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Estimating the variable cost for high-volume and long-haul transportation of densified biomass and biofuel

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ABSTRACT

This article analyzes rail transportation costs of products that have similar physical properties as densified biomass and biofuel. The results of this cost analysis are useful to understand the relationship and quantify the impact of a number of factors on rail transportation costs of denisfied biomass and biofuel. These results will be beneficial and help evaluate the economic feasibility of high-volume and long-haul transportation of biomass and biofuel. High-volume and long-haul rail transportation of biomass is a viable transportation option for biofuel plants, and for coal plants which consider biomass co-firing. Using rail optimizes costs, and optimizes greenhouse gas (GHG) emissions due to transportation. Increasing bioenergy production would consequently result in lower GHG emissions due to displacing fossil fuels. To estimate rail transportation costs we use the carload waybill data, provided by Department of Transportation's Surface Transportation Board for products such as grain and liquid type commodities for 2009 and 2011. We used regression analysis to quantify the relationship between variable transportation unit cost ($/ton) and car type, shipment size, rail movement type, commodity type, etc. The results indicate that: (a) transportation costs for liquid is $2.26/ton–$5.45/ton higher than grain type commodity; (b) transportation costs in 2011 were $1.68/ton–$5.59/ton higher than 2009; (c) transportation costs for single car shipments are $3.6/ton–$6.68/ton higher than transportation costs for multiple car shipments of grains; (d) transportation costs for multiple car shipments are $8.9/ton and $17.15/ton higher than transportation costs for unit train shipments of grains.

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Introduction

Fossil fuels, such as oil, coal and natural gas currently represent the prime source of GHG emissions in the world. The increasing energy demand, coupled with increasing concerns over global warming, have resulted in an increased interest in a variety of renewable energy resources (RES) such as biomass, solar, and wind. United States Department of Energy (2006) has identified biofuels as one of the energy sources in the USA that will reduce nation's dependency on fossil fuels, thereby having a positive impact on the environment, and economy. A variety of biomass feedstocks are presently used to produce biofuel and electricity. According to EIA, biomass contributes nearly 3.9 quadrillion British thermal units (BTU) and accounts for more than 4% of total US primary energy consumption (EIA, 2010a). Over the last 30 years, the share of biomass

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in the total primary energy consumption has averaged less than 3.5% (EIA, 2010a). The US federal government passed the Energy Independence and Security Act (2007) to increase the share of biomass in the total energy production. The Act specifically calls for US production of liquid transportation biofuels to increase to more than 136 billion liters annually by 2022, with approximately 76 billion liters coming from non-cornstarch feedstock. Additionally, a number of policies and incentives at the Federal and State level are expected to increase generation of electricity from renewable resources, such as using biomass for co-firing. A recent study by Roni et al. (in press) shows that a 10% biomass co-firing in coal fired power plant would result in 81–96 Million Ton reductions in CO_2 emissions. Policies at the Federal level – such as, the renewable energy production tax credit (PTC) – provide an income tax credit of 2.2 cents/kilowatt-hour. The Annual Energy Outlook (EIA, 2013) projects that electricity production from biomass will increase from 37.26 billion kilowatt-hours in 2011 to 131.89 billion kilowatt-hours in 2040 (see Fig. 1).

It is expected that bioenergy production will increase in the near future due to the policies and incentives listed above. Fig. 1a. shows that ethanol production has continuously increased in the recent years mainly due to the RFS requirements. Fig. 1b. presents the current amount of electricity generated through biomass co-firing, as well as, the expected increase of electricity generation in the next few years.

Investors in second-generation biofuels will face decisions related to biorefinery locations and supply chain design. These decisions are not easy since they are subject to a number of factors, such as proximity to biomass resources, transportation costs, and railway accessibility. In the past, corn-based biofuel plants were typically located within 50 miles radius of their supply in order to minimize in-bound transportation costs (Aden et al., 2002). Consequently, the size of these plants was limited by the amount of biomass within this radius. Physical characteristics of lingocellulosic biomass and geographical factors represent a serious limitation to bioenergy supply-chain dynamics. Identifying the factors that impact rail transportation costs of biomass, and quantifying the impact of these factors on unit transportation costs is important because this knowledge allows biorefineries and coal plants to plan ahead and better design and manage their supply chains.

Biomass, in the form of agricultural and forest waste, has low density and poor flowability properties, and thus, it is bulky, heterogeneous, and unstable. In addition, biomass suppliers are typically small or medium sized farms, which are widely dispersed geographically. For these reasons, processes such as loading, unloading and transportation of biomass are challenging and expensive. Recent reports published by the Idaho National Laboratory (INL) propose a commodity-based, advanced biomass supply chain design concept to support the large-scale production of biofuels (Hess et al., 2009; Searcy and Hess, 2010). This system relies on densifying biomass at local preprocessing facilities before delivering to a biorefinery and before long distance transportation. Densified biomass refers to biomass that has undergone preprocessing to increase the bulk density of the material, such as pelletization, briquetting. When we use the term densified biomass in this paper, we refer to pellets of size less than 3/16 in. which follows the target size specifications for the biochemical conversion process design under development by National Renewable Energy Laboratory (Tumuluru et al., 2010, 2011). Densifying transforms biomass into a stable, dense, and flowable commodity. This conversion makes the feedstock easier to load and unload on

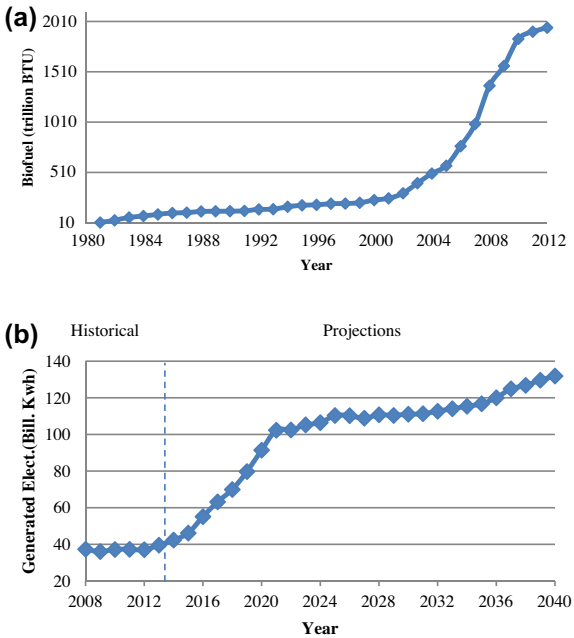

Fig. 1. (a) Historical data about biofuel consumption in the USA during 1980–2012 and (b) projections on electricity generation through biomass co-firing during 2014–2040 (EIA, 2013).

transportation vehicles, and cheaper to transport. Densified biomass is also easier to store. Therefore, biofuel plant locations are not limited to the agricultural regions where feedstock is most abundant. Instead, these plants have now the option to select locations which optimize system-wise costs (Argo et al., 2013). While energy and costs required to densify biomass are high (Miao et al., 2011, 2013a,b), these costs can be offset by decreased transportation costs, decreased storage space, and reduced capital costs for the biorefinery due to more efficient biomass feeding systems. Additionally, because biomass feedstock can be purchased from more distant areas, biorefineries can be of large production capacity and gain from economies of scale in production (Argo et al., 2013).

