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Identifying Factors and Quantifying their Impact on Transportation Costs of Pre-Processes Biomass

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By

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Identifying factors and quantifying their impact on transportation costs of pre-processes biomass

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This research presents a rail transportation cost analysis of bulk agricultural commodities (such as grain and wood chips) with similar characteristics as pre-processed biomass. This study analyzes the cost factors that affect rail pricing for shipments of bulk-commodities (such as grain) from the Midwest to various regions in the US using regression analysis theories. The rail cost equations developed from the regression analysis were used to compare the trade-offs that exist between truck, rail and barge transportation of pre-processed biomass.

DEDICATION

To the people that never stop holding my hand, my parents and brother.

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Foremost, I would like to express my most sincere gratitude to my major advisor Dr. Sandra Eksioglu, for the continuous support of my whole career at Mississippi State University. Her patience, motivation, enthusiasm and immense knowledge have guided me throughout my Bachelors and Masters studies. I sincerely appreciate and value all the time she gave me and the care she showed throughout my research and academic program.

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LIST OF ACRONYMS AND ABBREVIATIONS

BGY	Billion Gallons per Year
CWS	Carload Waybill Sample
EISA	Energy Independence and Security Act
EPA	Environmental Protection Agency
EPAct	Energy Policy Act
INL	Idaho National Laboratory
OD	Origin-Destination
ORNL	Oak Ridge National Laboratory
RFS	Renewal Fuel Standard
STB	Surface Transportation Board

CHAPTER I

INTRODUCTION

This section describes the motivation for this research study and provides a background of the evolution of the biofuel's industry in the US. The section includes insight of the different transportation modes available. In addition, the section introduces the commodity based, advanced biomass supply chain design proposed by INL and the implications of using high-capacity transport for biomass shipments. The section ends with the objectives planned for this study.

1.1 Motivation

Concerns ranging from greenhouse gas emissions to the national energy security have lead the US government in search for sources of energy that would replace gasoline and diesel use as vehicle fuels. The Environmental Protection Agency (EPA) is in charge of developing and implementing regulations set by the Renewal Fuel Standard (RFS). The RFS program was initially created in collaboration with refiners, renewable fuel producers, and many other stakeholders under the Energy Policy Act (EPAct) of 2005. The RFS program regulations ensure that transportation fuel sold in the U.S. contains a minimum volume of renewable energy. Under the Energy Independence and Security Act (EISA) of 2007, the standards for the minimum level of renewable fuels used in the U.S transportation industry were increased from 9.0 billion gallons (bgy) in 2008 to 36 bgy in 2022 (EPA). The production of renewable energy would displace conventional imported petroleum use and, consequently, decrease US dependence on foreign oil and offer a clean-burning alternative. The RFS mandates that starting 2016, all of the increase in renewable fuels must be met with advanced biofuels, such as cellulosic ethanol and other biofuels from feedstock other than corn starch. The RFS levels for advanced biofuels production will drive the creation of a major new industry, creating a foundation for future technology development and commercial growth.

National assessments (Perlack, Wright, Turhollow, Graham, Stokes, & Erbach, 2005) identify sufficient biomass resources to meet the production targets, though; much of these resources are inaccessible using the current biomass supply systems because of unfavorable economics. The two major challenges of making this production economically competitive with gasoline are the technology development for production of biofuels, and the logistics requirements for delivering biomass to biorefineries (Panoutsou, Castillo, & Bauen, 2011).

1.2 Biofuels Technology Development

The first generation of biofuels (corn- and soybean- based) is the largest substitute of gasoline in the US (USDA, 2010). The production of first generation biofuels has relied on local biomass resources to minimize logistics costs. Raw biomass, such as baled herbaceous biomass, is bulky, aerobically unstable, and has poor flowability properties, all which pose logistics challenges and increase supply chain cost. In order to minimize transportation related costs, the traditional supply chain model (used by corn-based biorefineries) locate biorefineries within 50-mile radius of corn farms (for example, (Aden, et al., 2002)). The limited amount of biomass available within this collection radius did not justify investments on large-scale biorefineries. As a consequence, traditional biorefineries have low production capacity and have not benefited from the economies of scale associated with high production volumes (Hess, Kenney, Ovard, Searcy, & Wright, 2009). Since most feedstocks for first generation biofuels (corn, soybean, etc) could also be used for feed or food (animal or human consumption), the production of first generation biofuels have initiated a nation-wide debate on food versus fuel. Concerns rise revolving the competition between feed/food and fuel and its implications on nutrition prices in the third world countries (Rosegrant, Msangi, Sulser, & Valmonte-Santos, 2006), (Babcock, 2011).

Second generation biofuels utilize agricultural and forest residues, and energy crops as a feedstock. Yet, first and second generation biofuels (such as ethanol and some types of biodiesel) have different properties than conventional fossil fuels, such as high acidity, high moisture content, or high oxygen content. Due to these properties, fuels that have high concentration of ethanol (such as, E85) can corrode some types of metal and even make some plastics brittle over time. As a consequence, the vehicles we currently own cannot run on highly concentrated ethanol blends. Additionally the pipeline system that is currently in place for transportation of fossil fuels cannot be utilized for transportation of second generation biofuels.

The next generation of biofuels, referred to as drop-in fuels, is expected to overcome the property challenges and will be interchangeable with conventional fossil fuels. Drop-in fuels can be handled with the existing petroleum infrastructure (storage, pipeline and distribution system from the refinery). Yet, all types of bio-based energy will continue to face the logistic challenges of biomass transportation related mainly to the physical characteristics of raw biomass. Advanced supply chain designs are needed to address the barriers imposed by using raw biomass. Ideally, these designs should minimize transportation and handling costs and enable the establishment of large-scale production.

1.3 Conventional Supply Chain Designs for Biofuels

Truck has been considered the primary transportation mode for studies on the supply chain of bioenergy since is the most flexible mode of transportation. Truck transportation allows shippers to access locations that other modes may not and is ideal for time sensitive freight. Furthermore, truck transportation has the ability to reach biomass locations and overcome biomass seasonality better than rail and barge. Biomass is inherently unstable, train and barge scheduling may put freight on a queue and allow for feedstock loss due deterioration. Conventional supply chain designs for biofuels have been utilizing a decentralized distribution system with low biorefinery capacities (small to regular biorefinery sizes) and high transportation costs. An expansion of the biofuels industry will require an improved supply chain that will take advantage of economies of scale in order to compete with fossil fuels.

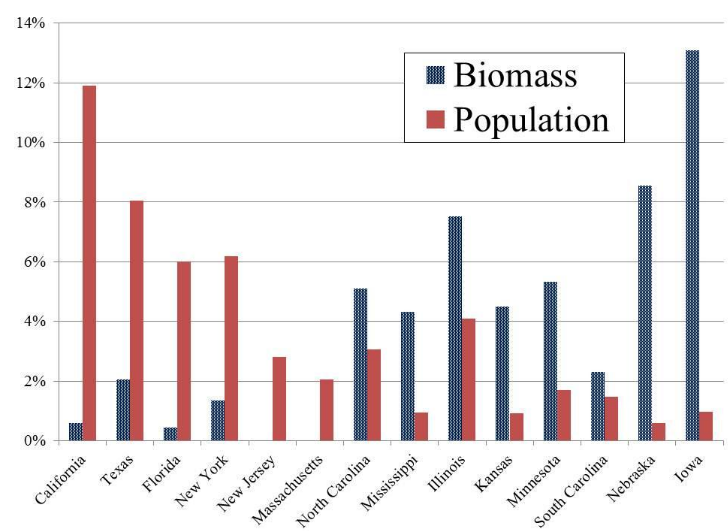

Figure 1.1 Distribution of Biomass and Population by State

The majority of biomass resources are located in the Midwest and Southeast of the US. However, the nation's population is mainly concentrated in the western and eastern coasts. The US Census Bureau estimated that in 2011, 37% of the population resides in the states of California, Texas, New York, Florida and Illinois (US Census Bureau: Population Division, 2011). Furthermore, the US Energy Information Administration estimated that in 2009, Texas, California, Florida, New York and Illinois consumed 12%, 8.5%, 4.5%, 4% and 4% (a total of 33%) of the US Energy (US Energy Information Administration, 2009). Hence, the demand for bioenergy will also be highest in these states. Figure 1.1 presents the states in the US with a big gap between the amount of biomass available and the population size. For example, 12% of the nations population lives in California, yet only 0.59% of the available biomass is found in this state. Only, 0.97% of the US population lives in Iowa, yet 13% of the total national biomass available is located in Iowa. The geographical mismatch of supply and demand for bioenergy requires that either biomass or biofuel travel long distances to satisfy energy demands.

The geographical dispersion of biomass supply (located in remote areas in the US), combined with its inherent physical characteristics (unstable, bulky, non-flowable and low density), require a transition from the conventional biomass supply systems. A developing biofuels industry requires a biomass supply system adequate to provide the supply at an acceptable cost. The lack of such a system is likely an impediment to the development of a bioenergy industry of the desired scope.

1.4 A Commodity-Based, Advanced Biomass Supply Chain Design

Recent reports published by Idaho National Laboratory (INL) propose a commodity-based, advanced biomass supply chain design concept to support the production of biofuels (Hess, Kenney, Ovard, Searcy, & Wright, 2009), (Searcy & Hess, 2010). The commodity-based, advanced biomass supply chain design is substantially different from conventional feedstock logistics models that were design to support the agriculture industry. This advanced design leverages existing high-capacity transportation and handling equipment designed for established industries, such as grain, by moving preprocessing operations to earlier in the supply chain. The preprocessing (including drying, densification, etc.) would be performed in local biomass processing depots, reducing downstream supply chain costs. The depots would densify the biomass into a uniform format at facilities located within approximately 5 to 15 miles of feedstock production. The anticipated benefit is that the sustainability form a commodity system would outweigh the cost associated with densifying the biomass (Hess, Kenney, Ovard, Searcy, & Wright, 2009).

Handling and transportation costs for the densified biomass are lower than for raw biomass. The properties acquired by densifying biomass introduce the option of incorporating high-capacity transport alternatives (such as rail and barge) for long hauls. Rail and barge modes of transportation offer lower costs for longer hauls when compared to truck transportation. In addition, rail and barge modes of transportation use lower energy per unit of transport than truck and consequently, produce lower greenhouse gas emissions per unit of transport. These transportation modes generally are more cost efficient than trucks for longer hauls and higher volumes of bulk commodity. However, raw, unprocessed biomass (i.e. as collected from the land) is not in a format suitable for handling by these transportation modes. The use of high capacity transportation modes would greatly expand the potential collection radius of the biorefinery, reducing feedstock supply risk and introducing more resources into the biomass market.

The commodity-based biomass supply chain vision is for a national biomass market that would provide a buffer against supply upsets, biomass price, and quality due to a number of factors (e.g. feedstock availability, natural disasters). The significant investments required to establish a biorefinery, in addition to biomass supply uncertainty, make owner/operators risk averse and reluctant to scale up refineries. Larger biorefineries can take advantages of economies of scale, which can result in cost-per-unit output savings. Shortages caused by biomass supply uncertainties can be overcome by a larger feedstock supply area for a biorefinery and with a more stable feedstock. A change from the conventional design to a centralized design allows for expanding supply options for a biorefinery and offers investors confidence of a sustainable supply. Figure 1.2 illustrates the distribution changes from the conventional distribution design to a centralized supply chain for biomass. The biomass density in the 50-mile supply radius for a biorefinery in the conventional design, bounds the capacity of a sustainable plant. Incorporating the preprocessing depots may allow for lower cost of biofuels due to economies of scale at the biorefinery plant.

