dash ("-") represents no change. Aggregate use of truck transportation is expected to decline by 1-6% because of lock failures at LaGrange and by 1-8% due to lock failures at Upper Mississippi River locks. Volume shipped by truck in the Corn Belt and Lake States regions declines by 1-11% and trucking in the Great Plains region declines by 3-5% due to lock failures at LaGrange. Lock failures of less than three months at the Upper Mississippi River locks reduce truck usage by 2-8% and annual lock closure reduces truck volume by 46% in Lake States.

Aggregate use of rail transportation is increases by 1-5% due to lock failures at the LaGrange lock and by 1-6% due to lock failures at the Upper Mississippi River locks. Corn Belt and Lake States regions' usage of rail increases by 1-11% and Great Plains rail usage increases by 3-5% under lock failures scenarios at LaGrange. Lock failures of less than three months at Upper Mississippi River locks increase rail usage by 1-5% and annual lock closure increases truck usage by 28% in Lake States.

Table 33. Regional Changes in Modal Transportation Volume Induced by Lock Failure

Region	Transport mode	Baseline* 010	Lock20/25 Fall 1 quarter	Lock20/25 Summer 2 weeks	Lock20/25 Summer 1 month	Lock20/25 Summer 1 quarter	Lock20/25 Annual
Corn Belt	Rail	34,013	-	-	-	-	2%
	Truck	55,919	-	-	-	1%	-
	Barge	34,559	-	-	1%	1%	-
Great Plains	Rail	37,349	-	-	-	-	2%
	Truck	9,486	-	-	-	-	-6%
	Barge	195	-59%	-	-	-	178%
Lake States	Rail	19,920	1%	2%	5%	5%	28%
	Truck	12,069	-2%	-3%	-8%	-8%	-46%
	Barge	7,071	-3%	-12%	-21%	-26%	-100%
Southwest	Rail	542	-3%	-11%	-11%	-11%	-8%
	Truck	2,598	1%	2%	2%	2%	2%
	Barge	96	16%	65%	65%	65%	65%
		Baseline 2010	LaGrange Fall 2 weeks	LaGrange Fall 1 month	LaGrange Fall 1 quarter	LaGrange Annual	
Corn Belt	Rail	34,013	-	2%	6%	13%	
	Truck	55,919	-	-3%	-6%	-11%	
	Barge	34,559	-2%	-6%	-12%	-26%	
Great Plains	Rail	37,349	-	-	1%	1%	
	Truck	9,486	-	-	-3%	-5%	
	Barge	195	-	-	-59%		
Lake States	Rail	19,920	2%	4%	7%	4%	
	Truck	12,069	-3%	-7%	-11%	-4%	
	Barge	7,071	3%	2%	-5%	36%	
Northeast	Rail	1,932	-	-	1%	-7%	
	Truck	1,270	-	-	-1%	10%	
Rocky Mts	Rail	2,630	-	-		2%	
	Truck	185	-	-		-3%	
South Central	Rail	7,405	-	-	-7%	1%	
	Truck	9,998	-	-	6%		
	Barge	3,668	-	3%	3%	3%	
Southwest	Rail	542	-	-	-5%	-7%	
	Truck	2,598	-	-	-17%	1%	
	Barge	96	-	-	57%	57%	

Note: Baseline transportation volume is measured in 1000 metric tons

Simultaneously, aggregate usage of barge transportation is expected to decline by 1-15% due to lock failures. LaGrange lock failures of less than three months have the greatest impact. At the regional level, barge usage declines by 2-26% in Corn Belt where three quarters of the corn and soybean barge shipments originate from this region. For example, Table 36 shows that Corn Belt's barge shipments do not change even if Locks 20 or 25 are closed during the entire fall season. The main reason for this is most of Corn Belt's barge shipments originate from Illinois barge locations, therefore Corn Belts barge shipments are not affected by lock failures at Locks 20 and 25. Lock failures at Upper Miss. River locks reduce barge usage by 3-100% in the Lake States.

Next, we consider the welfare implications of lock failure scenarios where we divide consumers' surplus and producers' surplus by the cost of lock failures to shippers. Lock failures affect both consumers' and producers' surplus in domestic and foreign markets. Table 34 summarizes the welfare implications of lock failures. Any lock closure results in higher transportation cost and as a result total net welfare[4] declines. Aggregate consumers' surplus increases and producers' surplus decreases in the domestic market under lock failure scenarios at LaGrange. The largest change in welfare for domestic consumers and producers takes place when the LaGrange lock is closed during the entire fall quarter. Under this scenario, consumers' welfare increases by \$52.5 million, but producers' welfare decreases by \$112.6 million. In addition, foreign

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[4] Total net welfare is measured as the sum of both consumers' and producers' surplus in domestic and foreign markets.

consumers' surplus is affected negatively, while producers' surplus is affected positively by lock failures at LaGrange. For example, annual lock closure at LaGrange costs foreign consumers $61.6 million and foreign producers gain $30.6 million.

The effects of lock failures at Locks 20 and 25 on both the welfare of consumers and producers are almost identical. One-month lock closure at these locks in the summer costs $2.4 and $14.6 million for domestic and foreign consumers respectively and domestic and foreign producers gain $5.8 and $9.4 million respectively in excess producers' surplus. In case of one-year lock closure, domestic consumers' estimated gain is $2.2 million and domestic producers' loss in welfare amounts to $22.4 million. Annual lock failures at Upper Mississippi River locks decrease foreign consumers' welfare by $37.2 million and increase foreign producers' welfare by $26.1 million.

Table 34. Changes in Welfare and Barge Revenue Loss Due to Lock Failure

Lock	Quarter	Duration	CS domestic	CS foreign	PS domestic	PS foreign	Barge Revenue
LaGrange	Fall	2weeks	9.1	1.9	-14.0	0.3	-0.4
		1month	8.7	-13.5	-15.9	14.1	-19.2
		1quarter	52.5	-9.6	-112.6	23.9	-39.1
	Annual	annual	17.3	-61.6	-50.1	30.6	-73.5
Lock 20	Fall	1quarter	1.7	5.3	-10.6	-0.8	-10.7
	Summer	2weeks	-0.2	-6.9	3.4	3.3	-18.3
		1month	-2.4	-14.6	5.8	9.4	-29.2
		1quarter	-0.9	-6.9	-7.1	3.6	-25.6
	Annual	annual	2.2	-37.2	-22.4	26.1	-153.6
Lock 25	Fall	1quarter	1.7	5.3	-10.6	-0.8	-10.4
	Summer	2weeks	-0.5	-6.4	3.0	3.4	-18.1
		1month	-2.4	-14.2	5.5	9.2	-29.2
		1quarter	-0.9	-6.9	-7.3	3.6	-25.1
	Annual	annual	2.2	-37.2	-22.6	26.1	-154.4

Note: Welfare is measured in millions of USD. CS denotes consumers' surplus and PS producers' surplus.

One-month, three-month, and annual lock failures at LaGrange cause barge companies to lose \$19 million, \$39 million, and \$73 million respectively. Adverse effects of Upper Mississippi River lock failures to the barge industry are even more severe. For example, summer lock failures on the Upper Mississippi River for the duration of two weeks, one month, and three months reduce barge industry revenue by \$18 million, \$29 million, and \$26 million. The largest barge revenue loss, \$154 million, occurs when any of the Upper Mississippi River locks remains closed during the year. Simulated model results for drought scenarios are presented next.

4.5.2 Drought Scenarios

Simulated model results indicate that consequences of low water levels on the river due to drought conditions are more severe than the lock failures even under annual lock closure scenarios. This is primarily because the entire U.S. river system is affected by low water levels in the presence of drought, which ultimately leads to decreased barge freight capacity and higher barge rates.

Table 35 summarizes the changes in the volume of incoming shipments to port locations via each mode of transportation due to drought. Barge is the dominant mode of transportation for corn and soybean exports that are shipped from Gulf ports. In the United States, over 87% of the corn and soybean exports originate from those Gulf ports. Any significant impediment to barge transportation will affect the cost advantage enjoyed by U.S. producers.

Table 35. Changes in Incoming Shipments to Port Locations Due to Lower River Water Levels and Barge Transportation Volume Due to Drought

Port Location	Mode	Baseline 2010	1-foot	2-foot	3-foot	1-footRI	2-footRI	3-footRI
Gulf Ports	Barge	45,122	-7,803	-11,278	-15,053	-14,354	-22,616	-29,760
	Rail	7,007	5,737	8,045	11,765	11,437	18,504	24,141
	Truck	4,372	-124	758	743	95	479	555
	Total	56,502	-2,190	-2,475	-2,544	-2,822	-3,633	-5,064
PNW Ports	Rail	23,181	1,287	1,399	1,453	1,557	2,188	2,776
	Truck	472	0	0	0	0	0	0
	Total	23,653	1,287	1,399	1,453	1,557	2,188	2,776
Atlantic Ports	Rail	3,825	415	430	447	620	629	938
	Truck	200	0	0	0	0	0	0
	Total	4,026	415	430	447	620	629	938
Great Lakes	Truck	1,570	0	-76	-76	0	-76	293
All Ports	Total	85,750	-488	-721	-721	-645	-892	-1,058

Note: Quantity is measured in 1000 metric tons.

A one-foot decrease in the barge draft causes barge shipments to the Gulf to decrease by 7.8 million tons or 17%, while rail shipments to the Gulf increase by 5.7 million tons or by 82%. In the event of a 10% increase in barge rates, barge freight volume declines by 14.4 million tons or 32% and rail shipments increase by 11.4 million tons or 163%. In addition, a 2-foot or 3-foot decrease in the barge draft levels causes barge freight volumes decline by 25% and 33%, while rail shipments to the Gulf increase by 115% and 168% respectively. Under 2-footRI and 3-footRI scenarios, barge freight volume decreases by 22.6 million tons (-50%) and 29.8 million tons (-66%) and rail shipments increase by 18.5 million tons (264%) and 24.1 million tons (345%) respectively. Decreased barge freight volume also affects total volume of incoming shipments to the Gulf ports. Total incoming shipments decrease by 4-5% under lower barge draft scenarios and by 5-9% when barge rate increases are included.

Not all grains diverted from barge are delivered to the Gulf ports. Additional grain is delivered to other ports via rail. Because drought induces more demand for rail, PNW and Atlantic ports receive more grain via rail under all drought scenarios. For example, PNW ports receive 6% more grain under all cases without barge rate increases and 7-12% more grain with barge rate increases. Atlantic ports' incoming shipments increase by 11% under all cases without barge rate increase and 16-25% more grain with barge rate increase. Drought conditions do not significantly change total incoming shipments to Great Lakes ports.

Changes in the total volume of grain shipments by mode of transportation under drought conditions are presented in Table 36. Results indicate that truck and barge transportation volume decreases and rail transportation increases under all drought scenarios. As a result of low water levels on the river, total amount of grains shipped by barge declines by 17%, 24%, and 33% under 1-foot, 2-foot, and 3-foot scenarios respectively. With increased barge rates, usage of barge declines by 31%, 49%, and 65% respectively under the same lower barge draft scenarios. In response to lower barge freight volumes, the need for truck transport declines and that grain is delivered by rail instead. The volume shift involves 12.3 and 26.8 million tons of grain moving to rail under 3-foot and 3-footRI scenarios respectively. This translates to increases of 12% and 26% in rail transport volumes. Although the total amount of grains loaded onto big ships declines by 1%, the volume of grain shipments increases by 2% on a ton-mile basis. This suggests that grains are shipped longer distances under drought conditions.

Table 36. Changes in Total Volume of Grain Shipments by Mode of Transportation under Drought Conditions

Transport Mode	Baseline 2010	1-foot	2-foot	3-foot	1-footRI	2-footRI	3-footRI
	Transportation volume (1000 tons)						
Truck	93,699	-7,468	-9,064	-12,740	-13,065	-19,871	-27,507
Rail	103,961	6,602	8,510	12,263	12,473	19,344	26,805
Barge	46,594	-7,803	-11,249	-15,466	-14,559	-22,820	-30,192
Small Ship	1,570	0	-76	-76	0	-76	293
Big Ship	85,750	-488	-721	-721	-645	-892	-1,058
	Transportation volume (billion ton-miles)						
Truck	8,350	-621	-673	-927	-961	-1,471	-2,069
Rail	66,181	6,488	8,996	11,186	11,552	17,262	23,641
Barge	43,492	-8,148	-11,487	-14,359	-14,931	-21,727	-29,841
Small Ship	829	0	-40	-40	0	-40	154
Big Ship	756,433	13,317	13,964	13,942	13,516	14,422	14,888

Note: Ton-miles = tonnage x mileage of the shipment.