Thus, under these advanced supply system designs, using high capacity transportation for long-hauls becomes an option worth investigating. The option of reducing long distance transportation costs by using high capacity transportation, such as rail, may be an incentive for biorefineries to increase the supply radius, and therefore increase the production capacity. This in return will increase biomass availability and reduce feedstock supply risk. A study by Argo et al. (2013) argues that, if the capacity of a biorefinery plant using densified corn stover is between 5000 and 10,000 dry metric tons (DMT) per day, then, the resulting minimum ethanol selling price could be $2.25–$2.40 per gallon. Such a facility would be receiving 75–150 truck shipments of biomass daily, or equivalently, 30–60 rail cars daily. This implies that high-volume transportation modes, such as rail, would be a viable and beneficial option to deliver biomass to biorefineries of high production capacity. A positive side effect of using rail is improved highway safety due to shifting the traffic from roads to railroads. Additionally, GHG emissions due to transportation are order of magnitude lower for rail as compared to truck transportation. Table 1 presents emissions of different greenhouse gases in lbs per ton-mile (Tennessee-Tombigbee Waterway, 2014).

The transportation-related challenges that biorefineries face are also due to the outbound transportation of biofuel. For example, the pipeline system which is in place for transportation of fossil fuel cannot be used to transport ethanol due to its corrosive properties, among other reasons. Additionally, the distribution of population and the distribution of biomass in the USA do not overlap. The majority of the population lives in the East and West USA but the majority of the biomass is available mainly in the Midwest and South USA (see Fig. 2). For example, 12% of the nation's population lives in California, but only 0.59% of the available biomass for the production of biofuels is located in California. About, 0.97% of the country's population lives in Iowa, but, 13% of biomass is available in Iowa (Cen, 2010; KDF, 2012). Therefore, either biomass or biofuel will have to be shipped long distance to reach its customers. Moreover, regulations and policies at the State level may inspire the requisition of biomass from other states which have higher biomass supply. For example, California's renewable portfolio standards (RPS), one of the most ambitious RPS in the country, require that investor-owned utilities, electric service providers, and community choice aggregators increase procurement from eligible renewable energy resources to 33% of total procurement by 2020. This, and similar policies, will inspire California to purchase biomass/biofuel from other states that have these resources. As of January 2012, 30 States and the District of Columbia have enforceable RPS or other mandated renewable capacity policies (EIA, 2013).

This paper makes two important contributions to the literature. First, this paper uses actual data from the carload waybill data – provided by Department of Transportation's Surface Transportation Board – in order to estimate rail transportation costs (STB, 2013). The paper uses the corresponding datasets for products such as grain and liquid type commodities for 2009 and 2011. Since at the moment denisfied biomass is not delivered using rail, we could not collect such a data. Therefore, we use data about grain type commodity (barley, corn, oats, rice, and grain) instead since the physical characteristics of these products are the same as densified biomass. Liquid type commodities are products such as, crude petroleum; natural gas or gasoline; and byproducts of petroleum refining, paving or roofing materials. That is the reason why we use this data to estimate variable transportation costs for biofuels.

Since railways are privately owned companies, there is not much publicly available data related to transportation costs. Some Class I companies, such as, CSXT Corporation and Burlington Northern Santa Fe Corporation (BNSF) provide in their websites tariffs charged for a number of origin–destination shipments. These rail tariffs, although give some insights about the factors that impact rail transportation costs, do not tell the whole story. First, the tariffs posted on these websites are subject to negotiations. Second, the tariffs are composed of transportation costs and profit margins. On the other side, the carload waybill data is a stratified sample of carload waybills for all US rail traffic submitted by those rail carriers terminating 4500 or more revenue carloads annually. We used regression analysis to quantify the relationship between variable transportation unit cost ($/ton) and car type, shipment size, rail movement type, commodity type, etc.

The second contribution of this paper is the fact that it estimates the rail transportation costs of products with similar physical characteristics to densified biomass and biofuel. The results of this cost analysis are useful to understand the relationship and quantify the impact of a number of factors to rail transportation costs of denisfied biomass and biofuel. Ultimately, these results will be beneficial and help evaluate the economic feasibility of high-volume and long-haul transportation of biomass and biofuel. High-volume and long-haul transportation of these products by rail is a viable

Table 1
GHG emissions by mode of transportation.

Mode of transportation	Hydrocarbons (lbs/ton-mile)	Carbon Monoxide (lbs/ton-mile)	Nitrous Oxide (lbs/ton-mile)
Train	0.0046	0.0064	0.0183
Truck	0.0063	0.0190	0.1017

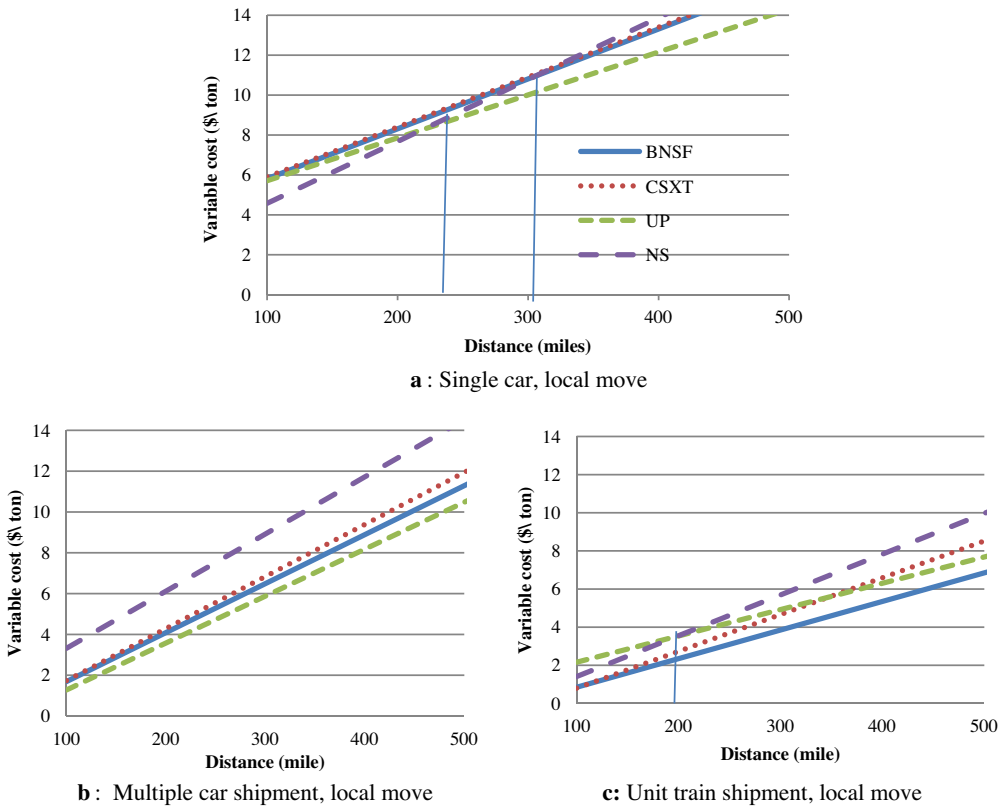

Fig. 2. Relationship between distance and unit transportation cost ($/ton) for grain type commodities.

in-bound and out-bound transportation option for high capacity biofuel production plants. High-volume and long-haul rail transportation of biomass is also a viable transportation option for coal plants which consider biomass co-firing.

The results of this analysis are useful to bioenergy investors and policy makers. From an investors point of view, understanding the impact that shipment size (unit train versus single car shipment), movement type (local versus forwarded or received move), railway ownership, and railcar ownership have on variable unit cost help make better decisions with respect to facility location, in-bound and out-bound logistics management. Variable costs do impact the tariffs charged by railway companies. Investors can leverage the knowledge gained from this discussion of rail cost to successfully negotiate tariffs charged by railway companies. Policy maker, such as officials at the US Department of Energy (DOE), rely on logistics models developed by researchers at the DOE laboratories in order to formulate policies and incentives similar to the ones listed in the beginning of this chapter. For example, the Idaho National Laboratory has developed the Biomass Logistics Model (BLM) to estimate logistics costs of biomass and biofuels (Jacobson and Searcy, 2010). The regression equations we propose in this paper can be incorporated with BLM to provide accurate estimates of rail transportation costs for high-volume and long-haul biomass transportation.