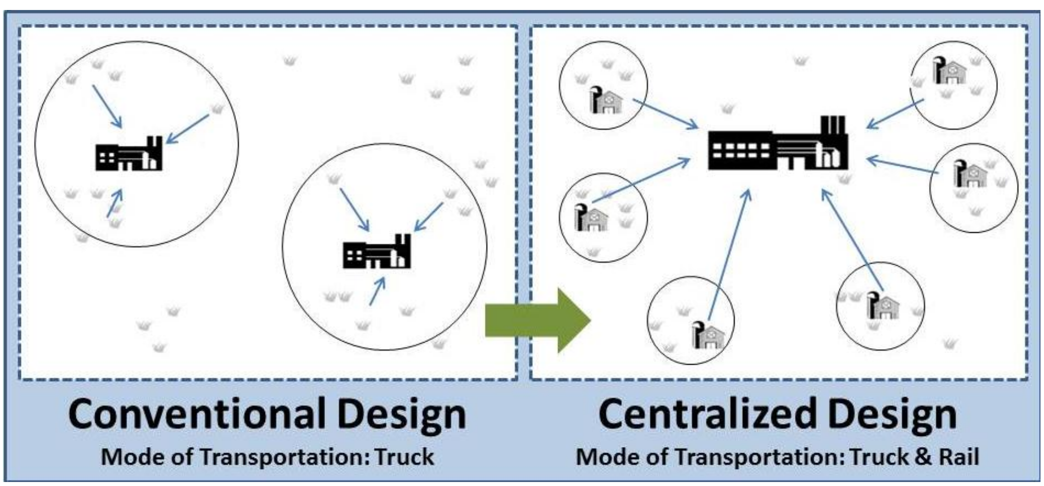

Figure 1.2 Transition from the Conventional Supply Chain Design

1.5 High Capacity Transportation Modes for Bulk Solid Biomass

Bulk solid biomass in the commodity-based, advanced biomass supply chain design concept would have similar properties as other bulk commodity products, such as grain. Hence, bulk solid biomass transportation would emulate the grain system. Grains in the US move to domestic and foreign markets through barge, rail and truck. Corn, wheat and soybeans are the major grain field crops in the US (USDA, 2010). Barge usually provides the strongest intermodal competition to railroads for the long-distance movement of grain to export ports. While portions of the corn-belt states have suitable access, many other regions where biomass is plentiful do not have navigable waters. In addition, the optimal location, as determined by a variety of factors, for biorefineries may not be along rivers. In contrast, rail tracks are laid out throughout the US, which allows for higher accessibility to shippers when compared to barge transportation. Rail tracks are laid out along the regions of biomass resources as well as throughout the most populated regions in the US, which would be the most likely destinations for bioenergy shipments. Therefore, rail transport is the most preferable form of high capacity transport for meeting the demands of a developing biofuels industry.

The economics of transporting grain using rail is not well understood. Rail transportation costs are impacted by various factors, including but not limited to government acts and policies, the commodity transported and the viability of alternative forms of transportation (intermodal as well as intramodal). Furthermore, fundamental questions remain regarding the current capacity of the rail infrastructure to meet demands of an expanded biofuels industry.

In addition to capacity issues, the deregulation of rail rates and the railroad consolidation have affected agricultural shippers and have increased the market power of railroads over shippers. Most of the agricultural shippers in the US are considered captive shippers. A captive shipper is charged with higher rates because either he only has one viable mode of transportation (lack of intermodal competition) or it can only be served by a single rail company (lack of intramodal competition).

In order to decrease high transportation costs, agricultural shippers have been taking advantage of efficiency incentives offered by the railroad companies for unit train or shuttle train shipments. In order to improve the productivity of rail lines and increase equipment utilization, railway companies offer lower tariffs for aggregate shipments. Aggregate shipments reduce the number of railcar switching in freight yards, and lower the in-transit time and inventory carrying costs (CBO, 2006). Thus, railway companies can maintain their service level with significantly fewer resources. A bulk commodity biomass system could take advantage of the efficiency incentives offered by railroads, much like the grain industry.

1.6 Objectives

The main objective of the study presented in this thesis is to analyze the impact that rail and barge transportation costs have on the transportation of biomass feedstock when formatted as a bulk solid commodity. Rail cost equations for the transportation of bulk commodities such as, grain and wood chips were derived from publicly available data using regression analysis theories. The study involved the analysis of the factors that affect rail pricing for single and unit train shipments of grain and wood chips. In addition, the study compared the transportation costs of using truck, rail and barge for the transportation of bulk commodities.

CHAPTER II

BACKGROUND

This section presents a review of the current status of the US grain industry and rail industry.

2.1 The Grain Industry

The advanced supply chain design concept proposed by INL relies on leveraging the existing bulk commodity distribution infrastructure and using high-capacity transport modes for long haul shipments of densified biomass, such as rail and barge. Because of the similar characteristics (source, flowability, sustainability, etc) to the grain commodity, the proposed supply chain will emulate the grain system.

Truck, trains and barges, compete and complement each other in moving grain to successively larger elevators. Grain elevators are used to accumulate masses of grain to reach economies of scale in shipping bulk grain (Frittelli, 2005). Most grain shipments use two or more modes of transportation before reaching their final destination (USDA, 2010). Trucks traditionally have an advantage in moving grain for shorter distances (less than 250 miles) and therefore function primarily as the short haul gatherers of grain. Rail and barge transport have a cost advantage for long-hauls of grain, with barge having a higher cost advantage than rail when available.

In order to take advantage of the different modal transportation cost relative to shipment distance, domestic and exported grain tends to exhibit different transportation patterns. Much of the grain exported has to travel long distances to reach US ports (most of grain exports ship out of the Mississippi Gulf or the Pacific Northwest), so Class I railroads and barges are the primary modes of transportation for grain exports. Most domestic grain is transported using either trucks or short line railroads.

The US is considered the world's top grain producer and exporter. Much like grain production, exports fluctuate because they are a function of many factors including global grain production; economic conditions of importer and exporter countries, exchange rates, grain prices, policies, and freight rates (AAR, July 2011). Figure 2.1 shows that total grain exports have kept fairly steady for the last 32 years while the domestic market of grains has increased significantly.

Figure 2.1 Total Grain Movements to Domestic and Export Markets (1978-2010)

Adapted from "Transportation of US Grains: A Modal Share Analysis 1978-2010 Update" by USDA. March 2012. Page 3.

The increasing demand of grain in the domestic market has led to a growth in demand for truck transportation. More grain is transported off-farm to feed cattle and poultry because of a continuing trend in consolidation of livestock and poultry production into large-scale operations. Because of the continuing trend toward consolidation of livestock and poultry production, demand for grain is moving away from major feed-grain producing states to areas of deficit grain production.

Rising production of ethanol has also contributed to the growth in demand for grain transportation off the farm. To get a perspective, corn, soybeans and wheat combined make up for 96% of all US grain transportation tonnages, with corn production been around three times as much as wheat and soybean (USDA, 2011). In 2010, 38% of US corn was utilized was for feed, 37% was turned into ethanol, 4% was used as high fructose corn syrup, 6% was for other industrial uses and 14% was destined as exports. Figure 2.2 illustrates the increase in the truck modal share when compared to rail and barge.

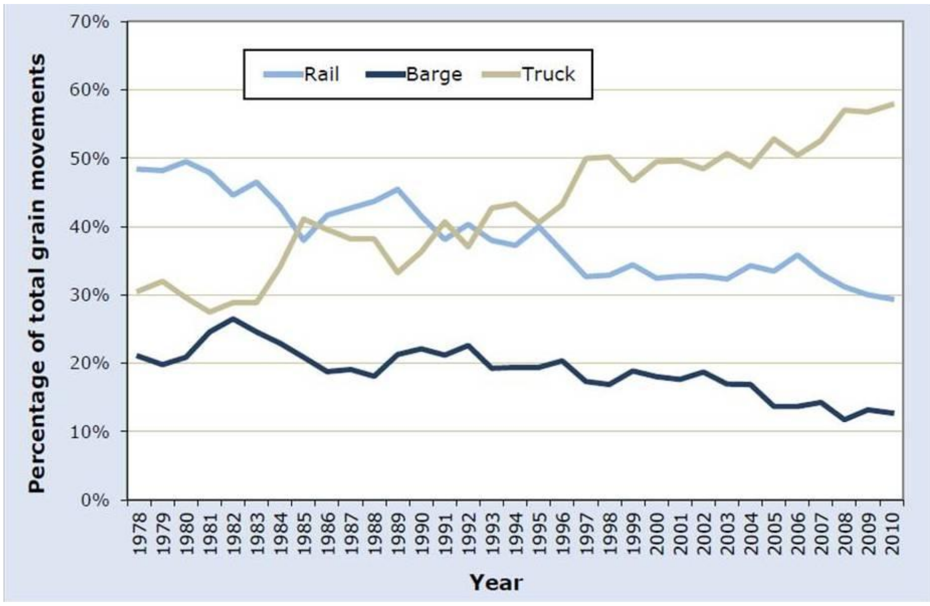

Figure 2.2 US Grain Modal Shares, 1978-2010

Adapted from "Transportation of US Grains: A Modal Share Analysis 1978-2010 Update" by USDA. March 2012. Page 5.

The increase of truck transportation for grain movements demands a higher logistics cost when compared to barge and rail transport. In order to compete with conventional fossil energy sources, a developing biofuels industry would have to reduce the current logistics cost. Barge offers the most economical shipment rates for long-hauls of bulk commodity. While portions of the corn-belt states have suitable barge access, many other regions where biomass is plentiful do not have navigable waters. In addition, the demand for bioenergy may not be along rivers. Therefore, rail transport is expected to be the most likely form of high capacity transportation mode for meeting the demands of the developing bioenergy industry.

2.2 Rail Transportation

To further understand how rail transportation could influence a developing biofuels industry, a background on the rail industry is presented below.

2.2.1 Rail Infrastructure Capacities and Investment

While highways and waterway facilities are largely maintained by the government and funded by taxpayers, the rail companies must invest in the expansion and maintenance of rail infrastructure (CBO, 2006). The rail industry, therefore, assumes the risk of shifts in demand to other rail locations or possibly other transportation modes, and the possibility of a negative return of investment (CBO, 2006). Concerns increase regarding the capability of the current freight infrastructure to support an expanding biofuel production. The US Department of Transportation has predicted that total freight transportation will increase over 90% from 2002 to 2035 (DOT, 2008).

A study prepared for the Association of American Railroads (AAR) (Cambridge Systematics, Inc., 2007) calculated the capacity of the main rail corridors based on the number of tracks, the type of control system, and the mix of train types. Similarly, the Oak Ridge National Laboratory (ORNL) uses the work by Clarke's (1995) to estimate the theoretical rail capacity. This estimation is based on the number of tracks, the occurrence of passing sidings, the terrain where the corridor is laid, and the control system.

Various sources note that the values estimated for the theoretical capacity of rail corridors should be reduced to reflect a practical capacity. The practical capacity is typically lower because a portion of the theoretical maximum capacity is lost to maintenance, weather delays, equipment failures, and other factors. Krueger (1999) estimates that the practical capacity is 67% of the theoretical capacity, while, Cambridge Systematics Inc. (2007), suggests a factor of 70% for the practical capacity. ORNL calculates the practical daily train capacity based on a 70% factor.