Average transportation cost of grains deliveries changes in response to changes in transportation volume and modal usage. Changes per unit shipped under drought conditions are summarized in Table 37. Under 1-foot, 2-foot, and 3-foot scenarios, the per unit cost of truck transportation increases by 1%, 3%, and 5%, and the unit cost of barge transportation increases by 4%, 1%, and 8% . In the presence of higher barge rates, the unit cost of truck transportation increases by 4%, 6%, and 7%, and the unit cost of barge transportation increases by 10%, 18%, and 15% under the same lower barge draft scenarios. However, unit transportation cost for big ship decreases by 2% under drought scenarios with higher barge rates.

Table 37. Changes in Transportation Costs Due to Drought

Scenario	Duration	Truck	Rail	Barge	Small Ship	Big Ship
1-foot	annual	1%	1%	4%	-5%	0%
2-foot	annual	3%	1%	1%	-5%	-1%
3-foot	annual	5%	0%	8%	-1%	0%
1-footRI	annual	4%	0%	10%	-5%	-2%
2-footRI	annual	6%	0%	18%	-5%	-2%
3-footRI	annual	7%	1%	15%	-5%	-2%

Tables 38 and 39 provide results for drought-induced changes in the volume of regional corn and soybean shipments. Aggregate corn shipments from each region do not change under drought scenarios, except those from the Great Plains where the total shipments rise by 1-4%. Drought induces big reductions in barge shipments from the Corn Belt to the Gulf ports. As a result, barge shipments decline by 3-6 million tons under lower barge draft scenarios and 5-14 million tons under lower barge draft plus higher barge rate scenarios. This translates to 12%, 20%, and 24% declines in barge shipments under 1-foot, 2-foot, and 3-foot scenarios respectively, and 21%, 33%, and 57% declines in barge shipments under the same scenarios with higher barge rates. The Northeast and Southwest regions and Atlantic ports also receive fewer corn shipments from the Corn Belt. However, drought induces more corn shipments from the Corn Belt to the South Central region and PNW ports and local shipments within the region. For example, the Corn Belt intra-regional corn shipments increase by 9-16% under lower barge draft scenarios and 13-44% under lower barge draft plus higher barge rate scenarios. The highest increase in corn shipments occurs between the Corn Belt and the

South Central. In particular, the Corn Belt corn shipments to the South Central region increases by 19-80% and shipments to PNW ports increase by 30-54% due to drought.

Under all drought scenarios corn shipments from the Great Plains to the Gulf ports and intra-regional shipments increase, but shipments to the Pacific and South Central regions and PNW ports decrease. Unlike the results found for the Corn Belt, the drought conditions induce higher corn shipments from the Great Plains to the Gulf ports and lower corn shipments to the PNW ports. Under 1-foot, 2-foot, and 3-foot scenarios, corn shipments from the Great Plains to the Gulf increases by 45%, 84%, and 84% respectively. Under the 1-footRI, 2-footRI, and 3-footRI scenarios, the increase in corn shipments from the Great Plains to the Gulf ports equal to 86%, 107%, and 125% respectively. However, corn shipments to the PNW ports decline by 25% (1.2 million tons) on average under most drought scenarios. Intra-regional corn shipments in the Great Plains increase by 15-16% under all drought scenarios.

Table 38. Changes in Volume of Regional Corn Shipments Due to Drought

Origin	Destination	Baseline	1-foot	2-foot	3-foot	1-foot RI	2-foot RI	3-foot RI
Corn Belt	Corn Belt	11,840	1,114	1,881	1,881	1,594	3,330	5,158
	Great Plains	82	0	0	0	0	-32	-32
	Northeast	2,612	-146	-146	-146	-166	-166	-146
	Rocky Mts	354	13	13	13	13	13	13
	S. Central	8,213	1,593	2,124	3,010	2,230	3,602	6,547
	Southeast	12,422	112	112	112	149	132	112
	Southwest	1,685	-761	-471	-471	-280	-287	-287
	Atlantic Ports	845	-369	-369	-353	-200	-200	53
	Great Lakes	766	0	-76	-76	0	-76	293
	Gulf Ports	25,196	-3,149	-5,075	-5,977	-5,341	-8,324	-14,282
	PNW Ports	4,177	1,271	1,686	1,686	1,679	1,686	2,251
	Total	68,192	-322	-322	-322	-322	-322	-322
Great Plains	Great Plains	5,580	17	854	854	847	884	910
	Pacific	4,907	-420	-420	-420	-420	-420	-420
	Rocky Mts	1,773	-8	-8	-8	-7	-31	-31
	S. Central	1,374	-243	-243	-243	-294	-704	-704
	Southwest	7,206	280	287	287	280	287	287
	Gulf Ports	2,139	967	1,804	1,804	1,848	2,294	2,676
	PNW Ports	4,892	-404	-1,241	-1,241	-1,235	-1,248	-1,274
	Canada	1,299	0	0	0	0	0	0
	Mexico	3,783	6	0	0	6	0	0
	Total	32,954	196	1,033	1,033	1,026	1,063	1,445
Lake States	Corn Belt	1,751	-105	-105	-105	-105	-105	460
	Great Plains	2,607	179	179	179	179	179	535
	Lake States	7,111	-863	-1,390	-1,390	-1,390	-2,818	-5,051
	Northeast	444	-81	-81	-81	-75	-75	-81
	Pacific	2,567	524	946	946	946	946	946
	Rocky Mts	2,032	-4	-5	-5	-6	-5	46
	S. Central	574	17	122	122	105	266	1,500
	Southeast	2,218	116	116	116	92	109	116
	Atlantic Ports	1,375	218	218	218	253	253	235
	Gulf Ports	0	0	0	0	0	1,249	1,295
	PNW Ports	1,661	0	0	0	0	0	0
	Total	22,340	0	0	0	0	0	0
Northeast	Northeast	1,416	227	227	227	241	241	227
	Southeast	471	-227	-227	-227	-241	-241	-227
	Atlantic Ports	0	0	0	0	0	0	0
	Total	1,887	0	0	0	0	0	0
Pacific	Pacific	298	0	0	0	0	0	0
	PNW Ports	472	0	0	0	0	0	0
	Total	769	0	0	0	0	0	0
Rocky Mts	Rocky Mts	2,815	0	0	0	0	0	0
	Total	2,815	0	0	0	0	0	0
South Central	S. Central	4,945	-68	-172	-172	-155	553	-383
	Southeast	524	47	47	47	47	0	0
	Gulf Ports	3,656	21	126	126	108	-553	383
	Total	9,125	0	0	0	0	0	0
Southeast	Southeast	290	0	0	0	0	0	0
	Atlantic Ports	75	0	0	0	0	0	0
	Total	364	0	0	0	0	0	0
Southwest	Southwest	240	0	0	0	0	0	0
	Gulf Ports	2,391	-480	-184	-184	0	0	0
	Total	2,631	-480	-184	-184	0	0	0

Note: Quantity is measured in 1000 metric tons.

Table 39. Changes in Volume of Regional Soybean Shipments Due to Drought

Origin	Destination	Baseline	1-foot	2-foot	3-foot	1-footRI	2-footRI	3-footRI
Corn Belt	Corn Belt	3,134	5	12	-41	365	1,404	1,501
	Lake States	771	0	79	133	133	191	191
	S. Central	1,999	3	-8	-28	3	-27	632
	Southeast	632	18	34	34	18	27	27
	Southwest	708	152	152	152	152	152	152
	Atlantic Ports	114	0	0	0	0	0	74
	Great Lakes	804	0	0	0	0	0	0
	Gulf Ports	13,576	-1,017	-1,108	-1,089	-1,510	-2,588	-3,417
	Total	21,738	-839	-839	-839	-839	-839	-839
Great Plains	Corn Belt	608	-13	41	94	60	-260	-260
	Great Plains	1,451	0	0	0	0	0	0
	Pacific	1,639	13	13	13	13	260	260
	S. Central	0	0	0	0	121	195	195
	Southwest	599	-216	-229	-244	-218	-244	-244
	Gulf Ports	195	216	174	137	23	50	50
	PNW Ports	5,545	0	0	0	0	0	0
	Canada	2,026	0	0	0	0	0	0
	Mexico	1,821	0	0	0	0	0	0
	Total	13,883	0	0	0	0	0	0
Lake States	Corn Belt	2,062	-831	-831	-831	-1,128	-1,514	-1,838
	Lake States	1,874	0	-112	-166	-270	-661	-661
	Pacific	1,870	0	79	133	133	524	524
	Rocky Mts	2,191	302	302	302	302	302	302
	S. Central	0	0	0	0	297	683	982
	Southeast	448	-38	-54	-54	-38	-47	-22
	Atlantic Ports	1,089	566	582	582	566	576	576
	PNW Ports	115	0	33	33	137	137	137
	Total	9,650	0	0	0	0	0	0
Northeast	Northeast	111	0	0	0	0	0	0
	Southeast	847	0	0	0	0	0	0
	Atlantic Ports	359	0	0	0	0	0	0
	Total	1,317	0	0	0	0	0	0
South Central	S. Central	806	0	0	0	0	0	0
	Southeast	994	37	37	37	37	37	12
	Gulf Ports	7,505	-34	-17	-36	384	814	1,570
	Total	9,305	3	20	1	421	851	1,582
Southeast	Southeast	222	0	0	0	0	0	0
	Atlantic Ports	169	0	0	0	0	0	0
	Total	390	0	0	0	0	0	0
Southwest	Southwest	113	-64	-64	-64	-64	-64	-69
	Gulf Ports	345	64	65	64	65	65	65
	Mexico	55	0	0	0	0	0	0
	Total	513	0	1	0	1	1	-4

Note: Quantity is measured in 1000 metric tons.

In the Lake States region, the significant changes in corn shipments occur in intra-regional shipments and shipments between the Pacific and South Central regions and the Gulf ports. Intra-regional corn shipments within the Lake States decline by 12% under 1-foot scenario and by 20% under 2-foot and 3-foot scenarios. Under drought with high barge rate scenarios, intra-regional corn shipments decrease by 20-71%. The Lake States ship 37% (0.9 million tons) of more corn to the Pacific region than the baseline scenario under most drought scenarios. Severe drought coupled with high barge rates (3-footRI) causes the Lake States to ship 1.5 million tons of more corn to the South Central region, which is a 261% increase over baseline scenario shipments. The Lake States do not ship to the Gulf ports under the baseline scenario. However, the Lake States region starts shipping 1.3 million tons of corn under the 2-footRI and 3-footRI scenarios. Drought conditions do not significantly change other regions' corn shipments.

Aggregate soybean shipments from the Corn Belt decrease by 4% under all drought scenarios. Most affected regions are the Corn Belt itself (intra-regional shipments) and the Gulf ports. The Corn Belt's soybean shipments to the Gulf decline by 8% under scenarios without high barge rates and decline by 11%, 19%, and 25% under the 1-footRI, 2-footRI, and 3-footRI scenarios respectively. Intra-regional soybean shipments in the Corn Belt are only affected under the 2-footRI and 3-footRI scenarios where shipments increase by 45% (1.4 million tons) and 48% (1.5 million tons) respectively. Soybean shipments from the Corn Belt to the South Central region also increase by 32% (0.6 million tons) under 3-footRI scenario.

No significant changes take place in the Great Plains' soybean shipments under drought. Under the 2-footRI and 3-footRI scenarios, a quarter million tons of soybeans are diverted from the Corn Belt to the Pacific region. The Southwest region receives 36-41% less soybeans from the Great Plains under drought conditions. Soybean shipments from the Lake States to the Corn Belt and Lake States are negatively affected and shipments to the Pacific, Rocky Mountains, and South Central regions plus the Atlantic ports are positively affected by drought conditions. The Rocky Mountains region and Atlantic ports receive 14% and 53% more soybeans from the Lake States under all scenarios. The Lake States biggest drought-induced reduction in soybean shipments takes place in terms of the Corn Belt region. Corn Belt' incoming soybean shipments from the Lake States declines by 40% under all scenarios without barge rate increase and declines by 55%, 73%, and 89% under the 1-footRI, 2-footRI, and 3-footRI scenarios respectively. The Lake States intra-regional shipments also decline by 35% under the 2-footRI, and 3-footRI scenarios.

In addition to changes in the volume of inter-regional corn and soybean shipments, modal shipments also change. Drought-induced regional changes in modal transportation volume are presented in Table 40. Aggregate usage of truck transportation is expected to decline by 8-14% due to lower barge draft levels and by 14-29% with higher barge rates. Usage of truck transport in Corn Belt region declines by 11-21% and 12-17% in the Lake States under lower water levels.