There is vast literature in the area biomass supply chain and logistics management. Miao et al. (2013a,b) present an overview of the costs and processes involved with lignocellulosic biomass feedstock harvesting, processing and delivery to biofuel plants. A number of recent works present deterministic facility location and transportation planning models for the biofuel supply chain (Eksioglu et al., 2009; Parker et al., 2010; Bai et al., 2011; Kim et al., 2011; Papapostolou et al., 2011). Other works present stochastic location–transportation models in order to capture the impacts of biomass supply uncertainty on biofuel supply chain performance (Cundiff et al., 1997; Huang et al., 2010; Kim et al., 2011; Chen and Fan, 2012; Gebreslassie et al., 2012). Multi-objective optimization models have also been proposed in order to capture the impact of biofuel production on costs, society and environment (Zamboni et al., 2009; Perimenis et al., 2011; Mele et al., 2009; You and Wang, 2011; You et al., 2012). Miao et al. (2012) review the implications that using different transportation modes have on supply chain and logistics management of various types of energy crops. The existing literature analyzes truck transportation cost for densified biomass when in the form of pellets, cubs and bales (Badger and Fransham, 2006; Rogers and Brammer, 2009). Other studies analyze pipeline transportation of lignocellulosic biomass (Searcy et al., 2007; Ileleji et al., 2010; Judd et al., 2011). Rail transportation of biomass is discussed in Mahmudi and Flynn (2006); Searcy et al., (2007); Bonilla and Whittaker (2009), Sokhansanj et al. (2009), Ileleji et al. (2010), Judd et al. (2011). These rail transportation-related studies mainly discuss distance-based fuel costs and loading/unloading costs per ton of biomass.

However, factors such as railway ownership, shipment volume, and type of rail movements – just to name a few – are not taken into consideration. Gonzales et al. (2013) provides a transportation cost analysis for densified biomass feedstock using the publicly available data. Thus, the work by Gonzales et al. (2013) is closely related to this paper. Different from Gonzales et al. (2013), this paper uses a different dataset, and considers in the analysis additional factors such as, type of rail movement, and provides a more detailed analysis about shipment volumes.

Background of rail transportation costs

The majority of US rail transportation is handled by four Class I railway companies. In the East these companies are Norfolk Southern (NS) and CSXT Corporation, and in the West BNSF and Union Pacific Railroad Company (UP) (CBO, 2006). Rail transportation cost per ton per mile is lower than truck transportation cost. A study by Mahmudi and Flynn (2006) indicates that for straw, rail transportation is more economical than truck transportation when the distance traveled is longer than 105 miles. For wood chips, rail transportation becomes more economical when the distance traveled is longer than 90 miles. Therefore, rail is preferable for long distance and high-volume shipments of bulk products, such as agricultural products. Rail companies offer lower tariffs for aggregate shipments to improve the productivity of rail lines, as 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. These incentives encourage shippers to use shuttle and unit trains. However, a unit train cannot be loaded and unloaded at every rail ramp, and infrastructural changes are required to meet operational needs. Usually, the infrastructure necessary to operate a unit rail is built by blenders, refiners, and third-party providers. Infrastructure developments are typically slow due to the high investment requirements and the long process of securing construction permits. Meeting the requirements set by Renewable Fuel Standard (RFS) (EPA, 2012) will increase the flow of biomass to biorefineries and the flow of biofuels to markets, and companies could take advantage of the existing railway infrastructure. However, an increase in the number of unit train origins and destinations will still be necessary to facilitate the increased flow in railways.

Estimating rail movement costs of freight rail is inherently more complex than estimating costs for trucking, as rail has more factors to consider. The most influential factors that affect the cost of rail movements are the distance traveled by the train. Another factor is line haul movement costs, which includes the expenses for train crews, train operations, locomotives, roadway maintenance and some clerical operations. Next, a major portion of rail cost is associated with switching activities. Switching activities include industry, interchange, inter-train, and intra-train switching. An industry switch represents a rail movement from an origin to a destination of a rail company, while an interchange switch represents a switch event between two railroad lines. An intra-terminal switch is the moving of rail cars from one place to another on the same railroad line and within the switching limits of one station and an inter-terminal switch is still contained within a single terminal area but requires an interchange between railroads. The cost of these switching services depends on the switch engine minutes.

The next major portion of the cost related to rail car movement is due to the freight car cost. Generally, the freight car cost is computed as a product of mileage and time charges. These costs are also a function of railcar ownership. Railroad owned cars receive an accessorial service cost. For privately owned cars, freight car costs are based only on mileage. The mileage costs for railroad owned cars depend on the car-miles running and the car-miles in switching services. Time costs depend on car-days running and car-days in switching services. The days in switching depend on the total car-days for all classes of switching services required by the shipment. Other cost components of rail movements are special service costs, motor vehicle unit loading and unloading costs, refrigerated car protective services, loss and damage claim payments, and intermodal special service costs.

At present, one can estimate the cost of rail movements by using existing rate arrangements between railroads and shippers for the movement of commodities. There are two types of rate arrangements: rail contracts and rail tariffs. Under rail contracts a price is negotiated between shippers and the railroad. This rate depends on the service provided, quantity shipped and commodity type. Rail tariffs are published by carriers showing applicable rates, rules, regulations governing service, routings, special services, demurrage, commodity definitions and price definitions. For example CSXT's price lists contain detailed shipment conditions and rail prices, by price authority, for any move on CSX (CSXT price list, 2013).

Data input

We used railroad way bill data to identify important cost factors that impact major Class 1 rail road movements and to quantify the impact of each factor. The waybill sample is a stratified sample of carload waybills for all US rail traffic submitted by those rail carriers generating 4500 or more revenue carloads annually. Rail waybill is a primary means of gathering information about freight rail shipments terminated in the US. A number of organizations, such as the Department of Transportation (DOT), the Department of Agriculture (DOA) and industry stakeholders used waybill to monitor traffic flows and rate trends in the industry. The DOT use this information for states when developing state transportation plans. The DOA uses the rail waybill to quantify transportation cost of agricultural products. The data contained in the waybill sample is considered as confidential propriety information because it contains sensitive revenue information. Therefore, we do not present raw data, rather only summarize the results from our analysis. Rail waybill 2009 and 2011 contain 518,607 and 599,588 samples, respectively. Rail waybill has 238 data fields. The major data fields used for this study are listed in Appendix A.

Variable cost given in the rail waybill data was calculated using The Universal Railroad Costing System (URCS). URCS produces average variable costs for Class I railroads using railroad specific accounting and operating data. Costs for local and regional railroads use URCS regional data. Multiple car and unit train cost reductions were applied at URCS to reflect economics of scale. The details of the URCS procedure can be found at the Surface Transportation Board Railway Cost Program (2013).

Regression analysis

We use a stepwise regression method (Draper and Smith, 1998) to identify and quantify the impact of a number of factors on the rail movement costs. Stepwise regression is a systematic method for adding and removing variables from a multi-linear model based on their statistical significance in the regression. Stepwise regression adds one independent variable at a time to the model until the addition of another variable does not make a significant partial contribution to predicting the dependent variable y. At each step, the variable added is the one that is most significant, in other words, the variable with the smallest P-value. For quantitative predictors, this is the variable with the largest t test statistic, or equivalently the one providing the greatest increase in the value of the adjusted R^2.

This analysis is focused on shipments by NS, CSXT, BNSF and UP which are the four major Class I railway companies in the USA (CBO, 2006). We also analyze international shipments of grains and liquids to and from Canada and Mexico. Three different shipment sizes are considered for each rail movement: (a) Single car, which represents the movement of one to five railcars; (b) Multiple cars, which represents the movement of six to forty-nine railcars tendered under one waybill; and (c) Unit train, which represents the movement of fifty or more railcars. Four types of movements are considered in the analysis: (a) Local move, which indicates that a single railway moves the shipment from its origin to its destination; (b) Forwarded move, which indicates that this railway originates the shipment from its origin, but it will deliver it to another railway; (c) Overhead move, which indicates that this railway receives the shipment from one railway, and will deliver it to another railway; and (d) Received move, which indicates that this railway receives the shipment from another railway, and it will deliver the shipment to its destination.