2.2.2 The Carload Waybill Sample

The Carload Waybill Sample (CWS) is the most accurate data available to determine the current freight and passenger rail movements in the US. Federal agencies use this data as a source for the analysis of rail revenues and prices, but, because of its sensitive nature, the data it is not publicly available. Instead, the STB publishes the Public Use Waybill, which reports similar information aggregated at the Business economic Area level (BEA). BEAs includes multiple counties often of different states.

2.2.3 Rail Competition and Deregulation

Congress deregulated the rail industry in 1980 through the Staggers Rail Act, but did not remove the industry's antitrust exemptions established in the mid-20th century. The deregulations lead to improvements in financial performance of railroads and railroad productivity. However, competition, captivity, rates, service performance, and financial viability are still a concern to the industry's stakeholders (GAO, 2006). The deregulation and exemption of the antitrust law allowed railroad companies to merge into larger entities and abandon marginal routes. These changes led to improvements of their financial situation (Informa Economics, 2010). The Staggers Rail Act also led to the formation of hundreds of short line railroads that operate track which was formerly ran by a major railroad (Class I) (Laurits R. Chistensen Associates, Inc., 2009). Paper barriers were imposed by Class I railroads upon the sale or lease of some of their short lines to short line railroads. Paper barriers are contractual provisions that prohibit the short line railroads from providing rail customers access to competing major railroads.

The total miles of track owned by Class I railways decreased by 18.9% between 1987 and 2006, however, the efficiency in usage of the Class I tracks and the revenue per ton-miles have increased during the same period (Laurits R. Chistensen Associates, Inc., 2009). Current deregulation policies do not require a rail company to provide the rail customer with a rate for transportation over a bottleneck line segment to a point where the rail customer can reach a competing railroad. The bottleneck issue allows rail companies to take advantage of captive shippers (who do not have alternative route options) with higher prices than shippers with viable options (USDA, 2010). The risk of investing in rail track expansion, the bottleneck issue, paper barriers and the cost disadvantages of captive shippers, among other factors, bring about the complexity of predicting rail rates in the US.

The accessibility to intermodal, as well as intramodal (access to other rail companies) competition both at the origin and destinations are factors considered by the rail companies when formulating rail prices. Some states with high grain production levels such as, Montana, North Dakota, South Dakota, Nebraska, Kansas and Colorado have limited intramodal competition and varying distance to water (200-850 miles). Therefore, these states are charged higher prices than states along waterways to reach export markets. Among these states, grain shipments originating in Montana and North Dakota have higher rates than shipments originating in South Dakota, Nebraska and Kansas. The difference in price is explained by shorter distances traveled over the same track to reach Pacific Northwest markets. However, Illinois, Indiana, Iowa and Missouri shippers are charged lower rates to reach export markets since these states border the Mississippi River, Ohio River or the Illinois River. The average distance from the middle of these States to barge-loading facilities varies from 50 to 150 miles (USDA, 2010).

According to USDA, agricultural shippers are affected the most by the differential pricing applied to rail rates, since most agricultural shippers are located in remote areas (note that a large amount of the lignocellulosic biomass is located in these same regions). Agricultural shippers in Montana and North Dakota are particularly dependent on rail transportation because of their distance to inland waterways and the prohibitive distance for the use of trucks (USDA, 2010). The rail rates charged for agricultural commodities are higher than any other commodity. Rail rates for grain have increased 9%, and rail rates for coal, motor vehicles, and miscellaneous mixed shipments have declined from1987 to 2004 (USDA, 2010).

CHAPTER III

DATA COLLECTION

This chapter presents the three different datasets collected for this study. First, rail rates were collected from the public rate books published by the Class I railway companies. Then, barge and truck transportation costs were recorded for grain shipments in order to compare them with rail rates. All prices showed in this section are prices that apply for year 2011.

3.1 Rail Rates

The majority of rail transportation in the US is handled by Class I railroad companies. Since there are significant differences between Eastern and Western carriers, the Surface Transportation Board has historically analyzed these carriers separately (Surface Transportation Board (STB): Office of Economics, Environmental Analysis & Administration, 2009). The railroad industry in the US is dominated by two large Class I railroad carriers in the east: Norfolk Southern (NS) and CSXT Corporation. The dominant Class I railroad carriers in the western US are Burlington Northern Santa Fe Corporation (BNSF) and Union Pacific Railroad Company (UP) (CBO, 2006). BNSF is considered the dominant grain carrier in the western US, with a 42% of the grain and oilseeds market share in 2007, as opposed to 19% of UP. There is no clear dominant grain carrier on the eastern side of the US. CSXT had 12% of the market of grains and oilseeds originations by 2007 while NS had 11% (Figure 3.1).

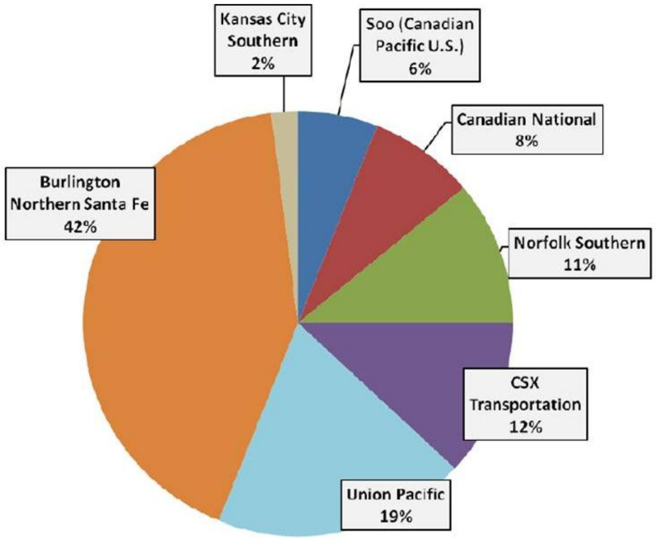

Figure 3.1 Railroad Grain Origination Market Shares, 2007

Adapted from: “Study of Rural Transportation Issues” by USDA. April 2010.

To keep pace with the volatility of fuel costs, shippers charge a fuel surcharge to recover the incremental fuel costs when fuel prices exceed a threshold fuel price (known as the strike price). The STB requires Class I railroads to list fuel charges based on the length of haul. Among the Class I railroads in the US, BNSF have listed the highest fuel surcharges in 2007, 2008 and 2009; however, BNSF has the lower tariff rate of the western railroads (Informa Economics, 2010).

Railroads in the US have actively expanded the network of unit train loaders and unloaders over the past decade, which has allowed for an increase in railroad productivity. Figure 3.2 illustrates grain loading and unloading facilities across the US.

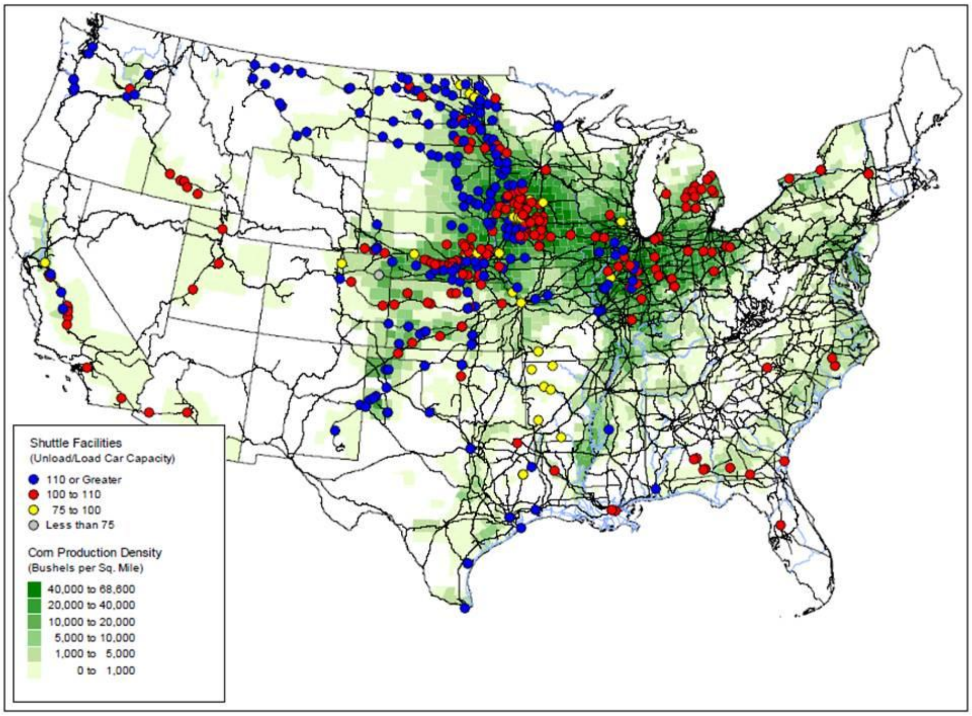

Figure 3.2 Shuttle/Unit Train Loading/Unloading Facilities

Adapted from: "Review and Analysis of Corn Rail Rates" by Informa Economics: An AGRA Informa Company. Prepared for the National Corn Growers Association. 2010.

To increase the productivity of the rail lines and equipment utilization, rail companies offer efficiency payments for aggregate shipments so that, shippers send many carloads at a time (shuttle or unit trains). Aggregate shipments enable railroads to provide services with significantly fewer resources than were previously needed (freight yards, railcars, etc), reduce the amount of railcar switching in freight yards and lower the in-transit time and inventory carrying costs (CBO, 2006). The Association of American Railroads defines a unit train as a single movement of 50+ cars (AAR, July 2011). But price breaks are offered by railroads at different shipment sizes.

3.1.1 Rail Prices for Bulk Commodity Shipments

A variety of freight rate arrangements are used between railroads and shippers for the movement of commodities. The two main mechanisms include rail contracts and rail tariffs. Rail contracts allow shippers to seek specific services and negotiate prices with railroads. Rail tariffs are published by carriers showing applicable rates, rules, regulations governing service, routings, special services, demurrage and other related matters (Informa Economics, 2010).

STB has no jurisdiction over contract rates, thus these rates are not easily available (USDA, 2010). BNSF and CSXT publish rail tariffs books for different origin-destination (OD) combinations for various commodities. This study used publicly available rates published by BNSF and CSXT, for the transportation of grain. At the time of the data collection (December 2011), the only published rates by CSXT were effective since November 2011; therefore, tariffs effective in the same period were collected from BSNF. In this period the fuel surcharge applied by CSXT was of 46 cents per mile while BNSF employed a fuel surcharge of 65 cents per mile. Fuel surcharges are not included in tariffs and will not be accounted for in the study.

The most common rail equipment used for transporting grain is a covered hopper. Consequently, the study considered covered hoppers for the transportation of densified biomass from the depot locations to coal plants. Railcar capacities differ among rail companies. BNSF offers shippers large covered hoppers and jumbo covered hoppers for the transportation of grain; with a gross rail load of 263,000lbs (132 tons) and 286,000lbs (143 tons) respectively (BNSF). CSXT also provides two sizes for covered hoppers, which they categorize as small (70-100 tons) and jumbo (100-110 tons) (CSX). Similarly, UP specifies equipment for grain transportation with capacities between 263,000-286,000 lbs (UP). NS did not specify equipment capacities for covered hoppers in their website. Rail tariffs were collected for the different covered hopper sizes available.

Tariffs were collected for single car shipments as well as unit train shipments. The number of cars required by the eastern railway companies (such as, CSXT) to take advantage of an efficiency incentive differs significantly from the number of cars required by the western railway companies (such as, BNSF). Differences in regional geography and topography allow western railroads to operate longer trains (Cambridge Systematics, Inc., 2007).