Under the higher barge rate scenarios, the Corn Belt and Lake States region truck usage declines by 20-35% and 20-58% respectively. Total rail usage increases by 6-12%

and 12-26% under drought-only and drought plus higher barge rate scenarios respectively. At regional level, usage of rail increases by 15-55% in Corn Belt region, 2-5% in in Great Plains region, and 7-35% in Lake States region. Aggregate usage of barge transportation is expected to decline by 17-65% under drought conditions. Drought-induced low barge draft levels reduce Corn Belt barge usage by 21-38% and Lake States usage by 6-13%. If barge rates increase in response to restricted barge navigation, the Corn Belt and Lake States usage declines further by 37-65% and 19-85% respectively.

Table 40. Regional Changes in Modal Transportation Volume Induced by Drought

Region	Mode	Baseline	1-foot	2-foot	3-foot	1-footRI	2-footRI	3-footRI
Corn Belt	Rail	34,008	15%	21%	31%	30%	40%	55%
	Truck	55,922	-11%	-15%	-21%	-20%	-26%	-35%
	Barge	34,560	-21%	-28%	-38%	-37%	-52%	-65%
Great Plains	Rail	37,351	2%	2%	2%	2%	4%	5%
	Truck	9,486	-5%	4%	4%	2%	-6%	-5%
	Barge	195		-28%	-55%	-100%	-100%	-100%
Lake States	Rail	19,921	7%	10%	10%	12%	22%	35%
	Truck	12,070	-12%	-17%	-17%	-20%	-37%	-58%
	Barge	7,071	-6%	-13%	-13%	-19%	-49%	-85%
Northeast	Rail	1,933	-8%	-8%	-7%	-8%	-8%	-8%
	Truck	1,271	12%	12%	11%	12%	12%	12%
South Central	Rail	7,407	-4%	-6%	-1%	6%	20%	34%
	Truck	9,998	3%	4%	1%		-6%	-7%
	Barge	3,669	-4%	-13%	-25%	-2%	-32%	-39%
Southwest	Rail	543	28%	28%	28%	28%	53%	61%
	Truck	2,600	-24%	-13%	-13%	-6%	-11%	-13%
	Barge	96	-66%	-68%	-66%	-68%	-68%	-74%

Note: Baseline transportation volume is measured in 1000 metric tons.

Welfare implications of low water levels on the Mississippi river system due to persistent drought conditions are summarized in Table 41. The results indicate that drought has more severe negative effects on total net welfare than lock failures. Each drought scenario leads to higher aggregate domestic consumers' surplus and lower aggregate domestic producers' surplus. The most significant change in the welfare of domestic consumers and producers takes place under the 1-foot lower barge draft scenario with higher barge rates where drought induces $56.9 million increase in consumers' surplus and $174.4 million decrease in producers' surplus. However, foreign consumers' surplus is negatively affected and producers' surplus is positively affected by drought. For example, drought costs foreign consumers $67.7 million and foreign producers gain $33.3 million under the 3-footRI scenario. Under the drought scenarios, total net welfare is reduced by $65-152 million depending on the scenario.

Table 41. Changes in Welfare Due to Drought

Scenario	Duration	CS domestic	CS foreign	PS domestic	PS Foreign	Total welfare
1-foot	annual	52.7	-11.3	-128.7	22.2	-65.0
2-foot	annual	37.5	-34.9	-110.3	25.7	-82.0
3-foot	annual	38.4	-35.5	-116.0	25.4	-87.7
1-footRI	annual	45.0	-37.2	-122.8	24.1	-91.0
2-footRI	annual	34.4	-58.9	-132.9	29.7	-127.8
3-footRI	annual	56.9	-67.7	-174.4	33.3	-151.9

Note: Welfare is measured in millions of U.S. dollars.

4.6 Conclusions

This section reported the effects of Mississippi River System lock failures and the effects of prolonged drought conditions in terms of their implications for agricultural transportation, market conditions, and the welfare of consumers and producers. Our analysis of lock failures presents evidence that lock failures on Illinois and Upper Mississippi Rivers have a significant impact on agricultural transportation and welfare. The following key implications were found:

- Aggregate corn and soybean exports from port locations decline by 2-3% due to lock failures. Such failures have a direct negative impact on the volume of exports from Gulf ports and most of the Gulf's lost export volume is handled by PNW and Atlantic ports.
- Aggregate demand for truck transportation is expected to decline by 1-6% due to lock failures at the LaGrange lock and by 1-8% due to failures at Upper Mississippi River locks. At regional level, demand for truck declines by 1-11% in Corn Belt and Lake States and by 3-5% in Great Plains regions due to lock failures at LaGrange. Lock failures of less than three months at Upper Mississippi River locks reduce demand for truck by 2-8% and annual lock closure reduces demand for truck by 46% in Lake States.
- Aggregate demand for rail transportation is expected to increase by 1-5% due to lock failures at LaGrange lock and by 1-6% due to lock failures at select Upper Mississippi River locks. At a regional level, the demand for rail increases by 1-11% in Corn Belt and Lake States and by 3-5% in Great Plains regions due to

lock failures at LaGrange. Lock failures of less than three months at the Upper Mississippi River locks increase demand for rail by 1-5% and annual lock closure increases demand for truck by 28% in the Lake States.

- Aggregate demand for barge transportation is expected to decline by 1-15% due to lock failures. LaGrange lock failures of less than three months have greater impact on barge demand. At a regional level the demand for barge transportation declines by 2-26% in the Corn Belt where three quarters of the corn and soybean barge shipments originate from this region. Lock failures at Upper Mississippi River locks reduce demand for barge by 3-100% in Lake States.
- Lock failures reduce net total welfare under all cases. In aggregate, domestic consumers’ are better off and domestic producers’ are worse off under lock failures. However, domestic producers’ loss in welfare outweighs domestic consumers’ welfare gains, hence leads to a net loss in total welfare. In particular, lock failures at LaGrange lock have the highest impact on the welfare of consumers and producers.
- As lock failures reduce usage of barge transportation, barge operators lose revenue. Barge industry lost revenue amounts to $19-73 million under lock failures at LaGrange and $10-154 million under lock failures at the Upper Mississippi River locks. The lost revenue that the barge industry has suffered due to lock failures can be viewed as a benefit of avoiding lock failures. From a policy perspective, discounted benefits of avoiding lock failures over a lock’s

economic life, 50 years, can be compared against the costs associated with building a new lock in a cost benefit analysis.

- Risk of failure at high priority locks increases as the locks age and their current condition worsens. Failures at Locks 20 and 25 and LaGrange lock would create choke points on the waterway system because each of these locks has just one 600-foot long chamber. Economic impact of lock failure at each lock may result in up to $60 million loss in net domestic welfare, $154 million loss in lost barge revenue, and $351 million increase in the cost of grain exports. In the short-run, devoting resources to maintaining these high priority locks may well be in order to avoid the consequences of lock failures. Eventually, these locks may need to be replaced with new, possibly longer 1200-foot lock chambers, which would also help to mitigate congestion problems and wait times. Building auxiliary lock chambers is another option to mitigate the lock failure impact.

Results indicate that the impacts of drought-induced navigation impediments are far greater than that of even one-year lock failures. The following key implications were found from the analysis of drought scenarios:

- Aggregate corn and soybean exports from port locations decline by 1% due to lock failures. Lock failures have a direct negative impact on the volume of exports from the Gulf ports in which incoming barge volume declines by 17-66% and incoming rail volume increases by 82-345%, and there is a 4-9% decline in total exports. In turn, the PNW and Atlantic ports increase their export volume by 5-12% and 10-23% respectively.

- Aggregate grain demand for truck transportation is expected to decline by 8-29% under drought-induced navigation difficulties. At the regional level, the demand for truck transportation declines by 11-35% in the Corn Belt region and 12-58% in the Lake States region.
- Aggregate demand for rail transportation is expected to increase by 6-26% due to drought. At the regional level, the demand for rail transportation increases by 15-55% in the Corn Belt region, 2-5% in the Great Plains region, and 7-35% in the Lake States region.
- Aggregate demand for barge transportation is expected to decline by 17-65% due to drought-induced navigation impediments. At the regional level, the demand for barge transportation declines by 21-65% in the Corn Belt region and 6-85% in the Lake States region.
- Net total welfare is reduced under all drought scenarios. In aggregate, domestic consumers are better off and domestic producers worse off under lock failures. However, domestic producers' loss in welfare outweighs domestic consumers' welfare gains, which leads to a net loss in total welfare. In particular, the increase in the domestic consumers' surplus amounts to \$37-57 million and the loss of domestic producers' surplus equals \$110-174 million.
- Low water levels on U.S. waterways increases the need for dredging the shallow segments. The U.S. Army Corps of Engineers is charged with maintaining a 300-

foot wide and 9-foot deep channel in the Mississippi to facilitate barge navigability. To meet that charge, more funds would need to be allocated to equip the agency with a larger fleet of dredges in the case of persistent droughts.

- As the results show, rail volume increases by as much as 26% due to lower barge draft and higher barge rates. If the occurrence and duration of droughts increase due to climate change, this may require significant investments in railroad infrastructure to handle higher volumes of rail shipments.

5. CONCLUSIONS, LIMITATIONS, AND FURTHER RESEARCH NEEDS

This study examined the effects that U.S. biofuel production and impediments to barge transportation have on agricultural transport system usage, on the welfare of consumers and producers, and on market conditions. In pursuing this, the work had two major objectives:

- Investigate the effects of past and projected U.S. grain based biofuel production on the agricultural transportation system as well as grain prices, welfare, consumption and production levels, and
- Investigate the economic impact of major impediments to barge transportation on major U.S waterways and their implications for grain transportation. In particular, two types of impediments will be considered: failures at selected locks and low water levels due to drought.

Section 2 outlined the conceptual structure of the international grain transportation model (IGTM) that was updated and restructured during the conduct of this work. The IGTM was empirically specified and calibrated for 2000, 2007, and 2010 crop years. The calibrated model was then used to carry out the studies addressing the research objectives in the later sections.

Section 3 reported on the implications of past and projected biofuel production levels for agricultural transportation, market characteristics, and welfare. In particular, this section addressed the implications of U.S. biofuel production associated with developments in the Renewable Fuel Provisions of the Energy Bills in 2005 and 2007 and simultaneous energy market developments. The impacts were examined in terms of transportation system use, grain prices, the consumers' and producers' welfare, and agricultural transportation.

The simulated results showed that the higher biofuel production levels associated with RFS1 and RFS2 affected production, consumption, prices, and exports of grain in both domestic and international markets. Without the higher biofuel production levels associated with RFS1, consumption of corn and soybean would have been 10-12% higher, prices for corn would have been 15-20% lower, and prices for soybeans would have been 11-12% lower. In addition, total U.S. corn and soybean exports would have been 20% higher than 2007 levels. In addition, RFS1 biofuel production was found to divert 19.7 million tons of corn and 8.3 million tons of soybeans from food and animal feed consumption, with 39.9 million tons of corn and 1.5 million tons of soybeans produced only to support the biofuel production.

Without RFS2 associated corn for ethanol use, consumption of corn and soybeans would have been 9-19% higher, prices would have been 16-22% lower, and total U.S. corn and soybean exports would have been 34% higher relative to 2010. RFS2 biofuel production diverted 26.3 million tons of corn from food and animal feed consumption, and 23.7 million tons of corn was produced only to support ethanol production. Higher levels of biofuel production caused a significant amount of corn and soybean production to be consumed in close proximity to biofuel production facilities. Without the RFS1 and RFS2 biofuel production levels, volume for truck transportation would have been higher by 2% and 6%, higher for rail by 9% and 17%, and higher for barge by 10% and 26% respectively. Thus, it is clear that biofuel production decreased transportation demands and increased international supplies.

Results under the forward-looking scenarios for 2021 indicate that foreign supply and demand quantities would go up and that a small decline in prices, especially in the domestic market. This is largely due to technological progress and a static, largely capped, level of grain use in biofuel production. This would affect domestic and international grain flows, demand for grain transportation, and U.S. grain exports. Grain exports from the Gulf Ports increased by 41% under the USDA2021 scenario, and the Pacific Northwest ports lost market shares to the Great Lakes and Atlantic ports. This would create a need for increasing the Gulf ports' capacity for grain receiving and handling, along with maintaining other infrastructure to handle higher volumes of freight.

Volume of truck freight for grain is expected to increase by 30%-40% by 2021. Volume of barge shipments and ocean transportation are also expected to increase by 41% and 9% respectively under the USDA2021 scenario. Volume of rail transportation is also expected to increase by 57%-60%. This projected increase in rail volume would require developing or maintaining tracks and expanding the fleet of rail cars needed to handle higher freight levels between the Corn Belt and other major grain destinations. One alternative may be to replace older and smaller capacity rail cars with newer and larger hopper cars. In addition, the projected increase in barge freight volume requires grain-handling facilities that are more efficient. This is needed at both barge loading and unloading locations, especially at the ports. This may require more investment in improving the efficiency of existing facilities or expanding grain-handling capacity, particularly on the Upper Mississippi and Illinois Rivers and at the port of Baton Rouge.