This paper analyzes transportation costs for feed grains, petroleum fuels, and liquefied gases since these commodities have similar physical characteristics to densified biomass feedstock and biofuels. Therefore, estimates of logistics-related costs for these products are a good representation of logistics-related costs which would occur when shipping biomass and biofuels. The rail waybill data presents the variable cost for each rail waybill sample. This variable cost depends on the product type, distance between shipment origin and destination, type of railcar used, railcar capacity, railcar ownership, shipment size and type of rail movements. We retrieve rail movement data from the rail waybill, and group this data based on the factors listed above. Next, we generate a number of regression equations to get an understanding of how these factors impact rail transportation costs. The dependable variable in these equations, denoted by y, is the variable cost (in \$/ton) listed in the waybill. The independent variables are listed in Table 2.

Estimating rail transportation costs of grain type commodity

The Standard Transportation Commodity Code (STCC) for grain type commodity starts with 113. The following is a list of products under this code: barley, corn, oats, rice, and grain. Covered hoppers are typically used to transport these commodities. Therefore, the type of rail car for all the regression equations developed is a covered hopper. The data reveals that there is no overhead move for grain type commodity. Therefore, regression equations are not developed for overhead moves.

The regression equations developed for grain type commodity are presented in Tables B.1–B.8 of Appendix B. These equations present the relationship among variable unit cost, transportation distance and car ownership for shipments of different sizes and move types.

Regression analysis of international shipment

The Canadian National Railway Company (CN) is a Canadian Class I railway that serves Canada and the Midwestern and Southern US. Tables B.9 and B.13 in Appendix B summarize the regression equations developed using 2009 and 2011 rail waybill datasets. Some local move shipments by CN do cross the Canada-US borders, and other shipments do not. The waybill data presents separately the information about the unit transportation cost for grain type commodity when CN serves US or Canada. Thus, we develop regression equations which represent variable costs of CN for both operations. Forwarded moves, on the other side, always originate in Canada. For these moves, the waybill does not provide separate information about US and Canada operations. The waybill does not include data about unit train shipments for grain type commodity.

The Kansas City Southern Railway (KCS) Company serves the Central and South Central US. Its international holdings, Kansas City Southern de Mexico (KCSM), serve North Eastern Mexico. For this reason, the transportation costs for grain type commodity are separated into costs for shipments that use routes along KCSM and KCS lines. The waybill did not provide data about single car shipments of KCS. This is the reason why we do not present regression equations for single car shipments. Tables B.11 and B.12 in Appendix B summarize the regression equations developed for KCSM using the 2009 and 2011 rail waybills, respectively.

Table 2
Variable definition.

Dependent Variables	
y_{BNSF}	Variable cost (in \$/ton) for BNSF
y_{CSXT}	Variable cost (in \$/ton) for CSXT
y_{NS}	Variable cost (in \$/ton) for NS
y_{UP}	Variable cost (in \$/ton) for UP
y_{CN}	Variable cost (in \$/ton) for CN
y_{CNUS}	Variable cost (in \$/ton) for CNUS
y_{KCS}	Variable cost (in \$/ton) for KCS
y_{KCSM}	Variable cost (in \$/ton) for KCSM
Independent variables	
x_1	Distance between the shipment origin and its destination (miles)
x_2	Indicator variable which equals 1 if the railcar used is owned by the railway company, and equals 0 o/w
x_3	Indicator variable which equals 1 for forwarded moves, and equals 0 o/w
x_4	Indicator variable which equals 1 for 2011 data, and equals 0 for 2009 data
x_5	Indicator variable which equals 1 for received moves, and equals 0 o/w
x_6	Indicator variable which equals 1 for liquid commodity types, and equals 0 o/w
x_7	Indicator variable which equals 1 for multiple cars, and equals 0 for single car shipments
x_8	Indicator variable which equals 1 for unit train, and equals 0 for single car shipments
x_9	Indicator variable which equals 1 for single car shipments by CNUS, and equals 0 for single car shipments by CN
x_{10}	Indicator variable which equals 1 for multiple car shipments by KCS, and equals 0 for multiple car shipments by KCSM
x_{11}	Indicator variable which equals 1 if the cost data for single car local moves comes from rail tariffs available at CSXT website, and equals 0 if the data comes from the waybill
x_{12}	Indicator variable which equals 1 if the cost data for unit train local moves comes from rail tariffs available at CSXT website, and equals 0 if the data comes from the waybill
x_{13}	Indicator variable which equals 1 if the cost data for unit train local moves comes from rail tariffs available at BNSF website, and equals 0 if the data comes from the waybill
x_{14}	Indicator variable which equals 1 if the rail company serves West, and equals 0 if the rail company serves East USA

Estimating rail transportation cost of bulk liquid type commodity

Bulk liquids are commodities whose STCC code on the waybill starts with 29 or 13. These commodities are crude petroleum; natural gas or gasoline; and byproducts of petroleum refining, paving or roofing materials. The size of the dataset for rail movements of bulk liquid products is smaller as compared to grain products. In 2009 waybill, bulk liquid products data represented only 1% of the overall dataset. The size of this dataset increased to 1.21% in the 2011 waybill. The type of cars which are typically used for shipping liquid type commodity are tank cars with a capacity less than 22,000 gallons, tank cars with a capacity of 22,000 gallons and over, open top hopper cars used for special services, open top hopper cars used for general services, and plain gondola cars. The waybill reveals that tank cars of capacity in excess of 22,000 gallons are owned by private companies. On the other side, open top hopper cars used for special services are owned by the railway company. Thus, in the resulting regression equations we do not include the independent variable x_2. These waybills present no data about unit train shipment of liquid type products.

The results from the regression analysis of liquid type commodities are summarized in Tables B.13–B.20. The equations listed in these tables represent the relationship between variable unit cost and railway distance for different move types, shipments size, car type and railcar ownership. Due to the limited number of observations for certain types of shipment size and moves, we did not develop corresponding equations. That is the reason why some of the tables miss equations for forwarded moves, or multiple car shipments.

Discussion of results

We list some important observations made from the regression analysis. These observations reveal important characteristics of current rail transportation costs in the US. The value of adjusted R^2 for the equations listed below (other than Eqs. (21) and (22)) ranges between 92% and 100%. The corresponding *P*-values for the independent variables are almost zero.

Observation 1. The variable unit cost for NS is smallest for travel distances up to 230 miles for single car, local move of grains. For longer distances, UP is the least expensive transportation mode (see Fig. 2a) for grains. The results indicate that UP has the smallest variable unit cost per ton for multiple car shipments of local moves (Fig. 2b) of grains. BNSF has the smallest variable cost per ton for unit train shipments of local moves (Fig. 2c).

Observation 2. NS has the smallest variable unit cost for shipment of liquid type commodities for distances up to 420 miles. For longer distances, UP has the smallest variable unit cost. Fig. 3 presents the relationship between distance and unit transportation cost for single car local moves of liquids. Data about single car local moves represents 53% of the waybill data on liquid type commodities.

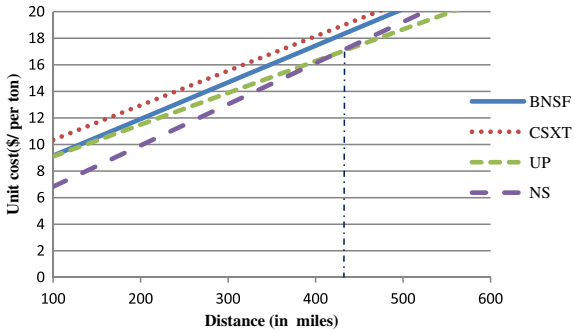

Fig. 3. Relationship between distance and unit transportation cost ($/ton) for liquid type commodities.