BNSF has an incentive program intended to promote efficient station operations for the loading and unloading of 110 cars or more. BNSF offers an origin efficiency payment (OEP) of $150 per car if loading of a shuttle train takes up to10 hours, $100 per car if it takes anywhere between 10 and 15 hours and $50 per car if loading takes no more than 21 hours. In addition, BNSF offers an incentive allowance at destination (DEP) of $100 per car if the cars are fully unloaded as a unit within 15 hours of actual placement at elevator. Furthermore, BNSF has a reload incentive of $200 per car for reloading a shuttle train at the same location where the shuttle was unloaded. In this case, a customer will have a total of 38 hours for loading and unloading of a unit rail. CSXT also offers financial incentives for loading and unloading a 90-car unit train within 15 hours. CSXT offers $125 per car to loading shippers and $75 per car to unloading shippers. Table 3.1 summarizes the efficiency incentives offered by the two railroad companies studied.

Table 3.1 BNSF and CSXT Efficiency Incentives

	Time (hours)	BNSF Incentive ($/car)	CSXT Incentive ($/car)
Load	10	150	n/a
	15	100	125
	21	50	n/a
Unload	15	100	75
Reload	38	200	n/a

3.2 Barge Rates

Barge has historically been used to ship agricultural producst such as, corn, feed grain, sorghum, and soybean, from the Midwest to the Gulf Port along the US agricultural waterways. Exported agricultural products (such as, oats) also move along these waterways from the Gulf Port to the north. The Mississippi River is the backbone of this system as 86% of all operating barges move along this river.

Typically, barges move in groups called tows, which are pushed along by a towboat. The size of a tow is impacted by the number of locks along the river. For example, on the lower Mississippi River, where there are no locks, it is common to see between 30 and 40 barges pushed by a single towboat. The amount of product loaded on a barge depends on the depth of the river the barge will be moving along. The travel time of barge from its origin to its destination depend on the number of locks along the path, the weight of the load, and most importantly, the horsepower of a towboat. Table 3.2 presents transportation costs per ton of grain moving by covered barge along the Mississippi River. Depending on the size, a covered barge can carry anywhere between 1,500 to 2,000 tons of grain. Table 3.2 was created based on data provided by a report from the US Army Corps of Engineers. The costs presented in the table consider the following barge and towboat related costs: barge replacement costs, barge operating costs, administrative costs, port cost, towboat replacement costs, towboat operating costs, crew related costs (such as, wages, fringe benefits, food, transportation). The table clearly shows that the cost per ton is a function of towboat horsepower and distance traveled. The distance from Minneapolis to St. Louis along the Mississippi River is approximately 673 miles, the distance between St. Louis and New Orleans is approximately 1,039, and; thereof, the distance between Minneapolis and New Orleans is about 1,712 miles. The price of shipping 1,400 tons or less is fixed.

Table 3.2 Barge Transportation Cost ($/ton) along the Mississippi River

Tow Boat Horsepower	St. Louis to New Orleans	Minneapolis to New Orleans	Minneapolis to St. Louis
400 – 600	3.47	5.36	8.83
600 – 1,200	3.77	5.83	9.60
1,200 – 1,800	4.11	6.35	10.46
1,800 – 2,400	4.49	6.94	11.43
2,400 – 3,000	5.39	8.33	13.72
3,000 – 4,000	5.88	9.07	14.95
4,000 – 6,000	6.92	10.68	17.60
6,000 – 8,000	8.17	12.62	20.79
8,000 – 11,000	9.84	15.20	25.04

Table 3.2 presents transportation costs, however, shipping rates charged for barge shipment fluctuate from one period to the next. These rates are typically at their lowest in the first and second quarter of the year. The rates reach their highest level during and right after the harvesting season due to the increased demand for barge shipments. Barge operators base their prices on the percent-of-tariff system. The institution benchmark tariff set in 1976 (USDA, 2010). Each segment of the Mississippi River has its own tariff benchmark. Tariffs increase the further north shipment originates. Other transportation costs that occur when using barges are certain penalties which are charged if agreements are not met. One example is the demurrage charge, which is incurred if a barge is not

loaded or unloaded within the time window agreed upon. The Agricultural Marketing Services (AMS), a division of the US Department of Agriculture (USDA) publishes weekly reports of the latest volume and price charged for movement of grain and barges.

3.3 Truck Rates

Trucks are often used for shipping agricultural products despite the fact that the cost per ton and per mile traveled by truck is higher as compared to rail and barges. The main reason for using trucks is accessibility. Different from barge and rail, highway infrastructure is larger and reaches many remote areas where agricultural products are cultivated.

Data on truck rates used in this study was provided by AMS (Transportation Services Division, 2011). The AMS reports summarizes the per mile rate charged for a truck load in different regions of the US. Truck rates are impacted by the origin and destination of the shipment and by the distance traveled. Table 3.3 illustrates the average rate per mile per truckload reported in the third quarter of 2011. Rates provided by USDA are based on 80,000 lbs. gross vehicle weight limit and are quoted in US dollars.

Table 3.3 Average Grain Truck Rates

Region	25 miles	100 miles	200 miles
National Average	3.74	3.29	3.18
North Central Region	3.37	3.15	3.06
Rocky Mountain	n/a	n/a	n/a
South Central	4.22	3.28	3.26
West	n/a	n/a	n/a

Adapted from “Grain Transportation Quarterly Updates” by USDA. December 8, 2011.

CHAPTER IV

RAIL COST EQUATIONS

This section describes the methodologies used in this study to develop rail cost equations to analyze the impact of using rail for the transportation of biomass.

4.1 Methodology for Calculating Rail Cost Equations

Stepwise regression was applied to the publicly available rail tariffs to a quantitative understanding of what impacts the tariff charged for railcar shipments of bulk solid commodities, such as soybean, wood chips, corn and other grains. The resulting equations were then used to compare the cost of using rail transportation with the cost of using barge and truck to ship bulk solid commodities.

The equations were developed by connecting the dependent/response variable (price) and the independent/predictor variables (distance, equipment capacity allowance, fleet capacity, route, etc). The response variable was denoted as “y” and the set of predictor variables as “x_1, x_2, x_3, …, x_p”, where p represents the number of predictor variables. The true relationship between “Y” and “x_1, x_2, x_3, … x_p” can be approximated by the regression model: $y = f(x_1, x_2, x_3, \ldots, x_p) + \varepsilon$, where ε is assumed to be a random error representing the discrepancy in the approximation, and accounts for the failure of the model to fit the data exactly. The function $f(x_1, x_2, x_3, \ldots, x_p)$ describes the relationship between Y and x_1, x_2, x_3, … x_p and is represented as follows:

$$f(x_1, x_2, x_3, \ldots, x_p) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \cdots + \beta_p x_p \qquad \text{(Eq. 4.1)}$$

where β_0, β_1, β_2, β_3, …, β_p are constants referred to as the model partial regression coefficients.

4.2 Rail Cost Equations

Forward regression was used to better understand how railway companies price for railcar shipments of soybean, woodchips, corn and other grains. This section describes how the rail cost equations models were. The data used in this regression analysis is available in the websites of CSXT and BNSF. The public tariffs used were effective on October 2011. The analysis was restricted to the origin-destination (OD) combinations and specific commodities provided by each rail company.

4.2.1 Single Car Shipments of Soybean

CSXT tariffs for soybean shipments were collected from the Midwest (such as, Illinois, Indiana, Kentucky, and Ohio) to the Southeast (Alabama, Florida and Georgia). The total number of origin-destination (OD) points used in this analysis is 1,036. The total number of tariffs collected for single car shipments of soybean was divided in two, 70% of the entries were used in the regression analysis and, the remaining 30% were used to validate the model. Soybean shipments by CSXT use covered hopper cars. Therefore, the results presented in this section refer to this particular railcar type. The dependable variable (Y^1_{CSXT}) in the regression equations presented below is the price charged per rail car.

Railway distance (x_1) is the first independent factor introduced in the regression analysis. Equation 4.1 illustrates the results from the regression.

$$Y^1_{CSXT} = 2{,}248 + 1.2\ x_1 \qquad \text{(Eq. 4.1)}$$

The value of the adjusted R^2 = 28.9% and the p-value for x1 is $2E^{-22}$. These values are an indication that railway distances are an important factor in determining railcar price. The value of the intercept ($2,248) represents the fixed shipment cost, and $1.2 represents the per mile rate charged. Regression was then re-run to evaluate the influence of highway distances between OD points (x'_1), the analysis resulted is represented in Equation 4.2. Highway distances were obtained using GoogleMaps, a web mapping service application and technology provided by Google.

$$Y^1_{CSXT} = 2{,}062 + 1.9\ x'_1 \qquad \text{(Eq. 4.2)}$$

It is of interest to note that the value of the adjusted R^2 = 48%, a higher value than when regressing soybean tariffs with railway distances. In addition, the p-value for x'_1 in Equation 4.2 is $7E^{-166}$, a lower value than the one obtained previously. These factors indicate that highway distances better explain the price charged by CSXT per railway car than railway distance does. Similar results were found from regression analysis of similar commodities shipped by CSXT. The finding suggests that truck transportation is a viable competitor for CSXT.

Variable x_2 is then introduced in the equation. Variable x_2 represents the impact that railway ownership has on rail tariffs. For certain origin-destinations, CSXT uses smaller, regional railway companies for a limited number of miles. The independent variable x_2 in Equation 4.3 is an indicator variable which takes the value 1 when CSXT uses regional rail ways for a given OD pair; and takes the value 0 otherwise.

$$Y^1_{CSXT} = 1{,}974 + 1.9\ x'_1 + 149\ x_2 \qquad \text{(Eq. 4.3)}$$

The adjusted R^2 = 49%, and the p-value for both independent variables are smaller than $1E^{-10}$. Equation 4.3 indicates an average increase of $149 per railcar in the price charged for shipments that use regional railways.

Equation 4.4 has one additional variable, x_3. This is an indicator variable which takes the value 1 when the railcar is owned by CSXT, and equals 0 otherwise.

$$Y^1_{CSXT} = 1{,}721 + 1.9\, x_1' + 105\, x_2 + 608\, x_3 \qquad \text{(Eq. 4.4)}$$

The value of the adjusted R^2 obtained was 81%, and the p-values for all independent variables were less than $7E^{-14}$. Note that the price charged per mile in equations 4.3 and 4.4 are the same, however the total cost is $608 smaller when the railcar is owned by the shipper.