Section 4 reported on an economic investigation of Mississippi River System navigation impediments in the form of river lock facilities and low water levels, and their implications for welfare and agricultural transportation. Two types of impediments to barge transportation are considered. The first involves select lock failures of varying duration. The second involves decreased water levels due to persistent drought. Lock failure was analyzed at five locks, and evidence was found that lock failures on the Illinois and Upper Mississippi Rivers have a significant impact on agricultural transportation and welfare.

Lock failure scenario results show that exports from the Gulf ports decline significantly with increased export volume handled by PNW and Atlantic ports. Lock failures cause modal shift from barge to rail. Aggregate truck and barge freight volume declines by 1-6% and 1-15%, while aggregate rail freight volume increases by 1-15%. The largest changes in modal shift and transportation volume occur in the Corn Belt, the Great Plains, and the Lake States regions.

Total welfare declines under all lock failure scenarios. In aggregate, domestic consumers are better off and domestic producers are worse off. Domestic producers' loss in welfare outweighs domestic consumers' welfare gains, hence leads to a net loss in total social welfare. Lock failures at LaGrange have the highest impact on the welfare of consumers and producers in the domestic market. Barge industry lost revenue amounts to \$19-73 million under lock failures at LaGrange and \$10-154 million under lock failures at Upper Mississippi River locks.

The results indicate that the returns are high to maintaining high priority locks in the short run to avoid the consequences of lock failures. In the longer term, these locks may well need to be replaced with new and possibly longer 1200-foot long lock chambers, which would also help to mitigate congestion and wait time problems. Building auxiliary lock chambers is another option to mitigate the lock failure impact.

Results of drought scenarios show that the impact of drought-induced navigation impediments is far greater than the negative impact of lock failures. Drought reduces total grain exports by 4-9% and incoming barge shipments to the Gulf ports decline by 17-66%. The PNW and Atlantic ports increase their export volume by 5-12% and 10-23% respectively. Aggregate truck and barge freight volume declines by 8-29% and 17-65%, and rail freight volume increases by 6-26% due to drought. Net total welfare declines under all drought scenarios.

Low water levels on U.S. waterways would increase the need for dredging in the shallow segments if the U.S. Army Corps of Engineers were to satisfy its charge to maintain channels in the Mississippi River system that are 300 feet wide and 9 feet deep. The results show that persistent droughts would yield high returns to the allocation of funds to dredging in the case of persistent droughts. Simultaneously, rail volume would increase by as much as 26% due to lower barge drafts and higher barge rates. If the occurrence and duration of droughts increase due to climate change, this may require significant investments in railroad infrastructure to handle higher volumes of rail shipments.

A number of limitations characterize this work. There is also a need for additional research.

- The model only considers RFS1 and RFS2 production levels; other provisions of biofuel policies, such as tax incentives, were not considered.
- Demand elasticities for corn and soybeans are the same for food and animal feed consumption and for biofuel consumption under both RFS1 and RFS2 scenarios. In reality, they may be different because grain consumption for biofuel production is influenced by biofuel policies and energy prices. Future studies could estimate or obtain separate demand elasticity parameters for biofuel, feed, and other uses.
- Biofuel and biofuel co-products such as distillers' dry grains are not modeled in the IGTM. Therefore, this study does not consider changes in transportation volume of co-products. It is possible the net change in transportation volume will not be positive after considering these two components. Future studies could include transportation biofuel co-products.
- Closure of Lock 27 is not considered in this study. Given its location, it can block all barge movements in the Upper Mississippi, Illinois, and Missouri Rivers. Future studies could examine failures at Lock 27 on the Upper Mississippi River.

- Only drought effects lasting for one year are considered in this study. Future studies could include drought scenarios of less than one-year duration in an effort to study short-term drought effects.
- It is more likely that drought reduces crop yields. Future studies could analyze the joint effects of drought on yield and water levels.
- Forecasted transportation rates for 2021 are treated as fixed in the IGTM in forward-looking scenarios. Hence, the rates do not change regardless of big changes in modal transportation volumes. This assumption seems to be reasonable in the short run and supported by empirical evidence from Yu et al. (2007). However, this may not be a reasonable assumption for the long run. Future studies could include variable transportation rates.
- High oil prices can induce more biofuel production (Tokgoz et al. 2007; Hayes et al. 2009), which in turn affects grain demand quantities and transportation volumes. Future studies could include high oil price scenarios.

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APPENDIX A

Table A1: The EP Act 2005 RFS1 Provisions (Billion Gallons per Year)

Year	2006	2007	2008	2009	2010	2011	2012
Applicable Volume of Renewable Fuel	4.0	4.7	5.4	6.1	6.8	7.4	7.5

Table A2. EISA, RFS2 Renewable Fuel Mandates (Billion Gallons/Year)

Year	Total Volume of Renewable Fuels	Advanced Biofuel Requirement	Cellulosic Biofuel Requirement	Biomass-based Diesel Requirement	Resulting Mandate on Corn Ethanol
2008	9.00				
2009	11.10	0.60		0.50	10.5
2010	12.95	0.95	0.10	0.65	12.0
2011	13.95	1.35	0.25	0.80	12.6
2012	15.20	2.00	0.50	1.00	13.2
2013	16.55	2.75	1.00		13.8
2014	18.15	3.75	1.75		14.4
2015	20.50	5.50	3.00		15.0
2016	22.25	7.25	4.25		15.0
2017	24.00	9.00	5.50		15.0
2018	26.00	11.00	7.00		15.0
2019	28.00	13.00	8.50		15.0
2020	30.00	15.00	10.50		15.0
2021	33.00	18.00	13.50		15.0
2022	36.00	21.00	16.00		15.0

Sources: http://www.cleanfuelsdc.org/renewable/renewable.html and EISA 2007

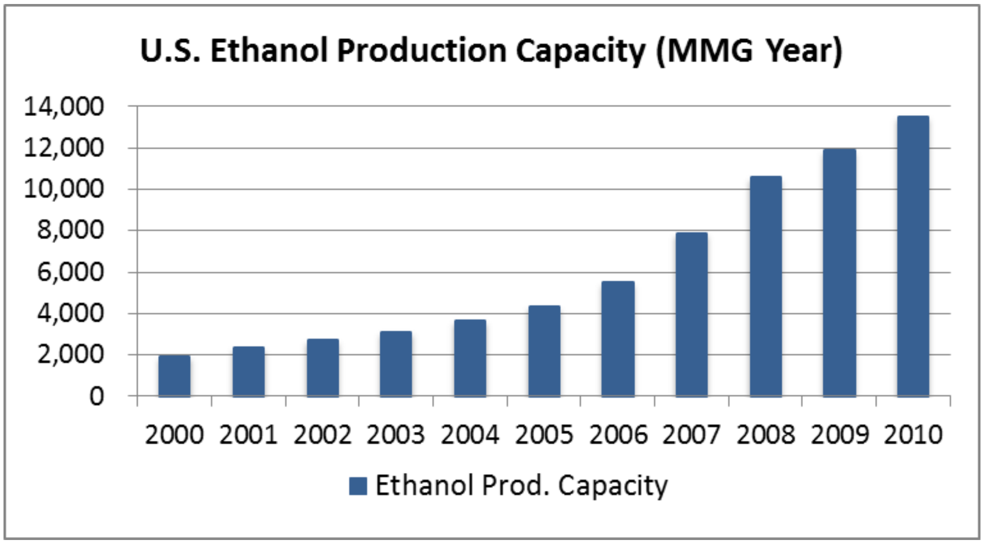


Figure A1. U.S. annual production capacity

Source: Renewable Fuels Association. http://www.ethanolrfa.org/pages/statistics

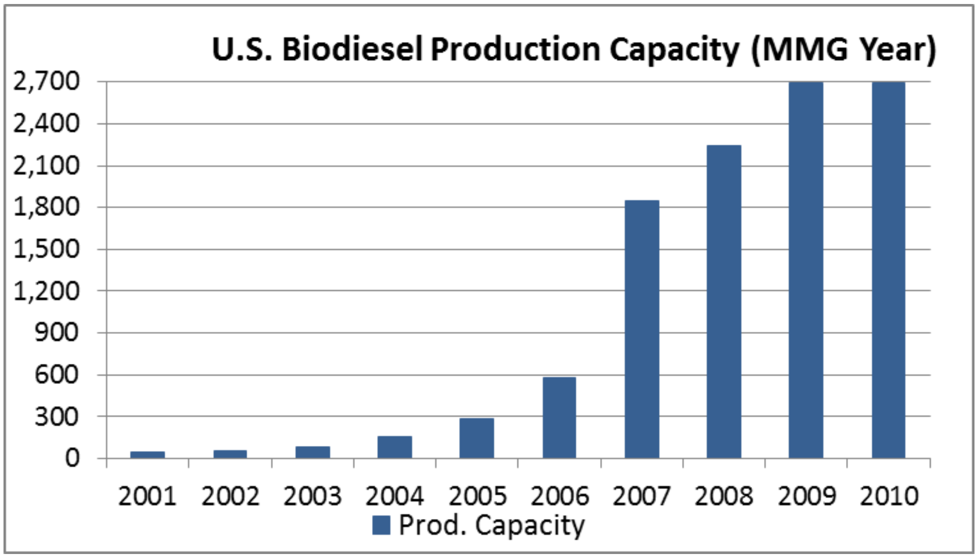


Figure A2. U.S. annual biodiesel production capacity

Source: National Biodiesel Board. http://www.biodiesel.org/

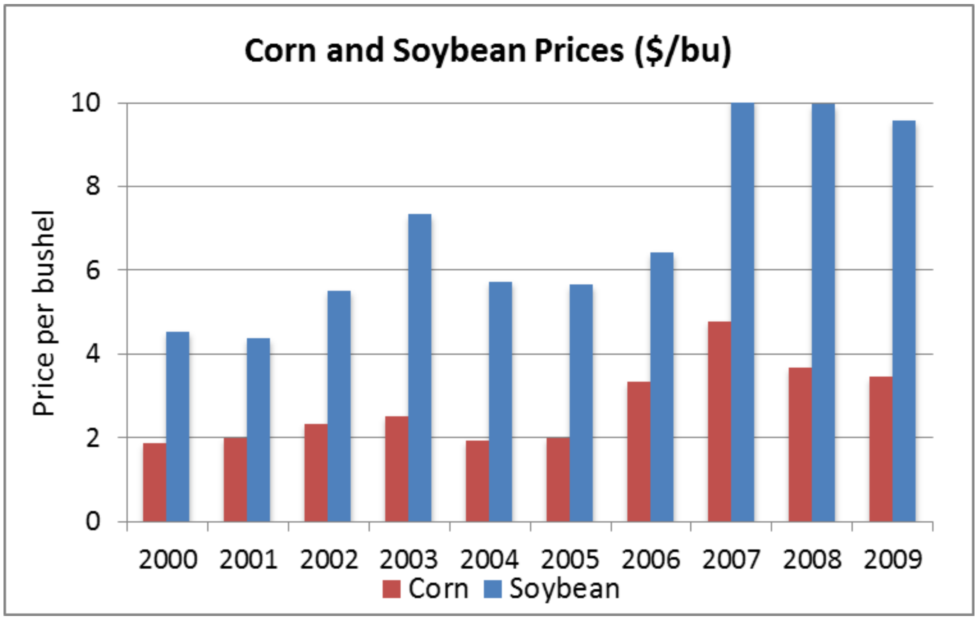


Figure A3. Average annual corn and soybean prices
Source: Feed Grains Database. ERS, USDA. http://www.ers.usda.gov/data/feedgrains/

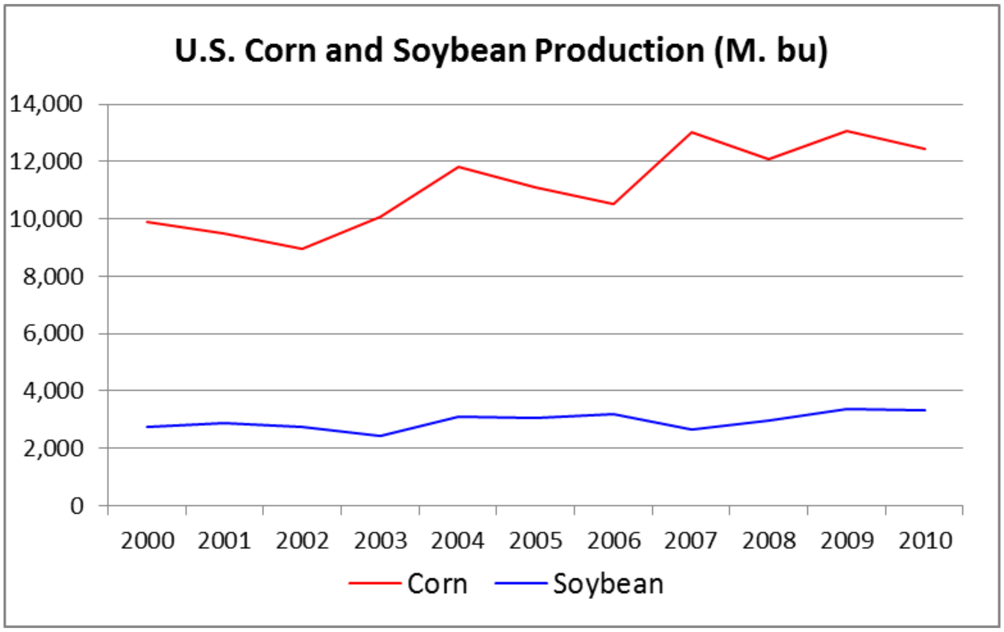


Figure A4. U.S. corn and soybean production (million bushels)
Source: Feed Grains Database. ERS, USDA. http://www.ers.usda.gov/data/feedgrains/