Observation 3. *Received and forwarded moves are typically less expensive than local moves*. The higher cost of local moves is due to the fact that a railway company handles the loading and unloading of these shipments. This is not the case for forwarded moves where the company handles only the loading of a shipment on a train; or received moves where the company handles only the unloading of a shipment from a train.

In order to quantify the difference in costs between *local and forwarded moves* we developed Eqs. (1) and (2). Eq. (1) corresponds to single car shipments and (2) corresponds to unit train shipments by BNSF in 2011.

$$y_{BNSF} = 3.58 + 0.025x_1 + 4.94x_2 - 3.28x_3 \tag{1}$$

$$y_{BNSF} = -.54 + 0.0154x_1 + 1.86x_2 - .203x_3 \tag{2}$$

The results support the claim that local moves are more expensive than forwarded moves. The difference in costs for single car movements is, on average, $3.28/ton. The difference in costs is small for unit trains.

In order to quantify the difference in costs between *local and received* moves we develop Eqs. (3)–(5) using the 2011 dataset. Eq. (3) is developed for single car shipments of CSXT. Eq. (4) is developed for single car shipments of UP; and (5) for unit train shipments of UP. The equation indicates that, on average, the unit cost for received moves is between $1.28/ton and $2.24/ton smaller as compared to local moves. We ran a similar regression for unit trains by CSXT, but variable x_5 was not found statistically significant. Due to the inadequate size of the dataset, we did not develop regression equations for received moves by NS.

$$y_{CSXT} = 3.43 + 0.0246x_1 + 4.73x_2 - 1.61x_5 \tag{3}$$

$$y_{UP} = 3.25 + 0.022x_1 + 7.57x_2 - 2.24x_5 \tag{4}$$

$$y_{UP} = .76 + 0.018x_1 + 3.75x_2 - 1.28x_5 \tag{5}$$

Observation 4. *Transportation costs for liquid type commodities are higher than grains*. Eqs. (6)–(9) are developed using 2011 waybill data for single car local moves. Recall that, for these moves of liquid type commodities, the waybill presents data only about privately owned, tank cars of capacity over 22,000 gallons. Thus, the data used in here corresponds to privately owned rail cars used for shipment of grains as well. The results indicate that the price difference between these two commodity types varies between $2.26/ton and $5.45/ton.

$$y_{BNSF} = 4.78 + .0236x_1 + 2.32x_6 \tag{6}$$

$$y_{CSXT} = 3.06 + .0254x_1 + 5.01x_6 \tag{7}$$

$$y_{UP} = 2.21 + .023x_1 + 5.45x_6 \tag{8}$$

$$y_{NS} = 1.72 + .031x_1 + 2.26x_6 \tag{9}$$

Observation 5. *Unit train shipments are cheaper than multiple and single car shipments, and multiple cars shipments are cheaper than single car shipments of grain type commodity*. In order to quantify the cost differences between single and multiple car shipments of local moves, we develop Eqs. (10)–(13). It is clear that multiple car shipments are less expensive. The average difference in costs varies between $3.6/ton and $6.68/ton depending on railway ownership.

$$y_{BNSF} = 4.71 + .0246x_1 + 4.087x_2 - 6.68x_7 \tag{10}$$

$$y_{CSXT} = 3.25 + .025x_1 + 4.12x_2 - 4.09x_7 \tag{11}$$

$$y_{UP} = 3.61 + .022x_1 + 6.89x_2 - 5.19x_7 \tag{12}$$

$$y_{NS} = 2.42 + .029x_1 + 4.6x_2 - 3.5x_7 \tag{13}$$

Similarly, Eqs. (14)–(17) are developed in order to quantify the difference in costs between single car and unit train shipments for local moves. The average difference in costs is between \$8.9/ton and \$17.15/ton depending on railway ownership.

$$y_{BNSF} = 10.72 + .0188x_1 + 3.66x_2 - 17.15x_8 \tag{14}$$

$$y_{BCSXT} = 5.12 + .023x_1 + 3.84x_2 - 9.9x_8 \tag{15}$$

$$y_{UP} = 9.34 + .017x_1 + 5.38x_2 - 13.85x_8 \tag{16}$$

$$y_{NS} = 4.88 + .025x_1 + 3.72x_2 - 8.95x_8 \tag{17}$$

Observation 6. *The variable cost for international shipments to Canada and Mexico is higher as compared to domestic rail shipments.* Eqs. (18) and (19) are developed for single car and multiple car shipments correspondingly. Both equations indicate that variable costs for CNUS are lower compared to CN.

$$y_{CNUS} = -1.37 + .03x_1 + 4.78x_2 - .52x_9 \tag{18}$$

$$y_{CNUS} = .028x_1 + 3.798x_2 - .89x_9 \tag{19}$$

Equation (20) is developed for multiple car shipments of grain along KCS and KCSM railways. Results indicate that the unit variable cost is \$0.37/ton smaller for KCS as compared to KCSM.

$$y_{KCS} = .67 + .023x_1 + 1.26x_2 - .37x_{10} \tag{20}$$

Observation 7. *Variable rail transportation costs have increased from 2009 to 2011*. The equations presented in Tables B.21 and B.22 of Appendix B support this observation. The increase on the variable unit costs varies between: \$1.7/ton and \$4.6/ton for single car, local moves of grains; \$1.4/ton–\$4.2/ton for unit trains, local moves of grains; and \$2.2/ton–\$5.6/ton for single car, local move of liquids. This increase is mainly due to the increase of fuel price. We collected retail prices for Diesel Ultra-Low Sulfur (0–15 ppm) for the period of 2007–2011 (EIA, 2013). Table 3 summarizes the mean, standard deviation and median of diesel price for 2009 and 2011. The retail price of diesel in 2011 is 1.55 times higher than in 2009.

Observation 8. *Rail tariff rates provided by BNSF and CSXT on their website are higher than the variable cost found from the carload waybill data.* This is due to fact that tariffs include investment cost and profit margins in addition to the variable cost. In order to quantify the difference between the rail tariffs posted in the CSXT website and the variable cost found from rail waybill, we developed the following equations. The value of the adjusted R^2 for Eq. (21) is 72% and (22) is 66%. The *P*-values for the independent variables are smaller than 0.01.

$$y_{CSXT} = 5.75 + .022x_1 + 3.23x_2 + 11.54x_{11} \tag{21}$$

$$y_{CSXT} = -2.044 + .022x_1 + 1.34x_2 + 15.3x_{12} \tag{22}$$

These equations indicate that the tariffs listed by CSXT for single car local moves are, on the average, \$11.54/ton higher than the variable cost for CSXT. For unit train local moves the corresponding difference is, on the average, \$15.3/ton. A similar analysis with BNSF (see Eq. (23)) indicates that the tariffs charged by BNSF are, on the average \$6.43/ton higher than the variable costs.

$$y_{BNSF} = 1.555 + .0152x_1 + 6.34x_{13} \tag{23}$$

Observation 9. *Shipments to West USA are less expensive as compared to shipments to the East USA*. Eqs. (24)–(27) correspond to local moves of grains on single cars (Eq. (24)), multiple cars (Eq. (25)), and unit trains (Eq. (26)). Eq. (27) represents

Table 3
The national mean, standard deviation and median price of diesel ultra-low sulfur (0–15 ppm) for 2009 and 2011 (EIA, 2013).