The indicator variable x_4 is included in Equation 4.5, which equals 1 if the origin of a shipment is located "far from a in-land port", and equals 0 otherwise. The purpose is to see the impact that the availability of barge transportation has on the price charged by CSXT. It is important to define the meaning of the term "far from an in-land port". Three regression analyses were performed updating the values of x_4 as follows. First, x_4 was set to 1 for those OD points where the distance from the shipment origin to the closest in-land port was more than 100 miles and 0 otherwise. Second, x_4 was set to 1 for those OD points where the distance from the shipment origin to the closest in-land port was more than 125 miles and 0 otherwise. Finally, x_4 was set to 1 for those OD points where the distance from the shipment origin to the closest in-land port was more than 150 miles and 0 otherwise. The regression in which the value of x_4 was set to 1 when the distance from the shipment origin to the closest in-land port was more than 100 miles (Equation 4.5) gave the highest adjusted R^2 = 82% and the smallest p-values for x_4 (less than $2E^{-11}$).

$$Y^1_{CSXT} = 1{,}714 + 1.8\, x_1' + 116\, x_2 + 607\, x_3 + 134\, x_4 \qquad \text{(Eq. 4.5)}$$

In the same way, variable x_5 was introduced, which represented the distance between the destination point of a shipment and the closest in-land port. The indicator variable x_5 equals 1 if the destination of a shipment is "far from an in-land port" and 0 otherwise. First, x_5 was set to 1 for those OD points where the distance from the shipment destination to the closest in-land port was more than 50 miles and 0 otherwise. Regression was re-run for cases when the value of x_5 was set to 1 when the distance between the destination of a shipment and the closest in-land port was 100, 150 and 200 miles. The regression in which the value of x_5 was set to 1 when the distance from the shipment destination to the closest in-land port was more than 150 miles (Equation 4.6) gave the highest adjusted R^2 = 83% and the smallest p-value for variable x_5 (less than $3E^{-12}$). A final regression analysis considered the interaction between variables x_4 and x_5. However, this interaction was not found significant, and it was not added to the equation.

$$Y_{CSXT}^{1} = 1{,}682 + 1.8\, x_1' + 105\, x_2 + 608\, x_3 + 137\, x_4 + 114\, x_5 \qquad \text{(Eq. 4.6)}$$

The results from regressions Equations 5.5 and 5.6 indicate that barge transportation is a competitor to rail. Barge becomes a competitor for those shipments in which the travel distance from shipment origin to an inland port is less than 100miles, or travel distance from the destination point to an in-land port is less than 150 miles. The discount received for shipments for which the origin is close to an in-land port is on average $137, and for shipments for which the destination is close to an in-land port is on average $114. These results are on-line with findings from the Christensen studies (Laurits R. Chistensen Associates, Inc., 2009) and (Laurits R. Christensen Associates, Inc., 2010).

The model validation of the regression equation was obtained by fitting the tariffs for the remaining OD pairs, not included in the regression, into the model. The model validation for the rail transport tariffs of soybeans resulted in a 5.47% average error gap.

4.2.2 Single Car Shipments of Wood Chips

Data was collected for wood chip shipments from the Midwest (Illinois, Indiana, Kentucky, and Ohio) to the Southeast (Alabama, Florida and Georgia) along CSXTT rail lines. The total number of OD points used in this analysis is 508. The total number of tariffs collected for single car shipments of wood chips was divided in two, 70% of the entries were used in the regression analysis and, the remaining 30% were used to validate the regression model. Wood chip shipments by CSXT use hopper and gondolas railcars. In the regression equations presented below, the dependable variable (Y^2_{CSXT}) is the price charged per railcar. Equation 4.7 represents the prices charged for railcars owned by CSXT as a function of highway distance between the origin and the destination of a shipment x'_1.

$$Y^2_{CSXT} = 3{,}010 + 1.3\,x'_1 \qquad \text{(Eq. 4.7)}$$

The value of the adjusted $R^2 = 31\%$, and the p-values for x'_1 is $8E^{-175}$. Based on the regression equation, the price charged per mile per rail car is about \$1.3. Predictor variable x_2 was then added to the regression model, with a value 1 when the route from the origin to the destination includes tracks not owned by CSXT, and 0 otherwise (Equation 4.8).

$$Y^2_{CSXT} = 2{,}858 + 1.3\,x'_1 + 255\,x_2 \qquad \text{(Eq. 4.8)}$$

The value of adjusted R^2 increased to 37%, and the p-values for both independent variables were less than $1E^{-45}$. Based on this regression, shipments that use tracks owned by a third party are charged (on average) an additional \$255. This charge reflects the price that CSXT pays for using third party tracks. The benefit to customers from using non-CSXT tracks is typically shorter lead time. Tariffs were then regressed including the indicator variable x_3 to consider railcar ownership. The indicator x_3 takes the value 1 when the railcar is owned CSXT and the value of 0 if the railcar is owned by the shipper.

$$Y^2_{CSXT} = 2{,}382 + 1.4\,x_1' + 256\,x_2 + 548\,x_3 \qquad \text{(Eq. 4.9)}$$

The value of adjusted R^2 in Equation 4.9 increases to 61%, and the p-values for the independent variables are less than $8E^{-71}$.

Similar to the analysis in Equations 4.5 and 4.6 independent variables x_4 and x_5 were added to the equations in order to estimate the impact of barge competition to the price charged per railcar. Equation 4.10 indicates that an average of $79 is added per railcar shipment of wood chips if the origin is more than 100 miles away from an in-land port. On average, $169 is added per railcar shipment of wood chips if the destination point is more than 150 miles away from an in-land port.

$$Y^2_{CSXT} = 2{,}336 + 1.2\,x_1' + 255\,x_2 + 573\,x_3 + 79\,x_4 + 169\,x_5 \qquad \text{(Eq. 4.10)}$$

The value of the adjusted R^2 for Equation 4.10 increased to 62%. The p-values for all the independent variables are smaller than $1E^{-6}$. The interaction between variables x_4 and x_5 was not found to be significant; therefore, it was not added to the equation.

CSXT uses railcars of two different capacities for shipment of wood chips, which are, railcars of capacity less than 6,000 cubic feet and railcars of capacity more than 6,000 cubic feet. In order to capture the impact of railcar capacity in price, indicator variable x_6 was introduced in the equation. This variable takes the value of 1 if the capacity allowance is greater than 6,000 cubic feet and 0 otherwise.

$$Y^2_{CSXT} = 2{,}056 + 1.1\,x_1' + 260\,x_2 + 708\,x_3 + 88.3\,x_4 + 181\,x_5 + 322\,x_6 \qquad \text{(Eq. 4.11)}$$

The adjusted R^2 value for regression Equation 4.11 increased to 70%. All the variables added were found to be significant (p-value less than $8E^{-10}$). The model validation of the regression equation was obtained by fitting the tariffs for the remaining OD pairs, not included in the regression, into the model. The model validation for the rail transport tariffs of soybeans resulted in a 4.75% average error gap.

4.2.3 Single Car Shipments of Grain

The tariffs charged by CSXT are the same for grains such as, barley, corn, rye, milo, sorghum, wheat, emmer, millet and soybeans. The price differentiation was studied between single and multiple car movements, in addition to the factors analyzed in previous sections.

Data was collected first, for single car shipments of grains from the Midwest (Illinois, Indiana, Kentucky, and Ohio) to the Southeast (Alabama, Florida, Georgia and Louisiana) and to the Northeast (Delaware, Indiana, Kentucky, New York and Pennsylvania) along CSXT rail lines. The total number of OD shipments considered in this analysis is 1,165. The total number of tariffs collected for single car shipments of grains was divided in two, 70% of the entries were used in the regression analysis and, the remaining 30% were used to validate the regression model. CSXT uses covered hoppers to ship the studied grains.

In the following regression equations, the dependable variable (Y^3_{CSXT}) represents the price charged per railcar. The definition of most of the independent variables used in the following regression equations are the same to the variables declared previous sessions. Therefore, in this session only independent variables which were not previously introduced will be defined.

$$Y^3_{CSXT} = 2{,}011 + 2.2\ x_1' \qquad \text{(Eq. 4.12)}$$

The value of adjusted R^2 for Equation 4.12.1 is 59% and the p-value for x'_1 is zero, which indicates that highway distance explains exactly 59% of the price charged per railcar for grain shipments.

$$Y^3_{CSXT} = 1{,}967 + 2.1\, x'_1 + 232\, x_2 \qquad \text{(Eq. 4.13)}$$

The value of the adjusted R^2 in Equation 4.13 is 61% and the p-values for x'_1 and x_2 are both zero.

$$Y^3_{CSXT} = 1{,}796 + 2.1\, x'_1 + 232\, x_2 + 321\, x_3 \qquad \text{(Eq. 4.14)}$$

The value of the adjusted R^2 in Equation 4.14 is 66% and the p-values for all the independent variables are less than $2E\text{-}^{47}$.

$$Y^3_{CSXT} = 1{,}746 + 1.7\, x'_1 + 211\, x_2 + 315\, x_3 + 26\, x_4 + 440\, x_5 \qquad \text{(Eq. 4.15)}$$

The value of the adjusted R^2 in Equation 4.15 is 73% and the p-values for all the independent variables are less than $2E^{-6}$.

$$Y^3_{CSXT} = 1{,}594 + 1.8\, x'_1 + 207\, x_2 + 315\, x_3 + 55\, x_4 + 436\, x_5 + 230\, x_6 \qquad \text{(Eq.4.16)}$$

The independent variable x_6 in Equation 4.16 equals 1 if the capacity allowance per railcar is more than 268,000 lbs, and takes the value 0 otherwise. Adding this variable to the regression Equation 4.16 resulted in an adjusted R^2 = 75%. All the independent variables were found significant.

The regression Equation 4.17 includes the indicator variable x_7, which represents the destination market of the shipment. This variable takes the value 1 if the destination of a shipment is in the South/Southeast, and takes the value 0 if the destination of a shipment is in the Northeast US.

Based on a USDA report, the majority of grains shipped to the South/Southeast are exported to different international markets. In 2007, 63% of corn exported was shipped out of the Mississippi Gulf (USDA, 2011).

$$Y_{CSXT}^{3} = 1{,}560 + 1.6\,x_1' + 157\,x_2 + 316\,x_3 + 69\,x_4 + 465\,x_5 + 290\,x_6 + 230\,x_7 \quad \text{(Eq. 4.17)}$$

The value of adjusted R^2 for Equation 4.17 is 77% and the p-values for all the independent variables are smaller than $2E^{-6}$. Based on this regression equation, the price charged for railcar shipments to the Southeast is on average $230 higher. The higher rate is due to the higher demand for rail shipments to the Southeast since many ports in the Southeast serve the international markets.

The model validation for the regression equations presented in this section resulted in 8.7% average error gap.

4.2.4 Unit Train Shipments of Grain

CSXT gives price breaks for shipments that consist of more than 65 railcars and a higher price break for shipments that consist of more than 90 railcars. Such shipments of multiple cars at a time are considered unit train shipments.

To develop the regression equations presented below, data was collected from CSXT's website. Tariffs correspond to grain shipments from the Midwest (Illinois, Indiana, Kentucky, and Ohio) to the Southeast (Alabama, Florida, Georgia and Louisiana) and to the Northeast of the US (Delaware, Indiana, Kentucky, New York and Pennsylvania).

4.2.4.1 Grain Shipments on a 65-Car Unit Train

The dependable variable Y^4_{CSXT} represent the tariffs charged per railcar for a unit train of 65 cars or more. The definition of most of the independent variables we use in the following regression equations are the same as the variables declared in previous sessions. The total number of OD shipments analyzed is 1,165. Again, the data was divided in two, 70% of the entries were used in the regression analysis and, the remaining 30% was used to validate the regression model. Equation 4.18 illustrates the regression steps taken for the analysis of 65-car unit train shipments.

(a) $$Y^4_{CSXT} = 1{,}588 + 2.3\,x_1'$$

(b) $$Y^4_{CSXT} = 1{,}551 + 2.3\,x_1' + 198\,x_2$$

(c) $$Y^4_{CSXT} = 1{,}474 + 2.3\,x_1' + 207\,x_2 + 115\,x_3$$

(d) $$Y^4_{CSXT} = 1{,}439 + 1.8\,x_1' + 196\,x_2 + 101\,x_3 + 122\,x_4 + 421\,x_5 \qquad \text{(Eq. 4.18)}$$

(e) $$Y^4_{CSXT} = 1{,}338 + 1.8\,x_1' + 201\,x_2 + 107\,x_3 + 107\,x_4 + 419\,x_5 + 227\,x_6$$

(f) $$Y^4_{CSXT} = 1{,}325 + 1.6\,x_1' + 157\,x_2 + 130\,x_3 + 80\,x_4 + 440\,x_5 + 263\,x_6 + 236\,x_7$$

Table 5.1 illustrates the adjusted R^2 values and the largest p-values of all independent variables at each step of developing Equation 4.18.