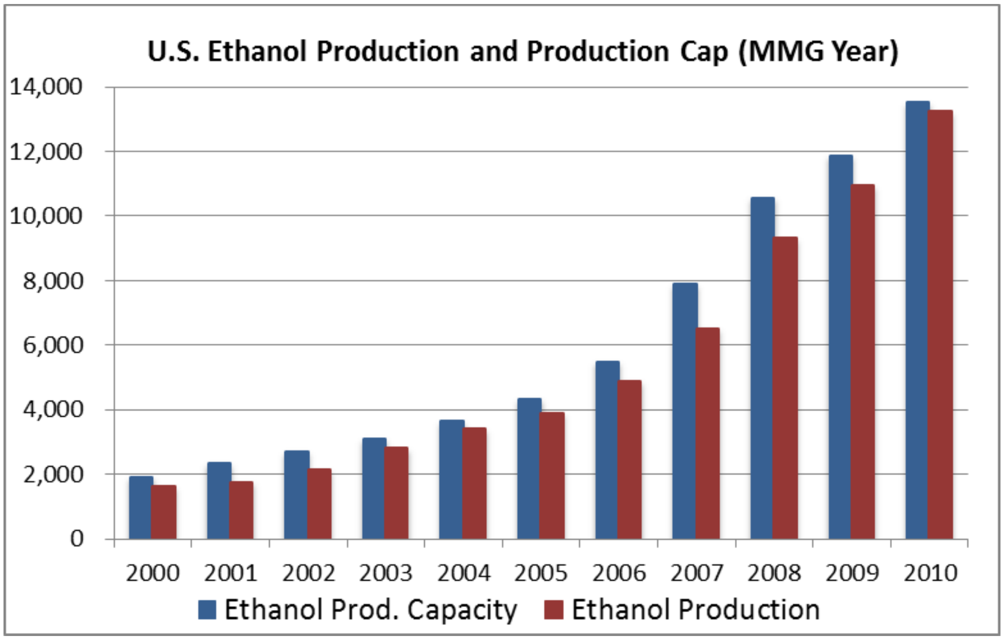


Figure A5. Annual U.S. ethanol production and production capacity (MG)

Sources: 1. U.S. EIA. http://www.eia.doe.gov/totalenergy/data/monthly/#renewable
2. RFA. http://www.ethanolrfa.org/pages/statistics

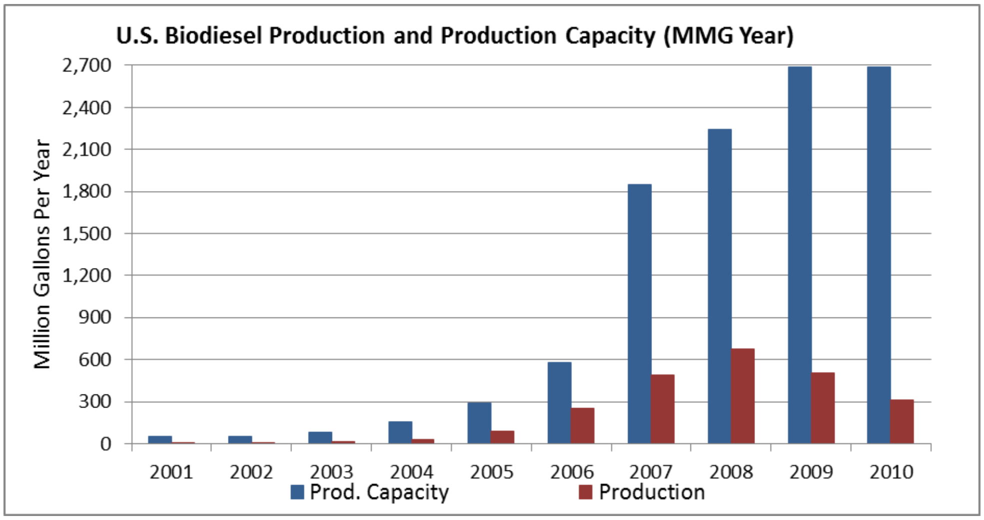


Figure A6. Annual U.S. biodiesel production and production capacity (MG)

Sources: 1. U.S. EIA. http://www.eia.doe.gov/totalenergy/data/monthly/#renewable
2. National Biodiesel Board. http://www.biodiesel.org/

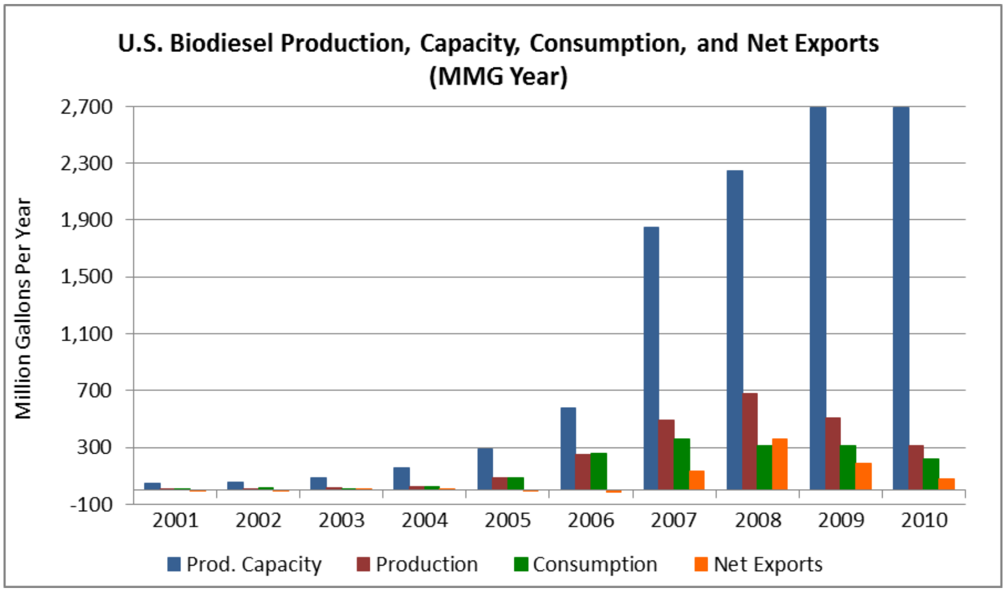


Figure A7. U.S. Biodiesel production, capacity, consumption, and net imports
Sources: 1. U.S. EIA. http://www.eia.doe.gov/totalenergy/data/monthly/#renewable
2. National Biodiesel Board. http://www.biodiesel.org/

Table A3. Total Biodiesel Capacity, Production, Consumption, Exports/Imports (MG)

Year	Production Capacity	Production	Consump-tion	Imports	Exports	Net Exports
2001	50	9	10	3	2	-2
2002	54	10	16	8	2	-6
2003	85	14	14	4	5	1
2004	157	28	27	4	5	1
2005	290	91	91	9	9	0
2006	580	250	261	45	35	-10
2007	1,850	490	358	140	272	132
2008	2,243	678	316	315	677	362
2009	2,690	506	317	77	266	189
2010	2,690	311	222	23	105	82

Sources: 1. U.S. EIA. http://www.eia.doe.gov/totalenergy/data/monthly/#renewable
2. National Biodiesel Board. http://www.biodiesel.org/

Table A4. Per Unit Input Cost of Biofuels

Per gallon cost of inputs for Ethanol ($/gallon)			
Item	2007	2008	2009
Transport cost	0.11	0.12	0.11
Corn	1.73	1.33	1.25
Input cost	1.84	1.45	1.36
Ethanol price	2.12	2.36	1.82
Excise tax credit	1.00	1.00	1.00
Gasoline price	2.08	2.48	1.69
Per gallon cost of inputs for Biodiesel ($/gallon)			
Item	2007	2008	2009
Transport cost	0.20	0.23	0.22
Soybean	6.87	6.79	6.53
Input cost	7.08	7.01	6.74
Soybean meal	4.98	4.91	4.61
Biodiesel price	3.23	4.37	2.90
Revenue	8.21	9.28	7.51
Excise tax credit	1.00	1.00	1.00
Diesel price	2.12	2.92	1.67

Source: Corn, soybean, and soybean meal annual prices from USDA Feed Grains Database. Biofuels prices obtained from data stream. Transport costs come from USDOT public waybill.

APPENDIX B

Table B1. ASM Regions and Sub-regions

Market Region	Production Region (States/Sub-regions)
Northeast (NE)	Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, West Virginia
Lake States (LS)	Michigan, Minnesota, Wisconsin
Corn Belt (CB)	Illinois, Indiana, Iowa, Missouri, Ohio
Great Plains (GP)	Kansas, Nebraska, North Dakota, South Dakota
Southeast (SE)	Virginia, North Carolina, South Carolina, Georgia, Florida
South Central (SC)	Alabama, Arkansas, Kentucky, Louisiana, Mississippi, Tennessee
Southwest (SW)	Oklahoma, Texas
Rocky Mountains (RM)	Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, Wyoming
Pacific Southwest (PSW)	California
Pacific Northwest (PNW)	Oregon, Washington

Source: Adams et al. (2005)