Year	Average	Standard deviation	Median
2009	2.52	0.24	2.59
2011	3.92	0.20	3.94

transportation costs of liquid type commodity. On the average, the unit cost for single car local moves to the West is \$0.89/ton cheaper as compared to single car local moves to the East. The unit cost for multiple car local moves to the West is \$3/ton cheaper; and the unit cost for unit train local moves is \$4.26/ton cheaper. Shipments of liquids follow the same trend. These differences in costs can be explained by the geospatial differences of East and West USA. West USA is flatter, thus, the same locomotive can pull a train with more cars to the West than East. For this reason the length of CSXT trains is typically 65–90 cars, and the length of BNSF trains is typically 110–120 cars. Train length impacts the variable unit cost since a longer train delivers more products in one trip.

$$y = 3.43 + .024x_1 + 6.16x_2 - .89x_{13} \tag{24}$$

$$y = 1.41 + .024x_1 + 4.10x_2 - 3.00x_{13} \tag{25}$$

$$y = 2.8 + .015x_1 + 2.66x_2 - 4.26x_{13} \tag{26}$$

$$y = 7.29 + .025x_1 - .61x_{13} \tag{27}$$

6. Conclusion

This article analyzes rail transportation costs of products such as grain and liquid type commodities. These products have similar physical properties as densified biomass and biofuel, and therefore, the equations developed can be used to estimate rail transportation costs for densified biomass and biofuel.

The results of this study are beneficial to and help evaluate the economic feasibility of high-volume and long-haul transportation of biomass and biofuel. High-volume and long-haul transportation of these products by rail is a viable in-bound and out-bound transportation option for high capacity bioenergy production plants. High-volume and long-haul rail transportation of biomass is also a viable transportation option for coal plants which consider biomass co-firing. Using rail not only optimize costs, but also optimize the GHG emissions due to transportation. Optimizing transportation costs of bioenergy production plants facilitates production of bioenergy. Increasing bioenergy production will consequently result in lower GHG emissions due to displacing fossil fuels.

This paper analyzes variable rail transportation costs for major Class I railway companies using the carload waybill dataset. This data is collected by Department of Transportation's Surface Transportation Board, and it is a stratified sample of carload waybills for all US rail traffic submitted by those rail carriers terminating 4500 or more revenue carloads annually. The paper uses the data corresponding to products such as grain and liquid type commodities for 2009 and 2011. The analysis relies on developing regression equations. These equations represent the relationship that exists between unit variable costs and transportation distance, railway ownership, railcar ownership, movement type, shipment size, etc. Some important observations made through this analysis are: (1) For local moves of grains: the unit variable cost of NS is smallest (as compared to other railway companies) for travel distances up to 230 miles. For longer distances, UP has the smallest unit variable cost. UP has the smallest unit variable cost for multiple car shipments. BNSF has the smallest variable unit cost for unit train shipments. (2) For single car local moves of liquids: NS has the smallest unit variable cost for distances less than 430 miles. For longer distances, UP has the smallest variable unit cost. (3) Received and forwarded moves are typically less expensive than local moves. (4) Transportation costs for liquid type commodities are higher than grains. (5) Unit train shipments are cheaper than multiple and single car shipments, and multiple cars shipments are cheaper than single car shipments of grain type commodity. (6) The unit variable cost for rail transportation within US is smaller as compared to shipments in Canada and Mexico. (7) Variable rail transportation costs have increased significantly from 2009 to 2011. (8) Rail tariff rates provided by BNSF and CSXT on their website are higher than the variable cost found from the carload waybill data. (9) Shipments to the West cost less than shipments to the East.

This paper contribution to the existing literature is twofold. First, this paper uses real data from the carload waybill. Since railways are privately owned companies, there is not much publicly available data related to transportation costs. Some Class I companies provide in their websites tariffs charged for a number of origin–destination shipments. These rail tariffs, although they give some insights about the factors that impact rail transportation costs, do not tell the whole story since they are subject to negotiations and they include profit margins. Second, this paper uses regression analysis to estimate rail transportation costs of products with similar physical characteristics to densified biomass and biofuel. These results are useful to bioenergy investors and policy makers. Investors can leverage the knowledge gained from this discussion of rail cost to successfully negotiate tariffs charged by railway companies. Policy makers can use these results to shape better policies and incentives to increase production and the use of bioenergy. The regression equations we propose in this paper can be incorporated into BLM to provide accurate estimates of rail transportation costs for high-volume and long-haul biomass transportation.

Appendix A. Major data fields used in the 2009 and 2011 waybill data acquired for the Surface Transportation Board

Name description:

Commodity Code (STCC)	The Standard Transportation Commodity Code (STCC) identifies the product designation for the commodity being transported
Number of Carloads	The total number of carloads on the sampled waybill
Billed Weight (CWT)	The total billed weight (in hundredweight) is the weight of the commodity being transported
Theoretical Expansion Factor	The theoretical expansion factor is the inverse of the sampling rate (Table 1)
Expanded Tons	The billed weight in tons multiplied by the expansion factor
Car Ownership	Alpha/numeric code which identifies the owner of the car: (R) railroad owned; (P) Privately Owned; (T) Trailer Train
Origin Railroad Alpha	Information about origin rail road
First-Sixth Interchange RR Alpha	Information about rail road between origin and destination
Termination Railroad Alpha	Information about termination rail road
First to seventh Railroad Distance	The actual distance traveled by the first carrier to seventh carrier in the route
STB Car Type	The STB car type is inferred from the AAR equipment type
Termination Railroad Distance	The actual distance traveled by the termination carrier in the route
Railroad 1–8 Variable Cost	The portion of the total variable cost for the first to eighth rail carrier in the route. Variable cost for all railroads in the waybill computed using the Uniform Railroad Costing System (URCS).
Origin Railroad Country Code	Country code for the origin railroad typically USA, Canada or Mexico
Termination Railroad Country Code	Country code for the termination railroad

Appendix B

See Tables B.1–B.22.

Table B.1
Regression equations of BNSF for grain type commodity, 2009.

Shipment Size	Move Type	Rail Cost Equation	Adjusted R^2 (%)	Sample Size	*P*-value
Single car	Local	$y_{BNSF} = 3.01 + 0.02x_1 + 5.52x_2$	96.0	764	0.03
	Forwarded	$y_{BNSF} = 4.05 + 0.016x_1 + 2.85x_2$	95.3	21	0.02
	Received	$y_{BNSF} = 2.50 + 0.0214x_1 + 3.55x_2$	97.0	146	0.03
Multiple car	Local	$y_{BNSF} = -.65 + 0.02x_1 + 2.58x_2$	98.7	1145	0.02
	Forwarded	$y_{BNSF} = .6 + 0.02x_1 + 1.372x_2$	99.5	48	0.01
	Received	$y_{BNSF} = .826 + 0.02x_1 + 1.06x_2$	99.5	55	0.01
Unit train	Local	$y_{BNSF} = -.471 + 0.012x_1 + 2.045x_2$	98.7	1298	0.01
	Forwarded	$y_{BNSF} = -1.276 + 0.0135x_1 + 1.71x_2$	97.1	55	0.02

Table B.2
Regression equations of BNSF for grain type commodity, 2011.

Shipment size	Move type	Rail cost equation	Adjusted R^2 (%)	Sample size	*P*-value
Single car	Local	$y_{BNSF} = 3.40 + 0.025x_1 + 5.11x_2$	98.8	614	0.01
	Forwarded	$y_{BNSF} = 5.14 + 0.019x_1 + 2.88x_2$	96.8	28	0.03
Multiple car	Local	$y_{BNSF} = -.71 + 0.024x_1 + 3.15x_2$	99.5	823	0.02
	Forwarded	$y_{BNSF} = 2.03 + 0.024x_1$	99.0	30	0.02
Unit train	Local	$y_{BNSF} = -.65 + 0.015x_1 + 1.96x_2$	99.7	1346	0.01
	Forwarded	$y_{BNSF} = .54 + 0.0152x_1 + .38x_2$	99.0	42	0.01

Table B.3
Regression equations of CSXT for grain type commodity, 2009.