Table 4.1 CSXT 65-Car Unit Train Regression Values

Step	Adjusted R^2	Largest P-Value
5.18 (a)	67%	0
5.18 (b)	68%	$1E^{-34}$
5.18 (c)	70%	$1E^{-15}$
5.18 (d)	74%	$1E^{-14}$
5.18 (e)	77%	$9E^{-13}$
5.18 (f)	79%	$3E^{-8}$

The model validation for the rail transport tariffs of grains resulted in a 9.7% average error gap.

4.2.4.2 Grain Shipments on a 90-Car Unit Train

The dependable variables Y^5_{CSXT} represent the tariffs charged per railcar for a 90-car unit train. The definition of most of the independent variables used in the following regression equations are the same to the variables declared in previous sessions. The total number of OD shipments analyzed is 672. Again, the data was divided in two, 70% of the entries were used in the regression analysis and, the remaining 30% were used to validate the regression model. Equation 4.19 illustrates the regression steps taken for the analysis of 90-car unit train shipments.

(a) $$Y^5_{CSXT} = 1{,}185 + 2.1\, x_1'$$

(b) $$Y^5_{CSXT} = 1{,}168 + 2.1\, x_1' + 76\, x_2$$

(c) $$Y^5_{CSXT} = 1{,}120 + 2.1\, x_1' + 46\, x_2 + 156\, x_3$$

(d) $$Y^5_{CSXT} = 1{,}098 + 1.6\, x_1' + 45\, x_2 + 172\, x_3 + 71\, x_4 + 487\, x_5 \quad \text{(Eq. 4.19)}$$

(e) $$Y^5_{CSXT} = 977 + 1.6\, x_1' + 60\, x_2 + 117\, x_3 + 82\, x_4 + 474\, x_5 + 233\, x_6$$

(f) $$Y^5_{CSXT} = 497 + 1.9\, x_1' + 54\, x_2 + 127\, x_3 + 102\, x_4 + 300\, x_5 + 222\, x_6 + 435\, x_7$$

Table 5.2 illustrates the adjusted R^2 values and the largest p-values of all independent variables at each step of developing Equation 4.19.

Table 4.2 CSXT 90-Car Unit Train Regression Values

Steps	Adjusted R^2	Largest p-Value
5.19 (a)	58.9%	0
5.19 (b)	59%	$3E^{-3}$
5.19 (c)	60%	$7E^{-3}$
5.19 (d)	68%	$5E^{-3}$
5.19 (e)	70%	$4E^{-4}$
5.19 (f)	72%	$1E^{-3}$

Furthermore, grain shipment prices were available for different fleet sizes. CSXT applies a price reduction per car for movements of 65 cars or more and an even higher reduction per car for movements of 90 cars or more. To represent this price differentiation in the rail cost equation, variables x_8 and x_9 were introduced. Variable x_8 was given a value of 1 if the fleet size was of 65 cars or more and 0 otherwise. Variable x_9 was given a value of 1 if the shipper requested a movement of 90 cars or more. Hence, for a movement of 93 cars both x_7 and x_8 variables would be equal to 1 in Equation 4.20.

$$Y_{CSXT}^{6} = 1{,}632 + 1.6\,x_1' + 151\,x_2 + 193\,x_3 + 83\,x_4 + 438\,x_5 + 278\,x_6 + 161\,x_7 - 268\,x_8 - 516\,x_9 \qquad \text{(Eq. 4.20)}$$

The value of adjusted R^2 for Equation 4.20 is 80% and the p-values for all the independent variables are smaller than $3E^{-33}$. The results from the analysis shows that distance, route, car ownership, origin and destination to inland waterways, capacity, destination market and fleet size explain approximately 80% of prices charged by CSXT to grain shippers. Each car shipment of grain is charged an approximate fixed cost of $1,632, in addition to $1.6 per mile distance from origin to destination, $151 if the route includes tracks other than CSXT-owned tracks, $193 if CSXT cars are used for the shipment, $83 if the origin is more than 100 miles away from inland waterways, $438 if the destination is more than 150 miles away from inland waterways, $278 if the carload exceeds 268,000 lbs. Furthermore, the CSXT rail company offers a reduction in price of

\$310 per car for shipments of 65 to 89 cars; and, a reduction of \$824 for movements of 90 cars or more.

4.2.5 Single Car Shipments of Corn

The data used to develop the regression equations presented in this section is available at BNSF's website. The tariffs collected are charged for corn shipments from the Midwest (Iowa, Minnesota and Nebraska) to the Northwest (Oregon and Washington) and to the Southwest (Arizona, California, New Mexico, Oklahoma and Texas). Corn is shipped using covered hoppers cars. BNSF lists prices charged for single railcars which represent shipments that consist of less than 25 railcars. BNSF also publishes tariffs for shipments that consist of 25-110 railcars, and for shipments between 110 and 120 railcars.

Tariffs were collected for 15,497 different OD shipments of less than 25 railcars. The dependable variables Y^1_{BNSF} represents the tariffs charged per railcar for shipments of 1 to 25 cars. Equation 4.21 gives the relationship between the tariff charged and the distance traveled along BNSF's rail lines (x'_1). The value of the adjusted R^2 is 50% and the p-value is 0.

$$Y^1_{BNSF} = 3{,}140 + 1.2\ x_1 \qquad \text{(Eq. 4.21)}$$

Regression was then run where the independent variable was the highway distance (x'_1) between the OD pair, rather than the railway distance. However, the value of the obtained adjusted R^2 was smaller. It is of interest to note that, highway distance, rather than railway distance, could better explain the tariffs charged by CSXT, which does not hold true for BNSF tariffs. The discrepancy can be explained by looking at the railway network of the two companies. The rail BNSF network is more dispersed when compared to the CSXT network. In fact, this can be generalized, the rail network in the western US is farther spread out when compared to the rail network in the eastern US. The distances traveled along BNSF lines to ship from the Midwest to the West are longer than the distances traveled along CSXT lines from the Midwest to the East. Therefore, western railroads may not really have truck as a viable competitor.

BNSF tariffs are provided to the public for shipments where the origin and destination rail ramp is owned/operated by BNSF and for shipments where either the origin or the destination rail ramp is owned/operated by BNSF. Similar to our previous definition of x_2, the independent variable takes the value 1 if either the origin or the destination rail ramp is owned/operated by BNSF and the value 0 otherwise. The adjusted R^2 obtained from Equation 4.22 was 51%.

$$Y_{BNSF}^{1} = 3{,}140 + 1.2\ x_1 - 450\ x_2 \qquad \text{(Eq. 4.22)}$$

BNSF does not provide tariffs for shipper-owned railcars therefore, the independent variable previously defined as x_3 was not included. Which, lead us to believe that all tariffs published apply for BNSF-owned railcars. In addition, indicators of viable barge alternatives (x_4 and x_5) were not introduced in the regression equations for BNSF, since barge is not an option for shipments from the Midwest to the western coasts.

BNSF tariffs depend on the capacity of a railcar. Variable x_6 in Equation 4.23 takes the value 1 railcar capacity of a shipment is greater than 5,000 cu ft, and takes the value 0 otherwise. The value of the adjusted R^2 is 52% and the p-values are all less than $5E^{-20}$.

$$Y_{BNSF}^{1} = 3{,}050 + 1.2\ x_1 - 542\ x_2 + 205\ x_6 \qquad \text{(Eq. 4.23)}$$

Variable x_7 was then introduced to estimate the impact that the destination of a shipment has on the tariffs charged. The variable introduced takes the value of 1 if the destination of a shipment is in the Northwest, and the value of 0 if the destination is in the Southwest. The adjusted R^2 obtained from Equation 4.24 was 79% and the p-values for the independent variables were all less than $6E^{-27}$.

$$Y^1_{BNSF} = 2{,}835 + 1.3\ x_1 - 426\ x_2 + 500\ x_6 - 1{,}462\ x_7 \qquad \text{(Eq. 4.24)}$$

This regression equation suggests that shipping corn from the Midwest to the Northwest is on average $1,462 cheaper when compared to shipping corn to the Southwest. The difference in price could be explained by the flow of shipments to these destinations. Figure 4.1 maps the volume-to-capacity ratios for each primary rail corridor across the US rail network. The map illustrates that the majority of corridors laid on the Southwest and Midwest of the US are the most congested.

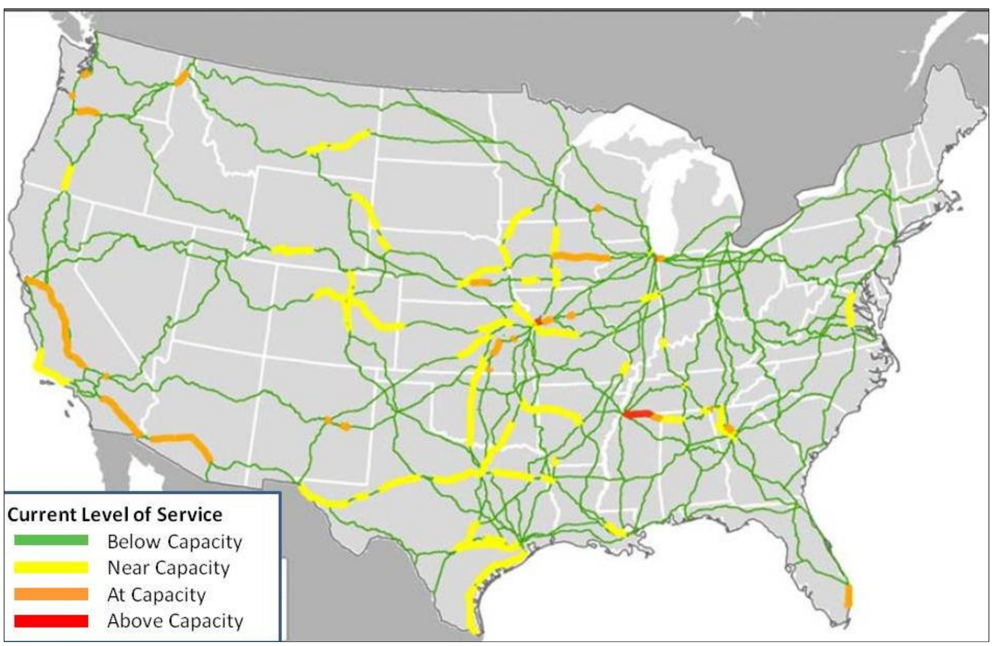

Figure 4.1 Current Rail Volumes Compared to Current Capacities

Adapted from "National Rail Freight Infrastructure Capacity and Investment Study" prepared for Association of American Railroads by Cambridge Systematics, Inc. 2007.

4.2.6 Unit Car Shipments of Corn

Similar to CSXT, BNSF provides price incentives for aggregate shipments. BNSF offers incentives for shipments of 110 to 120 railcars. Equation 4.25 summarizes the results from the regression analysis. Regression is run to consider the impact of the railcar capacity x_6, however, the variable was not found significant.