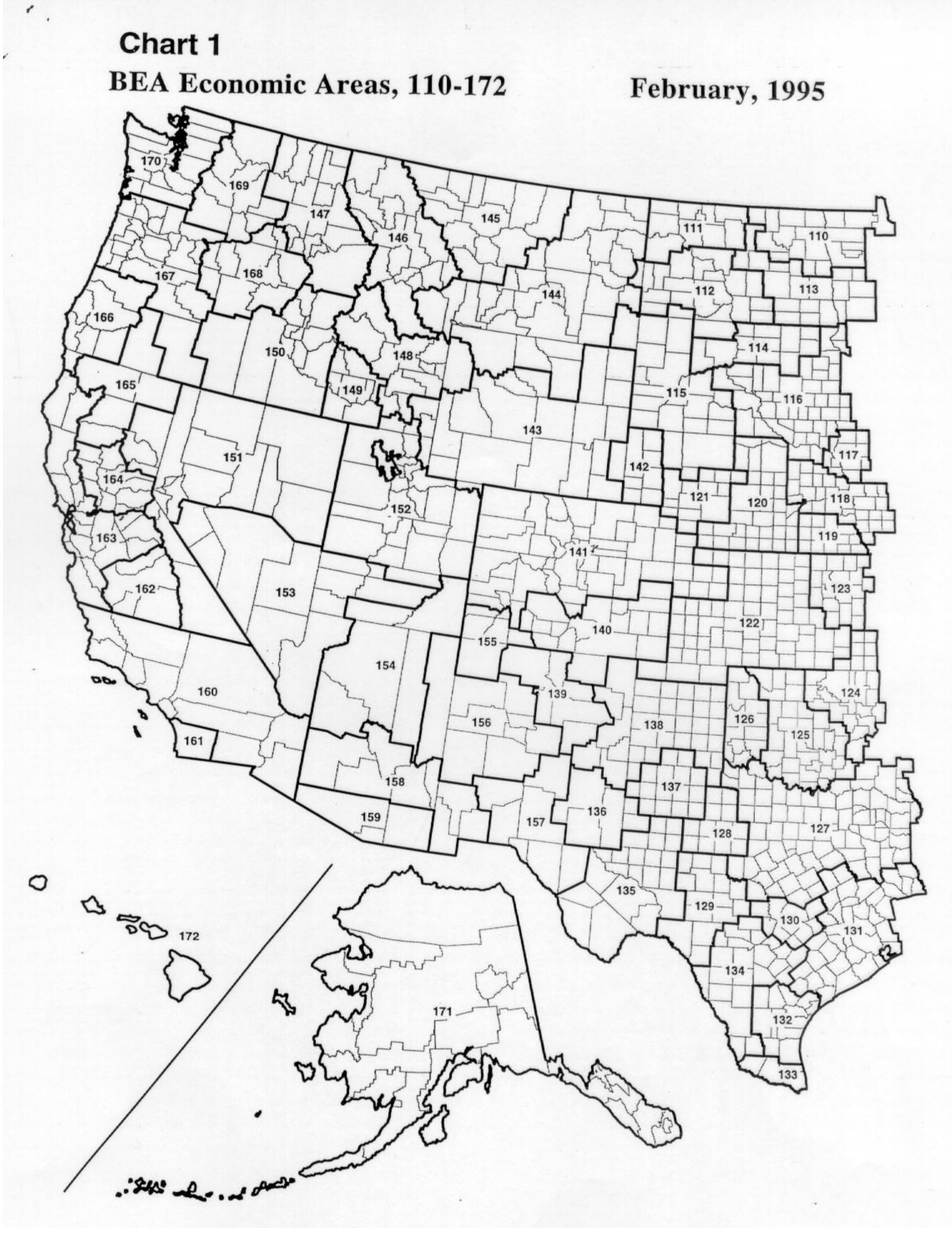


Figure B1. Map of BEA economic areas 110-172

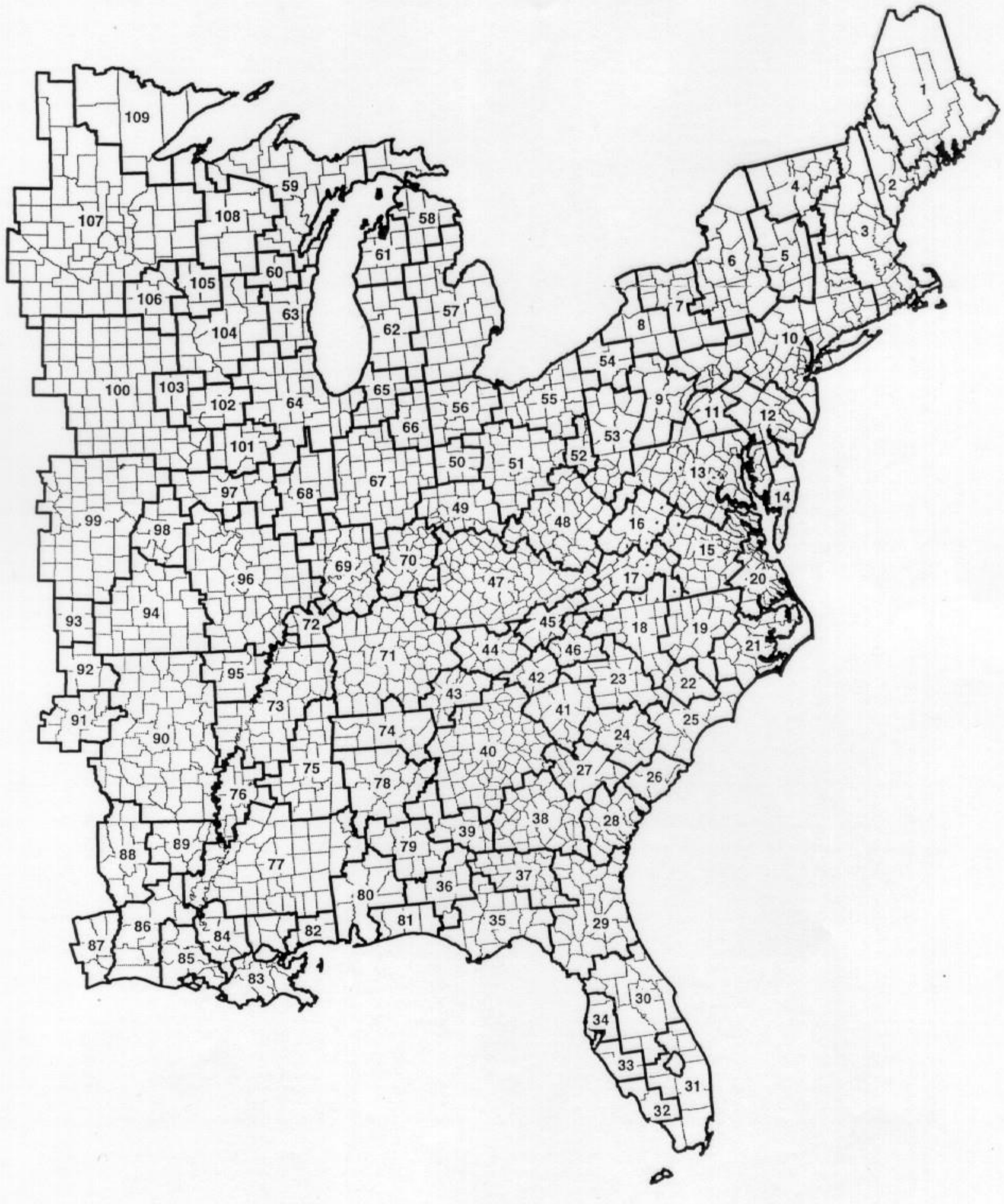


Chart 2

BEA Economic Areas, 001-109 February, 1995

Figure B2. Map of BEA economic areas 001-109

Table B2. BEA Areas That Belong to Rail Routes.

Rail Route	Grain	Origin BEA Areas	Destination BEA Areas
1	Corn	100, 107, 110, 113, 114, 116, 117, 118, 119,120	167, 170
2	Corn	99, 100, 103, 106, 107, 116, 117, 118, 119,120	162, 163, 164
3	Corn	64, 65, 66, 67, 68, 69	38, 39, 40, 41, 42, 43
4	Corn	97, 98, 99, 100, 117, 118, 119, 120	130, 131, 132, 133, 134
5	Corn	64, 100, 101, 102, 103, 104, 117, 118, 119, 120	137, 138
6	Corn	50, 51, 56, 65, 66, 67	15, 17, 18, 19, 22, 23
7	Corn	All others	All others
8	Soybeans	100, 103, 106, 107, 110, 113, 114, 116, 117, 118, 119,120	170
9	Soybeans	All others	All others

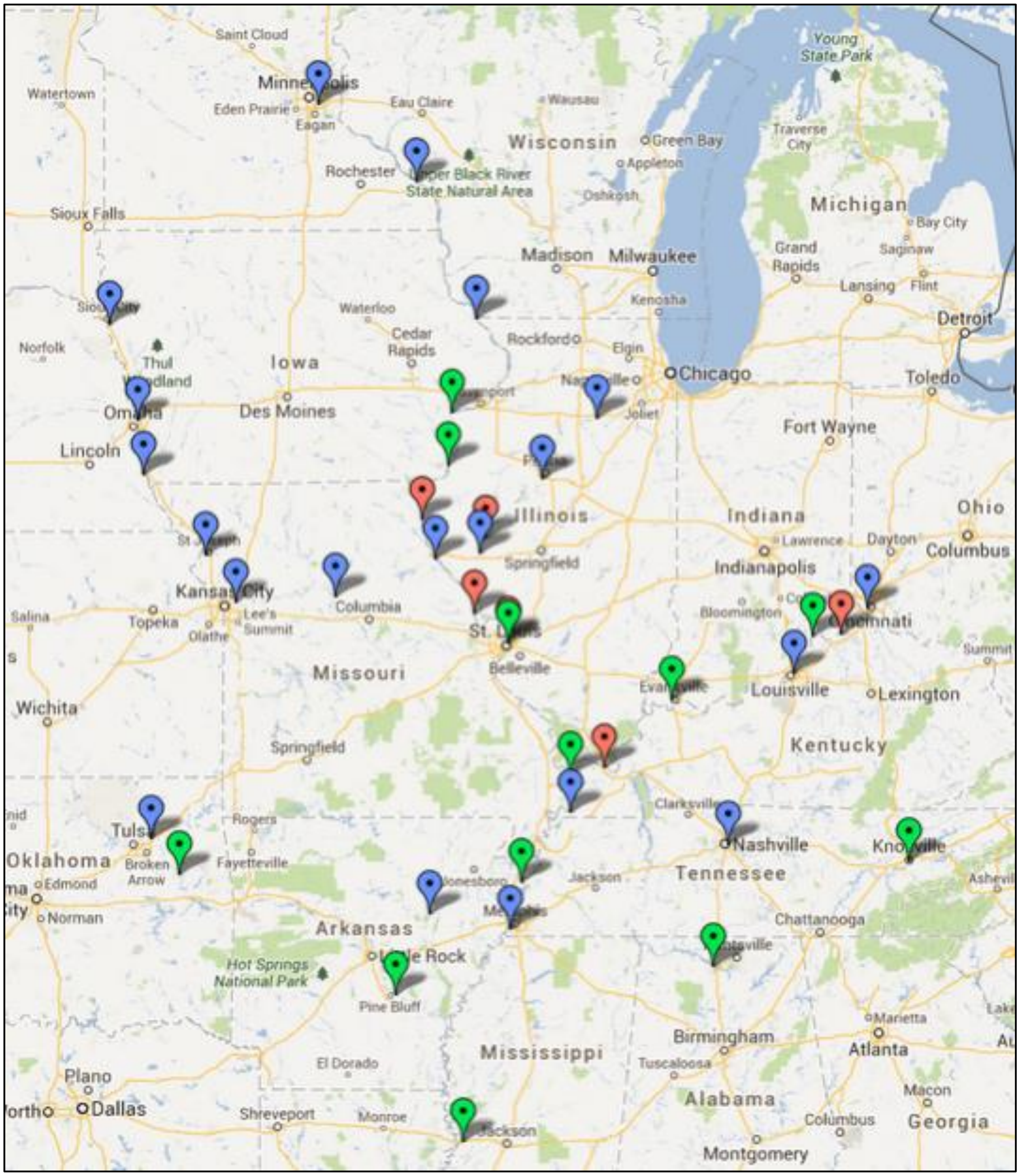


Figure B2. Map of barge terminals and locks

Note: Blue and green dots represent barge terminals and red dots represent lock.

APPENDIX C

Forecasts for Forward-looking Scenarios

Truck, rail, barge, and ocean rates need to be forecasted for use in the forward-looking scenarios. Two types of econometric models are used to construct the forecast. Structural models are used to forecast truck and rail rates and time series models are used to forecast barge and ocean rates. Choosing between the two models depends on the characteristics of the data. For example, data for barge and ocean rates are available in weekly time intervals and for specific origin destination points; hence, a time series model is used. However, rail rates for specific origin-destination points were not consistently observed on a weekly or monthly basis.

Rail Rate Forecast

This section provides detailed information on the type of data used in the forecast model and discusses the model selection and estimation procedure. Public waybill data, published by the Surface Transportation Board (STB), is used in forecasting rail rates. The data covers the period between 2000 and 2011. Because the waybill data provides observed rail rates for thousands of origin destination pairs, variability in rail rates between different geographic regions are significantly different. For example, rail rate (on ton-mile basis) for shipments from the Corn Belt to the Gulf ports are different from rates for shipments from the Lake States region to the Gulf ports. In order to capture the regional differences in rail rates, rail rate data needs to be grouped into origin-destination routes based on geographic regions that are determined by the waybill data. Nine transportation corridors, seven for corn and two for soybeans were used to combine observed origin-destination pairs into groups.

The STB uses geographic regions developed by the U.S. Bureau of Economic Analysis (BEA) to assign each observation to a specific region. Those geographic regions are called BEA Economic Areas or BEA Areas in the waybill. A map of the BEA Areas is shown in Figure B1 in Appendix B. Each of the nine routes developed in this study includes shipments between origin BEA Area(s) and destination BEA Area(s). BEA Areas that belong to rail routes are shown in Appendix B, Table B2.

In a data panel, these groups would represent cross sections and monthly observations would represent the time dimension. Rail rates and associated mileages belonging to the same route are combined on a monthly basis due to the irregularity of time intervals. All rail rates and associated mileages are monthly weighted average values. Rail rate (dependent variable) is measured in $/ton-mile and mileage represents the distance between origin and destination belonging to the observation. The data from all nine routes are pooled into longitudinal data set for further analysis.

Panel regression is used to estimate the rail rates. Grain prices and supply and demand shifters such as energy prices, barge rates, grain exports, and Gross Domestic Product (GDP) are used. Seasonal dummies are also used to capture the seasonal variability in the rail rates. The following dependent and explanatory variables are used in the model:

- Rail- rail rate in a given month for a given movement (2005 USD/ton mile) for a given corridor;
- Mile, distance between origin and destination of the shipment;
- Barge, barge tariff rate for Illinois River;
- GDP, GDP in billions of 2005 U.S. dollars;
- ExpCorn, volume of monthly corn exports (1000 MT);
- ExpSoy, volume of monthly soybean exports (1000 MT);
- ExpWheat, volume of monthly wheat exports (1000 MT);
- Corn, monthly (12) corn prices (2005 USD/bu);
- Soy, monthly soybean prices (2005 USD/bu);
- Wheat, monthly wheat prices (2005 USD/bu);
- Oil, monthly average price of crude Brent oil (2005 USD/BBL);
- Grain, grain dummy where Grain = 1 if soybeans and 0 otherwise; and
- Seasonal dummies, $Wint$ for winter, Sprs for spring, and Sum for summer.