Shipment size	Move type	Rail cost equation	Adjusted R^2 (%)	Sample size	*P*-value
Single car	Local	$y_{CSXT} = 3.14 + 0.0217x_1 + 3.618x_2$	92.5	261	0.01
	Received	$y_{CSXT} = 1.355 + 0.022x_1 + 5.1712x_2$	98.9	57	0.03
Multiple cars	Local	$y_{CSXT} = -1.01 + 0.026x_1 + 3.878x_2$	98.3	186	0.01
	Received	$y_{CSXT} = 0.022x_1 + 3.6234x_2$	98.8	21	0.05
Unit train	Local	$y_{CSXT} = -1.61 + 0.01783x_1 + 2.857x_2$	97.5	329	0.01
	Received	$y_{CSXT} = -1.68 + 0.018x_1 + 2.798x_2$	99.9	68	0.02

Table B.4
Regression equations of CSXT for grain type commodity, 2011.

Shipment size	Move type	Rail cost equation	Adjusted R^2 (%)	Sample size	*P*-value
Single car	Local	$y_{CSXT} = 3.31 + 0.025x_1 + 4.36x_2$	96.9	222	0.00
	Received	$y_{CSXT} = 2.89 + 0.023x_1 + 6.90x_2$	98.6	66	0.04
Multiple car	Local	$y_{CSXT} = -0.81 + 0.026x_1 + 3.84x_2$	99.0	206	0.04
Unit train	Local	$y_{CSXT} = -1.13 + 0.0194x_1 + 2.54x_2$	98.1	272	0.03
	Received	$y_{CSXT} = -1.03 + 0.019x_1 + 2.54x_2$	98.6	65	0.02

Table B.5
Regression equations of UP for grain type commodity, 2009.

Shipment size	Move type	Rail cost equation	Adjusted R^2 (%)	Sample size	*P*-value
Single car	Local	$y_{UP} = 3.47 + 0.019x_1 + 9.2x_2$	97.4	423	0.01
	Received	$y_{UP} = 2.84 + 0.021x_1 + 5.14x_2$	97.3	250	0.04
Multiple cars	Local	$y_{UP} = -1.67 + 0.021x_1 + 5.85x_2$	98.5	338	0.01
	Forwarded	$y_{UP} = -.64 + 0.021x_1 + 4.427x_2$	99.7	25	0.00
	Received	$y_{UP} = -1.75 + 0.021x_1 + 5.12x_2$	98.4	54	0.00
Unit train	Local	$y_{UP} = -.18 + 0.0123x_1 + 3.7x_2$	98.1	371	0.05
	Received	$y_{UP} = -.31 + 0.013x_1 + 1.99x_2$	98.8	67	0.01

Table B.6
Regression equations of UP for grain type commodity, 2011.

Shipment size	Move type	Rail cost equation	Adjusted R^2 (%)	Sample size	*P*-value
Single car	Local	$y_{UP} = 3.56 + 0.0215x_1 + 8.06x_2$	97.80	491	0.03
	Received	$y_{UP} = 1.89 + 0.0248x_1 + 4.6x_2$	97.8	171	0.02
Multiple cars	Local	$y_{UP} = -1.02 + 0.023x_1 + 4.93x_2$	98.7	374	0.02
	Received	$y_{UP} = 0.023x_1 + 3.81x_2$	99.1	23	0.02
Unit train	Local	$y_{UP} = .78 + 0.0138x_1 + 3.78x_2$	99.0	452	0.01
	Received	$y_{UP} = 0.0166x_1 + 2.22x_2$	98.1	16	0.02

Table B.7
Regression equations of NS for grain type commodity, 2009.

Shipment size	Move type	Rail cost equation	Adjusted R^2 (%)	Sample size	*P*-value
Single car	Local	$y_{NS} = 2.71 + 0.0228x_1 + 3.118x_2$	95.4	462	0.01
Multiple cars	Local	$y_{NS} = -.48423 + 0.024x_1 + 3.23x_2$	97.7	314	0.01
Unit train	Local	$y_{NS} = -.408 + 0.018x_1 + 2.10x_2$	99.0	287	0.00

Table B.8
Regression equations of NS for grain type commodity, 2011.

Shipment size	Move type	Rail cost equation	Adjusted R^2 (%)	Sample size	*P*-value
Single car	Local	$y_{NS} = 1.477 + 0.031x_1 + 3.8416x_2$	98.3	247	0.01
	Forwarded	$y_{NS} = 1.468 + 0.026x_1$	97.4	30	0.02
Multiple cars	Local	$y_{NS} = -.52 + 0.028x_1 + 4.66x_2$	98.7	347	0.01
Unit train	Local	$y_{NS} = -.7318 + 0.0214x_1 + 3.03x_2$	98.9	324	0.00

Table B.9
Regression equations of CN for grain type commodity, 2009.

Shipment size	Move type	Rail cost equation	Adjusted R^2 (%)	Sample size	*P*-value
Single car	Local	$y_{CN} = 0.023x_1 + 5.52x_2$	95.2	149	0.02
		$y_{CNUS} = 0.022x_1 + 5.45x_2$	98.8	136	0.01
	Forwarded	$y_{CN} = -1.20 + .023x_1 + 5.31x_2$	97.4	96	0.01
Multiple cars	Local	$y_{CN} = 0.018x_1 + 2.33x_2$	86.3	31	0.00
		$y_{CNUS} = 0.019x_1 + 2.97x_2$	92.1	30	0.00

Table B.10
Regression equations of CN for grain type commodity, 2011.

Shipment size	Move type	Rail cost equation	Adjusted R^2 (%)	Sample size	*P*-value
Single car	Local	$y_{CN} = -1.9 + 0.0311x_1 + 4.85x_2$	98.5	154	0.00
		$y_{CNUS} = -1.46 + 0.03x_1 + 4.6x_2$	97.6	154	0.00
	Forwarded	$y_{CN} = -2.14 + .029x_1 + 6.03x_2$	97.9	44	0.00
Multiple cars	Local	$y_{CN} = -3.31 + 0.031x_1 + 4.23x_2$	97.5	23	0.01
		$y_{CNUS} = 0.0256x_1 + 2.5x_2$	99.8	23	0.01

Table B.11
Regression equations of KCS (destination Mexico) for grain type commodity, 2009.

Shipment size	Move type	Rail cost equation	Adjusted R^2 (%)	Sample size	*P*-value
Multiple cars	Local	$y_{KCS} = .64 + 0.017x_1 + .79x_2$	99.8	41	0.02
		$y_{KCSM} = .56 + 0.0176x_1 + 1.70x_2$	98.2	41	0.02
	Received	$y_{KCS} = .68 + .0172x_1^*$	99.5	36	0.01
		$y_{KCSM} = 1.127 + .01337x_1^*$	96.0	34	0.01

Table B.12
Regression equations of KCS (destination Mexico) for grain type commodity, 2011.

Shipment size	Move type	Rail cost equation	Adjusted R^2 (%)	Sample size	*P*-value.
Multiple cars	Local	$y_{KCS} = .203 + 0.023x_1 + 1.158x_2$	99.9	44	0.05
		$y_{KCSM} = 1.14 + 0.0218 + 1.17x_2$	98.8	44	0.00
Unit train	Local	$y_{KCS} = -1.27 + 0.0219x_1 + 2.91x_2$	97.3	68	0.04
	Received	$y_{KCSM} = .016x_1 + 1.21x_2$	95.9	34	0.02

Table B.13
Regression equations of BNSF for liquid type commodity, 2009.