(a) $$Y^2_{BNSF} = 2{,}734 + 0.7x_1$$

(b) $$Y^2_{BNSF} = 2{,}706 + 0.73\,x'_1 + 224\,x_2 \quad \text{(Eq. 4.25)}$$

(c) $$Y^2_{BNSF} = 2{,}549 + 0.94\,x'_1 + 355\,x_2 - 637\,x_7$$

Table 4.3 BNSF 110-Car Unit Train Regression Values

Steps	Adjusted R^2	Largest P-Value
5.25 (a)	54%	0
5.25 (b)	55%	2E-13
5.25 (c)	71%	7E-45

4.3 Lessons Learned from Regression Analysis

The regression analysis showed that highway distance between the origin and destination, route and railcar ownership, origin and destination proximity to barge access, car capacity and region destinations are significant factors that affect CSXT rail tariffs for bulk solid commodities such as grains and wood chips. These factors may be able to explain up to 83% of the published rail tariffs. In particular, distance and rail line ownership are observed to be the main factors that impact rail tariffs. In all the regression equations presented above, the independent variables x_1 and x_2 were found statistically significant. Collectively, these two variables explain 49 to 68% of the tariffs charged per railcar shipment. Furthermore, distance between origins and destinations showed to have a higher impact on unit train tariffs than on single car shipments.

Truck and barge transportation are viable competitors for CSXT, which is not the case for the BNSF railway company. The tariffs studied were for long-haul shipments of bulk solid commodities from the Midwest to the South, East and West of the US. The distances traveled along BNSF lines to ship from the Midwest to the West of the US average 1,200 miles. While the distances traveled along CSXT lines from the Midwest to the East average 500 miles. Truck transportation is usually not economically viable for such long distances, but truck in combination with barge transportation can compete with rail prices. And, because the main inland navigable waterways run from North to South of the US, in our study, barge is only a viable option for CSXT shipments. For this reason, the regression analysis showed that highway distances better represented CSXT tariffs, while BNSF tariffs were best explained by railway distances.

Furthermore, the analysis showed that CSXT decreases its rates as the origin and/or destination is closer to inland waterways to compete with prices offered by barge transportation. Barge movements on the Missouri and Arkansas Rivers have fewer cost efficiencies compared to rail transportation; barge movements along the Mississippi, Ohio, and Illinois Rivers are cost-effective compared to rail, which have higher deepness (USDA, 2010). According to a report by USDA, barge offers a stronger intermodal competition to railroads for the long-distance movement of grain to export ports at less than 150 miles of highway transportation (USDA, 2010). The analysis revealed a higher increase in price for origins 100 miles or more away from barge access and for destinations 150 miles and more away from barge access.

Unit train shipments are more cost efficient when compared to single car shipments. Based on the regression Equation 4.20, unit rail shipments with 65 to 89 railcars cost, on average, $268 less as compared to single car shipments. Unit rail shipments with more than 90 railcars cost, on average, $784 less as compared to single car shipments. The value of adjusted R^2 for Equation 4.20 is 80% and the p-values for all the independent variables are smaller than $3E^{-33}$.

Shipments along CSXT rail lines are cheaper as compared to shipments along BNSF rail lines. Regression Equation 4.26 expresses the tariffs charged by railway companies as a function of distance traveled, rail line ownership, and rail company. The indicator variable z takes the value 1 if the tariff Y is charged by CSXT, and takes the value 0 if charged by BNSF. The value of adjusted R^2 for this equation is 70% and p-values for all the independent variables are less. This equation indicates that on average CSXT charges $295 less than BNSF. CSXT tariffs are smaller since it has to compete with truck and barge shipments.

$$Y = 2{,}767 + 1.2\ x_1 + 283\ x_2 - 295\ z \qquad \text{(Eq. 4.26)}$$

Among the Class I railways, BNSF has listed the highest fuel surcharges in 2007, 2008 and 2009 (Informa Economics, 2010). However, BNSF tariffs are lower as compared to other western railroads (Informa Economics, 2010).

The tariffs charged by CSXT are the same for grains such as, barley, corn, rye, milo, sorghum, wheat, emmer, millet and soybeans. In contrast, BNSF charges differently depending upon the commodity shipped. Corn shipments were recorded for this study since they represent the majority of grain production in the US.

The variable x_7 introduced in Equations 4.17, 4.18(f), 4.19(f), 4.24 and 4.25(c) showed that tariffs charged by BNSF and CSXT for shipments in the South (Southeast or Southwest) USA are more expensive than shipments to the Northern US. This is mainly due to the higher demand for rail service to these destinations. States like Texas demand grains for feedlots and states on the Mississippi Gulf are major exporters of grains.

CHAPTER V

ANALYSIS OF TRANSPORTATION COSTS

This chapter presents the cost analysis of shipping grain in truck, rail and barge based on distance traveled. The analysis was further expanded to different transportation volumes represented by case scenarios.

5.1 Transportation Cost Analysis Based on Distance Traveled

The regression equations developed were used to compare transportation costs by transportation mode and region. For shipments from the Midwest to East and Southeast, truck, rail and barge were compared (using CSXT rates for rail shipments). For shipments from the Midwest to the West and Southwest, truck was compared to rail shipments by BNSF.

The regression analysis from this study provided rail transportation costs per railcar as a function of the distance traveled. The type of railcar considered in the analysis is a jumbo hopper car, with a cargo capacity of 112 tons. Equation 4.12, 4.18(a) and 5.19(a) were used to estimate the cost charged by CSXT for a single car shipment, the cost per railcar on a 65-car unit train and on a 90-car unit train respectively. Likewise, Equations 4.21 and 4.25(a) were applied to evaluate the cost per railcar charged by BNSF for a single car shipment and for a 110 to 120-car unit train respectively.

The national average rates from Table 3.3, presented in CHAPTER III, were used to calculate truck transportation costs ($/truckload) as a function of the distance traveled. Rate differentiation was considered for shipments up to 25 miles, between 25 miles and

100 miles and between 100 miles and 200 miles, as defined by AMS. Based on these calculations, the cost per ton of grain was estimated considering that a semi truck is used for grain shipments. The semi truck was considered to have a cargo capacity of 26 tons.

Table 3.2, also presented in CHAPTER III, indicates that transportation costs for barge depend on the horsepower of the tow boat and distance traveled. According to the table, the cost associated with shipping one ton of grain form St. Louis to New Orleans using the most powerful tow boat (8,000 to 11,000 of horsepower) is $9.84/ton. This cost was picked in order to make a fair comparison among different transportation modes since barge movements are typically slower than truck and rail (For example, a total of 15 barges towed by a tow boat of 3,000 horsepower, travels 100 miles a day). Figure 5.1 and Figure 5.2 present the transportation costs per ton of grain for different distances and modes of transportation.

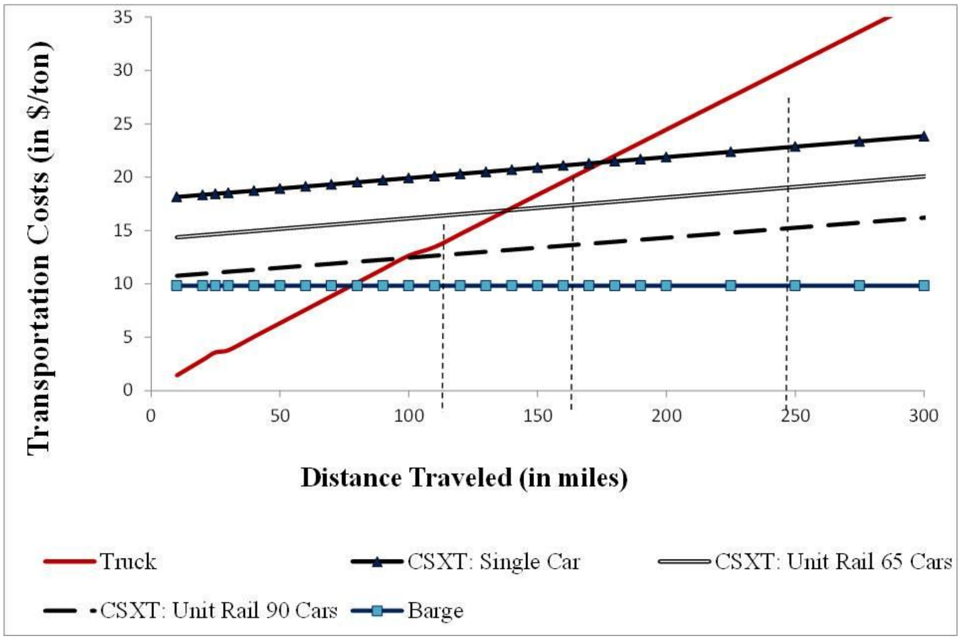

Figure 5.1 Transportation Costs as a Function of Distance Traveled: CSXT

The above table applies for shipments from the Midwest to the Southeast and East of the US.

Figure 5.1 indicates that for shipments from the Midwest to East of the US, for which barge is not an option, truck is the best mode of transportation for distances up to 100 miles. For longer travel distances, 90-car unit trains are more economical. However, when the volume shipped does not justify the use of a unit train, truck is the best alternative for transportation distances up to 175 miles. For longer distances, barge is the best option.

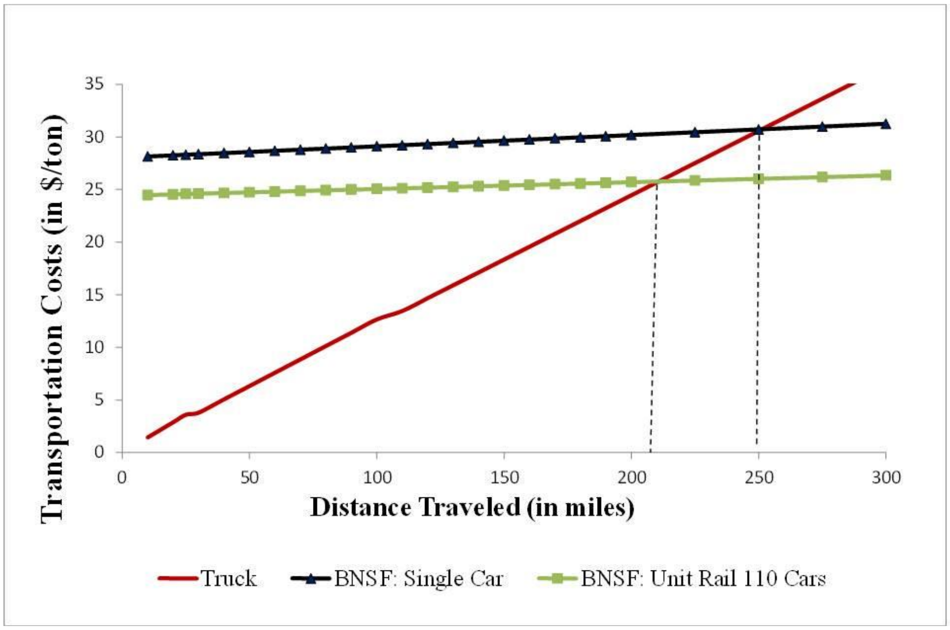

Figure 5.2 Transportation Costs as a Function of Distance Traveled: BNSF

The above table applies for shipments from the Midwest to the Southwest and West of the US.

Figure 5.2 indicates that for shipments from the Midwest to the West of the US, truck is the best mode of transportation for distances up to 210 miles. For longer travel distances, 110-car unit train shipments are more economical. If the volume shipped does not justify using unit trains, truck is the best alternative for transportation distances up to 250 miles. For longer distances, single railcar shipments of grain offer the best prices.

5.2 Transportation Cost Analysis Based on Distance and Volume

Transportation costs do depend not only on distance traveled, but also transportation volume. In order to analyze the impact of volume and distance on costs, several scenarios were created. Each scenario corresponds to a particular transportation volume. Table 5.1 presents the scenarios created. The scenarios were chosen in such a way that the volume shipped corresponds to a full truckload, a unit trail load or a full barge.