The dependent variable is defined as $Rail_{i,t}$ where subscript i represents rail route and t represents time. Thus, the model to be estimated is given by the following equation:

$$\text{(C1)} \quad \begin{aligned} Rail_{i,t} &= \beta_0 + \beta_1 Mile_t + \beta_2 Barge_t + \beta_3 GDP_t + \beta_4 ExpCorn_t + \beta_5 ExpSoy_t \\ &+ \beta_6 ExpWheat_t + \beta_7 Corn_t + \beta_8 Soy_t + \beta_9 Wheat_t + \beta_{10} Oil_t \\ &+ \alpha_1 Grain_t + \alpha_2 Wint_t + \alpha_3 Spr_t + \alpha_4 Sum_t + u_i + e_{i,t} \end{aligned}$$

where u_i captures the route specific individual effects that do not depend on time, and $e_{i,t}$ is a white noise, i.e. an independently and identically distributed error term with mean zero and finite variance. Table C1 provides summary statistics for variables used in the rail rate Equation C1.

Table C1. Summary Statistics of Pooled Series

Series	Obs	Mean	StdDev	Min	Max	Skew	Kurtosis
Rail	1296	0.0268	0.0087	0.0128	0.0667	0.89	4.12
Mile	1296	1213.66	408.35	571	1933	0.28	1.64
Barge	1296	320.87	147.43	120	724	0.53	2.34
GDP	1296	12471.8	736.6	11105	13506	-0.45	1.70
ExpCorn	1296	3920.1	775.1	2426	7093	0.91	4.28
ExpSoy	1296	2473.6	1568.6	216	7004	0.74	2.90
ExpWheat	1296	2302.2	615.4	1183	4824	1.06	4.43
Corn	1296	3.13	1.50	1.49	7.33	1.29	3.70
Soy	1296	7.77	3.00	4.14	14.85	0.67	2.17
Wheat	1296	4.26	1.72	2.04	9.75	1.16	3.52
Oil	1296	57.41	29.96	18.68	133.59	0.65	2.44

Panel data can be estimated with either fixed effects or random effects estimators. Before running panel regression, we need to determine whether a pooled OLS or a fixed or random effects estimator is more appropriate. The Breusch-Pagan Lagrange Multiplier test (Breusch and Pagan 1979) is conducted to choose between the pooled OLS and random effects model. The Breusch-Pagan Lagrange multiplier test for random effects yielded a test statistic of χ^2 = 5940.78 with a p-value = 0.000. The test results suggest that random effects model is appropriate. Next, we need to determine whether fixed effects model or random effects model is more appropriate. A Hausman test (Hausman 1978) is conducted to check whether there is a significant difference between fixed and random effects estimators. The Hausman test yielded a test statistic of χ^2 = 6.43 with a p-value = 0.9292. The test results support the choice for random effects model.

The maximum likelihood method is used in the estimation of regression coefficients. This is implemented in the STATA 11 software package. The route-specific error terms (u_i's) need to be estimated, because the model does not directly estimate the u_i terms and we need them for forecasting the future route-specific rail rates. STATA's $xtmixed$ procedure is used to obtain the best linear unbiased predictions for u_i's. Table C2 gives all the estimated coefficients necessary for the prediction of future rail rates.

All coefficient estimates, except for dummy variables, are statistically significant and most of them have the expected signs. The results suggest that rail rates per ton-mile decrease as the transportation distance increases. However, rail rates are positively influenced by changes in competing barge rates. GDP and grain exports reflect the demand for transportation. All of these factors are found to have positive effects on rail rates with the exception of wheat exports. Changes in grain and energy prices also positively affect rail rates. However, grain and seasonal dummies seem to be not significant in determination of rail rates.

Despite the statistically significant positive relationship between corn/soybean prices and rail rates suggested by the regression, this relationship should not be interpreted as grain prices cause rail rates. Empirical evidence suggests that corn prices considerably affected by perturbations in transportation rates (Yu et al. 2007). The model is used only for forecasting rail rates and the USDA projected grain prices are used in the model.

Table C2. Estimated Coefficients of Random Effects Model

Variables	**Coefficients**	**Standard Errors**
Mile	-0.0000105*	0.0000010
Barge	0.0000100*	0.0000013
GDP	0.0000025*	0.0000003
ExpCorn	0.0000002**	0.0000001
ExpSoy	0.0000002*	0.0000001
ExpWheat	-0.0000006*	0.0000002
Corn	0.0009999*	0.0002007
Soy	0.0006409*	0.0000879
Wheat	-0.0008192*	0.0001190
Oil	0.0000257*	0.0000105
Grain	-0.0005128	0.0021705
Winter	-0.0001685	0.0002886
Spring	-0.0000026	0.0003473
Summer	0.0000584	0.0003655
Intercept	-0.0001042	0.0037173
Cross-sectional SE	0.0026741	
Residual SE	0.003347	
Estimated u_i		
Route 1	-0.00131	
Route 2	-0.00165	
Route 3	0.00479	
Route 4	-0.00147	
Route 5	-0.00318	
Route 6	0.00285	
Route 7	-0.00002	
Route 8	0.00046	
Route 9	-0.00046	

Note: * denotes variables significant at 5% and ** denotes variables significant at 10%.

Barge and Ocean Rate Forecast

Barge and ocean rates for major grain importing destinations are published by the USDA AMS in its Grain Transportation Report on a weekly basis. Weekly barge spot rates ($/ton) are quoted for groups of barge locations located on certain segments of major rivers. In particular, the following benchmarks are published:

- TWC (Twin Cities), Minneapolis, MN, St. Paul, MN, Red Wing, MN, Shakopee, MN, and Winona, MN
- MM (Mid-Miss), Albany, IL, Keithsburg, IL, New Boston, IL, and Rock Island, IL; Clinton ,IA, Davenport, IA, and Muscatine, IA
- ILL, Beardstown, IL, Florence, IL, Hardin, IL, Havana, IL, and Meredosia, IL
- MO, and St Louis, MO
- CINC, Cincinnati, OH
- LOH (Lower Ohio), Louisville, KY
- CAR-MEM, Birds Point, MO, Linda, MO, and New Madrid, MO; Hickman, KY, and Cairo, IL
- MEM-SO, Memphis, TN and southern ports

Quotes for shipping rates from the Pacific Northwest to Japan (SHIP_PNW) and Gulf of Mexico to Japan (SHIP_GULF) are used for ship rates. Rail rates for unit trains are also included to represent the rates on a competing alternative transportation mode (UNITTRAIN). This is formed from near-month secondary rail market bids and monthly tariff rates, with the fuel surcharge ($/car) included. Corn and soybean production, exports, and GDP are included as indicators of demand for transportation. Corn production (CORNPROD) represents historical annual corn production (1000 metric tons) for the marketing years 2002 to 2011. CORNPROD is obtained from the USDA

Feed Grains Yearbook tables. Soybean production (SOYPROD) represents historical annual soybean production (1000 metric tons) for the marketing years 2002 to 2011, and it is obtained from the USDA Oil Crops Yearbook tables. Corn (EXP_CORN) and soybean (EXP_SOY) exports (1000 metric tons) represent weekly corn and soybean inspections respectively.

GDP represents U.S. historical quarterly GDP in billions of seasonally adjusted 2005 dollars. GDP series are extrapolated to create weekly series. Corn (CORN), soybean (SOYBEAN), and Brent crude oil prices (OIL) were also included as explanatory variables with data drawn from DataStream. Weekly corn prices ($/bu) are based on daily Corn No.2 Yellow prices that are sampled on Wednesdays. Weekly soybean prices ($/bu) are based on daily Soybeans No.1 Yellow prices that are sampled on Wednesdays. Weekly oil prices ($/bbl) are based on daily Crude Oil-Brent (Current Month FOB) prices, also are sampled on Wednesdays. The model also includes eleven monthly dummy variables to capture seasonal effects. Table C3 provides summary statics for time series used in the barge rate regression.

Consistent time and spatial characteristics of the barge and ship rates data makes it convenient to use time series methods. A vector auto regression (VAR) model is used to estimate the barge and ocean rates. Phillips-Perron and Sims-Bayes Unit Root Tests (Phillips and Perron 1988; Sims 1988) are conducted to check for the stationarity of regression variables. Results from both tests suggest that all barge rates, corn and soybean exports, and GDP are stationary, but that the other variables are non-stationary at the 5% significance level.

Table C3. **Summary Statistics of Time Series Used in Barge Regression**

Series	**Obs**	**Mean**	**StdDev**	**Min**	**Max**	**Skew**	**Kurtosis**
TWC	507	27.47	8.83	11.05	49.88	-0.16	-0.75
MM	507	21.80	7.67	8.15	48.72	0.32	-0.06
ILL	507	18.81	7.12	6.44	53.69	0.54	0.74
STLOUIS	507	13.67	6.43	3.74	50.57	1.33	3.39
CINC	507	17.23	7.85	5.74	48.45	0.90	1.13
LOH	507	14.87	6.79	4.94	41.74	0.92	1.21
CAR_MEM	507	9.92	5.16	3.05	38.35	1.79	5.05
MEM_SO	507	8.49	4.26	2.98	31.35	1.70	4.27
UNITTRAIN	507	158.39	40.02	96	230	0.16	-1.16
SHIP_GULF	507	260.74	106.86	103	631	1.46	1.97
SHIP_PNW	507	254.93	106.63	92	660	1.56	2.51
EXP_CORN	507	890	214	220	1,543	0.08	0.10
EXP_SOY	507	590	410	17	2,253	0.95	0.61
CORNPROD	507	296,023	30,996	227,767	361,586	-0.64	-0.52
SOYPROD	507	81,987	7,563	66,783	91,417	-0.68	-0.59
GDP	507	13,644	1,313	10,887	15,797	-0.46	-0.73
CORN	507	3.75	1.74	1.65	8.49	0.83	-0.46
SOYBEAN	507	9.17	3.14	4.80	17.82	0.45	-0.81
OIL	507	70.96	29.17	23.68	141.37	0.31	-0.88

Ideally, a vector error correction model (VECM) is appropriate when series are non-stationary (Engle and Granger 1987). However, this study used the VAR model for forecasting. Corn and soybean production and GDP are entered as exogenous variables and other variables are estimated endogenously. Two types of VAR models are estimated. First VAR model uses differenced series for the non-stationary variables and the second model is a level VAR and uses time series without differencing. Schwarz loss criterion is used in choosing the optimal lag length with a finding that it is one for both models. Both models are assessed based on mean absolute percentage error (MAPE) to measure the accuracy of the model. In turn, it was found that the levels VAR performed better in predicting six out of 11 transportation rates (mostly barge rates), and therefore was selected as the model of choice. 10-year-ahead barge and ocean rate forecasts are generated and presented in Figure C1. All barge rate forecasts seem to have an upward trend with strong seasonal variations. However, ship rate forecasts do not exhibit strong seasonal variations and an upward trend after 2015.