Shipment size	Move type	Car type	Rail cost equation	Adjusted R^2 (%)	Sample size	*P*-value
Single car	Local	Tank car, over 22,000 gallons	$y_{BNSF} = 5.46 + 0.0212x_1^*$	97.2	381	0.01
		Open top hopper car, general service	$y_{BNSF} = 1.83 + 0.0213x_1 + 9.58x_2$	97.6	219	0.02
	Received	Tank car, over 22,000 gallons	$y_{BNSF} = 4.16 + 0.0216x_1^*$	98.5	94	0.01
Multiple cars	Local	Covered hopper car	$y_{BNSF} = 1.138 + 0.0179x_1 + 1.41x_2$	99.9	65	0.02

Table B.14
Regression equations of BNSF for liquid type commodity, 2011.

Shipment size	Move type	Car type	Rail cost equation	Adjusted R^2 (%)	Sample size	*P*-value
Single car	Local	Tank car, over 22,000 gallons	$y_{BNSF} = 6.40 + 0.0276x_1^*$	98.7	313	0.01
		Open top hopper car, general service	$y_{BNSF} = 5.526 + 0.0233x_1 + 5.96x_2$	97.8	146	0.00
	Forwarded	Tank car, over 22,000 gallons	$y_{BNSF} = 4.11 + 0.026x_1^*$	99.2	199	0.02
	Received	Tank car, over 22,000 gallons	$y_{BNSF} = 5.052 + 0.0272x_1^*$	99.0	101	0.01

Table B.15
Regression equations of CSXT for liquid type commodity, 2009.

Shipment size	Move type	Car type	Rail cost equation	Adjusted R^2 (%)	Sample size	*P*-value
Single car	Local	Tank car, over 22,000 gallons	$y_{CSXT} = 7.07 + 0.0213x_1^*$	92.7	187	0.02
	Forwarded	Tank car, over 22,000 gallons	$y_{CSXT} = 3.713 + 0.022661x_1^*$	94.9	44	0.02
	Received	Tank car, over 22,000 gallons	$y_{CSXT} = 4.668 + 0.02281x_1^*$	97.1	174	0.00
Multiple cars	Local	Open top hopper car, special service	$y_{CSXT} = 2.38 + 0.02889x_1^{**}$	99.0	68	0.00
	Received	Open top hopper car, general service	$y_{CSXT} = .26 + 0.0338x_1 + 2.562x_2$	99.0	33	0.00

Table B.16
Regression equations of CSXT for liquid type commodity, 2011.

Shipment size	Move type	Car type	Rail cost equation	Adjusted R^2 (%)	Sample size	*P*-value
Single car	Local	Tank car, over 22,000 gallons	$y_{CSXT} = 7.75 + 0.026x_1^*$	92.9	595	0.01
	Received	Tank car, over 22,000 gallons	$y_{CSXT} = 4.19 + 0.0282x_1$	96.4	290	0.02
Multiple cars	Local	Open top hopper car, special service	$y_{CSXT} = 4.53 + 0.0357x_1^{**}$	95.0	55	0.01

Table B.17
Regression equations of UP for liquid type commodity, 2009.

Shipment size	Move type	Car type	Rail cost equation	Adjusted R^2 (%)	Sample size	*P*-value
Single car	Local	Tank car, over 22,000 gallons	$y_{UP} = 5.507 + 0.0228x_1^*$	96.9	315	0.01
		Equipped box car	$y_{UP} = 3.9 + 0.020x_1 + 12.12x_2$	96.2	74	0.01
	Forwarded	Tank car, over 22,000 gallons	$y_{UP} = 3.54 + 0.020217x_1^*$	92.2	121	0.00
	Received	Tank car, over 22,000 gallons	$y_{UP} = 4.65 + 0.02x_1^*$	98.4	55	0.01

Table B.18
Regression equations of UP for liquid type commodity, 2011.

Shipment size	Move type	Car type	Rail cost equation	Adjusted R^2 (%)	Sample size	*P*-value
Single car	Local	Tank car, over 22,000 gallons	$y_{UP} = 6.7174 + 0.0239x_1^*$	98.8	456	0.00
		Equipped box car	$y_{UP} = 5.11 + 0.023x_1 + 6.27x_2$	97.4	69	0.02
	Forwarded	Tank car, over 22,000 gallons	$y_{UP} = 3.18 + 0.0276x_1^*$	94.4	45	0.01
	Received	Tank car, over 22,000 gallons	$y_{UP} = 4.55 + 0.0235x_1^*$	99.3	77	0.02
Multiple Cars	Local	Open top hopper car, general service	$y_{UP} = 5.38 + 0.02x_1^{**}$	96.1	22	0.01

Table B.19
Regression equations of NS for liquid type commodity, 2009.

Shipment size	Move type	Car type	Rail cost equation	Adjusted R^2 (%)	Sample size	*P*-value
Single car	Local	Tank car, over 22,000 gallons	$y_{NS} = 3.47 + 0.02759x_1^*$	99.2	315	0.03
	Forwarded	Tank car, over 22,000 gallons	$y_{NS} = 3.818 + 0.02381x_1^*$	99.6	36	0.00
	Received	Tank car, over 22,000 gallons	$y_{NS} = 3.065 + 0.0264x_1^*$	98.7	123	0.02

Table B.20
Regression equations of NS for liquid type commodity, 2011.

Shipment size	Move type	Car type	Rail cost equation	Adjusted R^2 (%)	Sample size	*P*-value
Single car	Local	Tank car, over 22,000 gallons	$y_{NS} = 3.73 + 0.031x_1^*$	98.8	116	0.02
	Forwarded	Tank car, over 22,000 gallons	$y_{NS} = 2.468 + 0.03245x_1^*$	97.3	31	0.01
	Received	Tank car, over 22,000 gallons	$y_{NS} = 3.116 + 0.03x_1^*$	98.8	166	0.00
Unit Train	Local	Open top hopper car, general service	$y_{NS} = -1.08 + 0.031x_1 + 1.97x_2$	98.7	104	0.00

** All cars owned by rail Companies.
* All cars owned by private companies.

Table B.21
Analyzing the impact of inflation on grain transportation costs: Local moves.

Shipment size	Rail cost equation	Adjusted R^2 (%)	Sample size	*P*-value
Single car	$y_{BNSF} = 1.09 + 0.0223x_1 + 5.39x_2 + 4.6x_4$	93.8	1378	0.00
	$y_{CSXT} = 1.74 + 0.0223x_1 + 4.47x_2 + 2.484x_4$	94.0	483	0.01
	$y_{UP} = 2.93 + 0.02x_1 + 8.59x_2 + 1.68x_4$	94.2	914	0.00
	$y_{NS} = .66 + .025x_1 + 4.07x_2 + 3.91x_4$	96.1	709	0.00
				0.00
Unit train	$y_{BNSF} = -2.81 + 0.0137x_1 + 2x_2 + 4.2x_4$	95.3	2644	0.01
	$y_{CSXT} = -2.03 + 0.0185x_1 + 2.74x_2 + 1.37x_4$	97.0	601	0.01
	$y_{UP} = -1.06 + 0.013x_1 + 3.93x_2 + 2.68x_4$	97.4	823	0.01
	$y_{NS} = -2.01 + .019x_1 + 2.68x_2 + 2.89x_4$	96.8	611	0.00

Table B.22
Analyzing the impact of inflation on liquid transportation costs: Single car, local moves.

Rail cost equation	Adjusted R^2 (%)	Sample size	*P*-value
$y_{BNSF} = 3.88 + .0243x_1 + 5.59x_4$	95.3	694	0.01
$y_{CSXT} = 4.92 + .024x_1 + 3.93x_4$	93.9	782	0.00
$y_{UP} = 4.80 + .023x_1 + 2.19x_4$	94.8	771	0.00
$y_{NS} = 1.83 + .03x_1 + 3.05x_4$	95.8	431	0.01

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