Table 5.1 Scenario Definitions

Scenario	Transportation Volume (tons)	Number of Trucks	Number of Railcars	Number of Barges
1	26	1	1	1
2	52	2	1	1
3	112	4	1	1
4	1,500	58	14	1
5	7,280	280	65	5
6	10,080	388	90	7
7	12,320	474	110	7
8	14,560	560	130	10
9	20,160	776	180	14
10	24,640	948	220	17

Table 5.2, Table 5.3 and Table 5.4 present the total transportation costs for each scenario using truck, rail and barge respectively. These costs are presented as a function of distance traveled. The distances used in the tables are close to the breakpoints identified in Figure 5.1, so that the reader can easily see the impact of transportation distances on costs. In these tables, the colored cells represent the minimum cost per scenario and distance traveled.

Table 5.2 Truck Costs from the Midwest to the East and Southeast

Sc.	Truck Distances (miles)					
	90	**120**	**150**	**200**	**673**	**1,039**
1	0.3	0.4	0.5	0.6	2.1	3.3
3	0.7	0.8	1.0	1.3	4.3	6.6
3	1.4	1.7	2.1	2.7	9.2	14.2
4	19.4	22.8	28.5	36.7	123.5	190.6
5	94.2	110.5	138.2	178.1	599.2	925.1
6	130.5	153.1	191.3	246.6	829.7	1,280.9
7	159.5	187.1	233.8	301.4	1,014.1	1,565.6
8	188.5	221.1	276.4	356.2	1,198.5	1,850.3
9	261.3	306.5	383.1	493.8	1,661.6	2,565.2
10	319.0	374.1	467.7	602.7	2,028.2	3,131.2

Table 5.2 illustrates that for every case were the traveled distance is of 90 miles or less, truck is always the best option. In the case were the traveled distance is between 90 and 120 miles, truck is most economical only for Scenarios 1 through 5. At these distance range (90-120), rail transportation is most economical for scenarios 6 through 10 (Refer to Table 5.3). In the same way, for shipments with a travel distance between 120 and 150 miles, were the volume shipped is less than or equal to 1,500 tons (Scenarios 1 through 4), the best transportation mode is truck. But, at the same distance range and a tonnage greater than 1,500, rail transportation becomes more economical than truck (See Table 5.3). Table 5.2 also shows that truck is no longer the most economical option for shipments of more than 200 miles. Table 5.3 indicates that for distances traveled greater than 200 miles and tonnages shipped less than 1,500 tons (equivalent to a full barge), rail transportation is always a the most economical option.

Table 5.3 Rail Costs from the Midwest to the East and Southeast

Sc.	CSXT Distances (miles)					
	90	**120**	**150**	**200**	**673**	**1,039**
1	2.2	2.3	2.3	2.5	3.5	4.3
3	2.2	2.3	2.3	2.5	3.5	4.3
3	2.2	2.3	2.3	2.5	3.5	4.3
4	30.9	31.9	32.8	34.3	48.9	60.2
5	116.1	120.4	124.7	131.8	199.5	251.8
6	123.7	129.3	135.0	144.5	233.8	303.0
7	167.8	174.8	181.8	193.5	303.7	389.0
8	232.2	240.8	249.3	263.6	398.9	503.6
9	247.3	258.7	270.0	288.9	467.7	606.0
10	335.7	349.7	363.9	386.9	607.4	777.9

Table 5.4 Barge Costs from the Midwest to the East and Southeast

Sc.	Barge Distances (miles)	
	673	**1,039**
1	8.2	12.7
2	8.2	12.7
3	8.2	12.7
4	42.8	66.1
5	59.3	91.5
6	72.4	111.8
7	85.6	132.1
8	118.5	182.9
9	144.9	223.6
10	223.6	368.4

Table 5.4 indicates that shipments from the Midwest to the East and Southeast of the US with a traveled distance greater than 673 miles and a tonnage shipped greater than or equal to 1, 5000 tons, barge offers the most economical transportation rate.

Similarly, case scenario analysis was performed for shipments from the Midwest to the West and Southwest of the US. Table 5.5 and Table 5.6 represent the costs estimated for each scenario and for each distance traveled.

Table 5.5 Truck Costs from the Midwest to the West and Southwest

Sc.	Truck Distances (miles)					
	200	300	673	1039	1712	
1	0.7	1.0	2.2	3.4	5.6	
3	1.3	2.0	4.4	6.8	11.3	
3	2.7	4.1	9.2	14.2	23.4	
4	38.0	56.9	127.7	197.2	325.0	
5	184.2	276.4	620.0	957.1	1577.1	
6	255.1	382.7	858.4	1325.3	2183.7	
7	311.8	467.7	1049.2	1619.8	2668.9	
8	368.5	552.7	1239.9	1914.3	3154.2	
9	510.9	766.3	1719.0	2653.9	4373.0	
10	623.6	935.4	2098.4	3239.5	5337.9	

Table 5.6 Rail Costs from the Midwest to the West and Southwest

Sc.	BNSF Distances (miles)					
	200	300	673	1039	1712	
1	3.4	3.5	3.9	4.4	5.2	
2	3.4	3.5	3.9	4.4	5.2	
3	3.4	3.5	3.9	4.4	5.2	
4	47.3	49.0	55,3	61.4	72.7	
5	227.7	219.7	256.6	285.1	337.6	
6	304.2	315.0	355.3	394.8	467.5	
7	316.6	324.5	354.0	383.0	436.3	
8	384.2	394.5	433.0	470.8	540.2	
9	553.2	569.5	630.4	690.1	799.9	
10	633.2	649.0	708.1	766.1	872.7	

CHAPTER VI

CONCLUSIONS

The study gave constructive insights about rail transportation tariffs for grain, which can easily be applied to the transportation of long hauls of densified biomass. The cost analyses showed the big difference in pricing rail tariffs between the western and eastern rail companies and how barge transportation affects eastern tariffs.

The regression equations presented in this study identify the main factors that impact the tariffs charged by railway companies for shipments of agricultural products with similar characteristics as densified biomass. Some of the most important factors identified are distance traveled quantity shipped, railcar ownership, service provider and shipment destination.

CSXT published different tariffs for railroad owned and shipper owned railcars. The analysis revealed an approximate rental charge of $600 per covered hopper (equipment used for grain loads) and $690 for hoppers or gondolas (equipment used for wood chip loads). A high reduction in price per covered hopper is observed for unit train shipments, approximately $190 per railcar. It is important to note that this rates are approximations based on the data collected. The fee for renting railcars may vary depending upon the equipment availability.

The study exposes lower rail tariffs when shippers have viable alternatives than when shippers are in captivity. Furthermore, the analysis suggested that tariffs show a higher impact with barge competitors within a 100 mile radius from the origin and 150 mile radius from the destination point. Hence, competition at the destination locations negatively affect tariffs more than competition at the origins do.

The analysis revealed that rail tariffs charged by BNSF and CSXT are in general higher when traveling from the Midwest to the Southeast and Southwest of the US than when shipping grain from the Midwest to the Northeast and Northwest of the US.

The regression analysis in this study concludes that the distance from origin to destination point, the route taken, railcar ownership, origin and destination proximity to competitors, railcar capacity, and the number of cars shipped at once and the directed market at the destination point can all represent approximately 80% of the rail tariff prices. The rail cost equations developed could be applied to mathematical models to optimize the implementation of an expanding commodity-based biomass supply.

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APPENDIX A

PRACTICAL DAILY TRAIN CAPACITY

Note that the capacity of ABS signaled lines is half of the capacity of CTC signaled lines. The lines with main track authority type MAN have 32% of the capacity of CTC signaled lines. Double track lines have triple the capacity of similarly configured single track CTC lines. For passing siding spacing, doubling the siding spacing reduces the physical capacity by 40% .

Table A.1 Practical Daily Train Capacity

Terrain	**Tracks**	**Siding/crossing occurrence**	**CTC**	**ABS**	**MAN**
Flat	1	Under 10 miles	60	30	19
Flat	1	Between 10 and 20 miles	36	18	12
Flat	1	Over 20 miles	22	11	7
Hilly	1	Under 10 miles	50	26	16
Hilly	1	Between 10 and 20 miles	30	15	10
Hilly	1	Over 20 miles	18	9	6
Mountainous	1	Under 10 miles	48	24	15
Mountainous	1	Between 10 and 20 miles	29	14	9
Mountainous	1	Over 20 miles	17	9	5
Flat	2	Under 10 miles	181	90	58
Flat	2	Between 10 and 20 miles	108	54	35
Flat	2	Over 20 miles	65	32	21
Hilly	2	Under 10 miles	151	76	48
Hilly	2	Between 10 and 20 miles	91	45	29
Hilly	2	Over 20 miles	54	27	17
Mountainous	2	Under 10 miles	143	71	46
Mountainous	2	Between 10 and 20 miles	86	43	27
Mountainous	2	Over 20 miles	51	26	16
Flat	3	Under 10 miles	301	151	96
Flat	3	Between 10 and 20 miles	181	90	58
Hilly	3	Under 10 miles	252	126	81
Hilly	3	Between 10 and 20 miles	151	76	48
Mountainous	3	Under 10 miles	238	119	76
Mountainous	3	Between 10 and 20 miles	143	71	46
Flat	4	Under 10 miles	452	226	145
Hilly	4	Under 10 miles	378	189	121
Mountainous	4	Under 10 miles	357	179	114
Flat	5 or 6	Under 10 miles	587	294	188
Hilly	5 or 6	Under 10 miles	491	246	157
Mountainous	5 or 6	Under 10 miles	464	232	149

APPENDIX B

DETAILED DEPOT TO TERMINAL ASSGINMENT PROGRESS

The table below represents the cardinalities of sets I and A used for assigning depots to terminals with the heuristic approach. The first column indicates the maximum average distance considered at each step and column two specifies the number of closest rail stations to a depot considered in every instance. Columns three and four indicate the number of depots left to be assigned to a terminal and the number of depots with a terminal assignment respectively.

Table B.1 Detailed Depot to Terminal Heuristic Approach

Max Average Distance	Number of Rail Stations	Unassigned Depots	Assigned Depots
-	-	2035	0
20	1	1991	44
20	20	1608	427
20	40	1529	506
20	60	1498	537
20	80	1498	537
20	100	1498	537
30	20	1332	703
30	40	1148	887
30	60	1055	980
30	80	1045	990
30	100	1024	1011
40	20	1005	1030
40	40	967	1068
40	60	908	1127
40	80	838	1197
40	100	789	1246
50	20	789	1246
50	40	789	1246
50	60	766	1269
50	80	762	1273
50	100	716	1319
50	120	699	1336
50	140	670	1365
50	160	657	1378
50	180	652	1383
50	200	623	1412

Table B.1 (Continued)

50	220	614	1421
50	240	614	1421
50	260	614	1421
50	280	606	1429
50	300	606	1429
60	100	567	1486
60	200	474	1561
60	300	434	1601
60	400	434	1601
60	500	434	1601
70	100	425	1610
70	200	407	1628
70	300	369	1666
70	400	343	1692
70	500	326	1709
80	100	326	1709
80	200	313	1722
80	300	292	1743
80	400	292	1743
80	500	292	1743
90	100	292	1743
90	200	272	1763
90	300	246	1789
90	400	246	1789
90	500	211	1824
100	100	211	1824
100	200	211	1824
100	300	211	1824
100	400	211	1824
100	500	211	1824