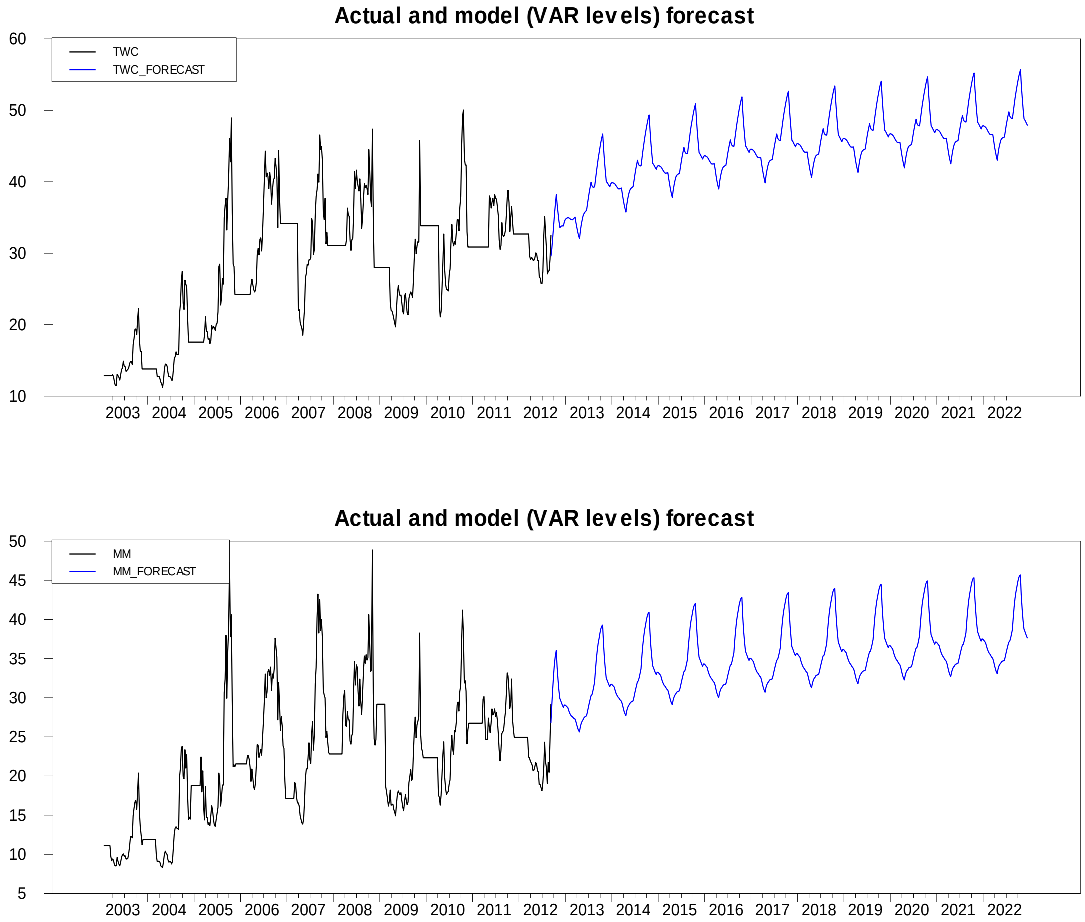
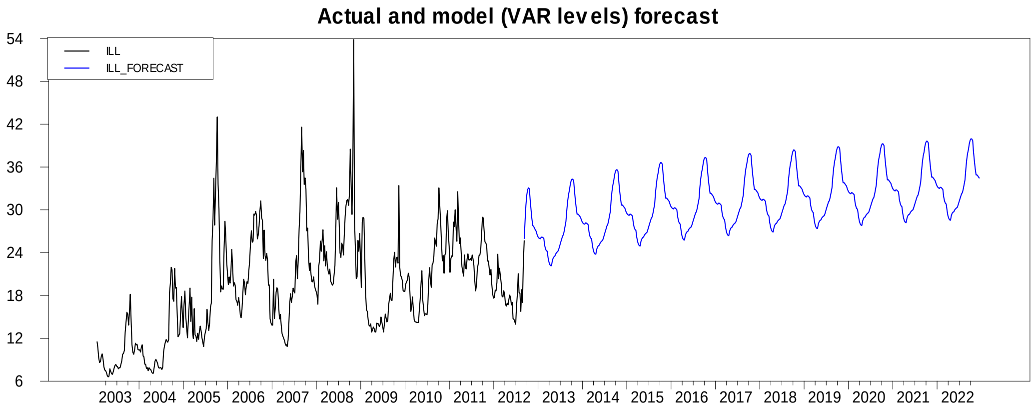
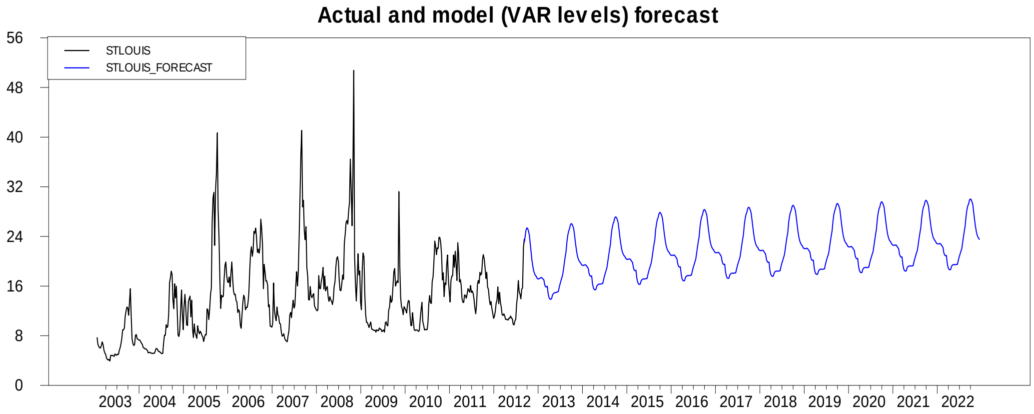


Figure C1. Long-run barge and ocean rate VAR forecasts





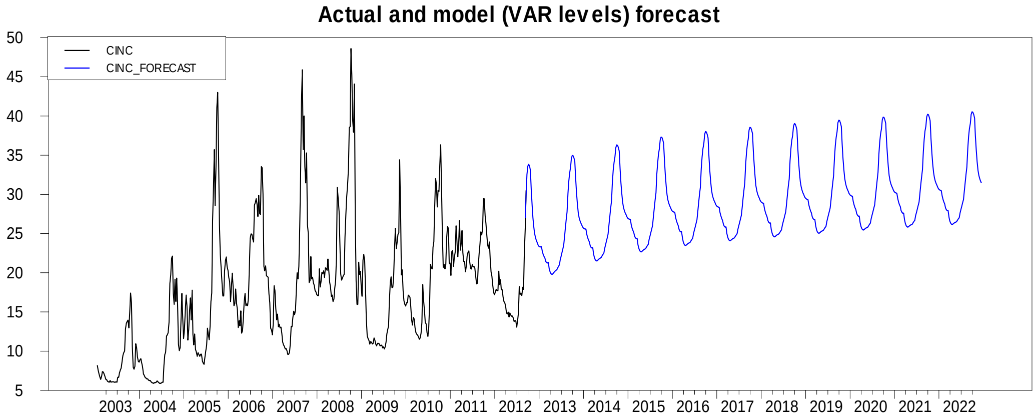
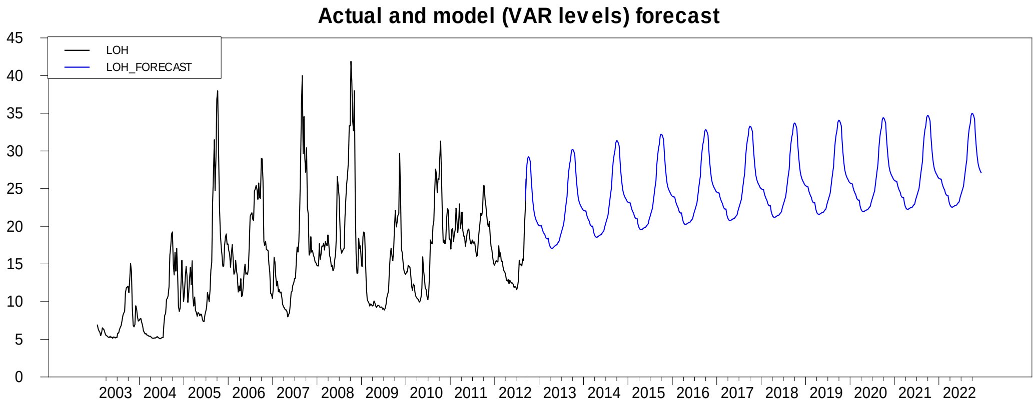
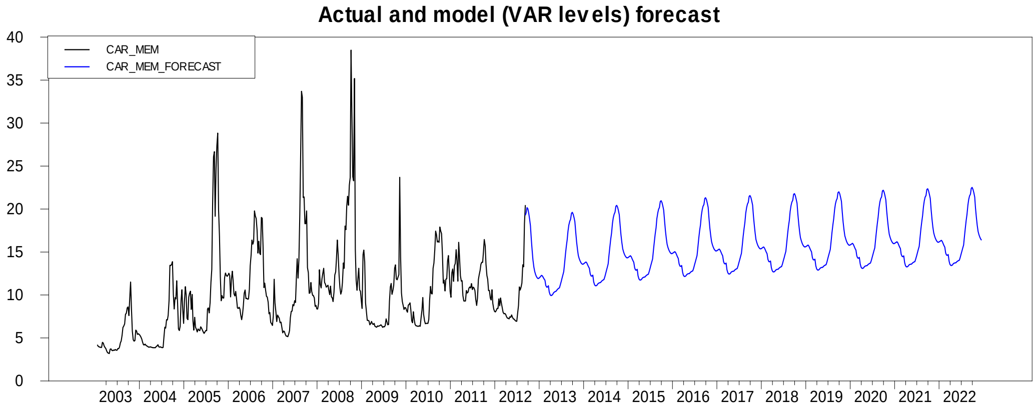


Figure C1 continued





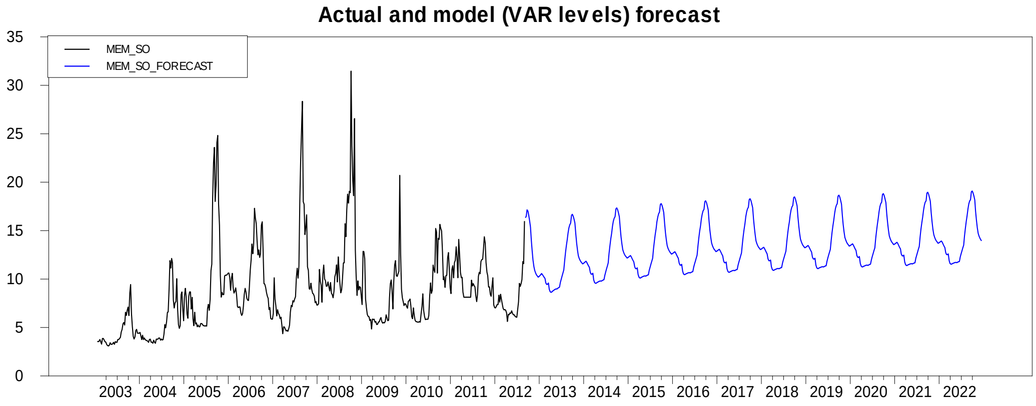
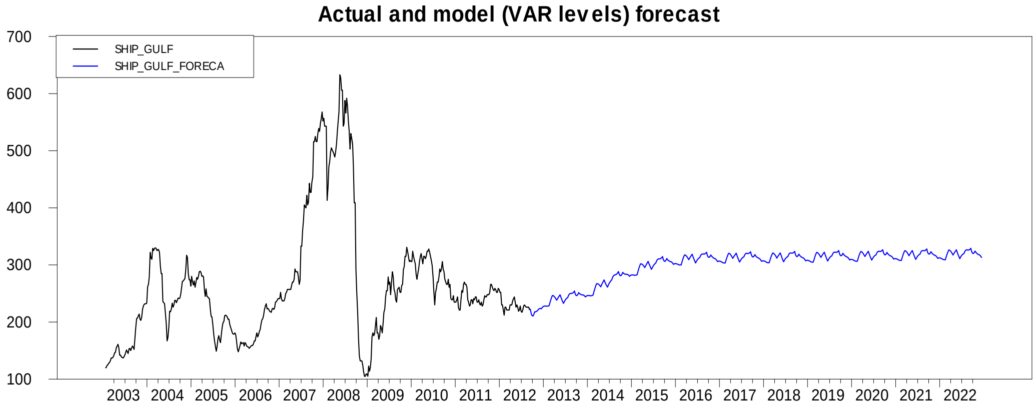


Figure C1 continued



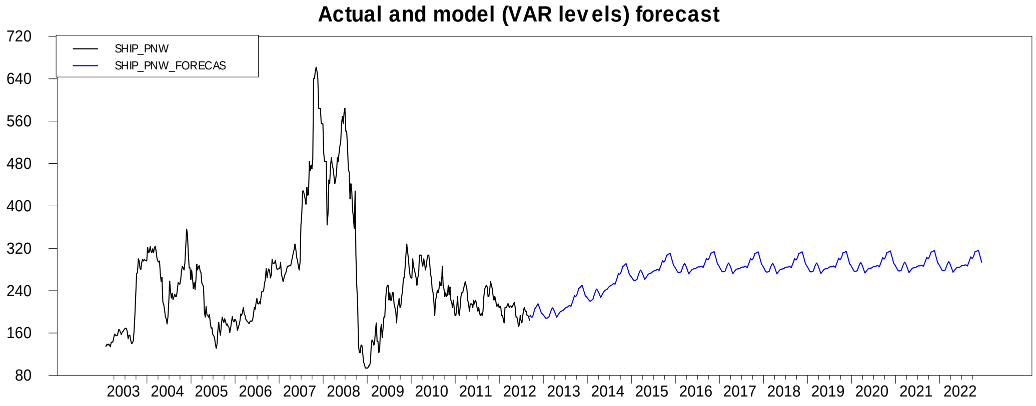


Figure C1 continued