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Fertilizer freight rate disparity in Brazil: a regional approach

CASE STUDY

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Abstract

An increase in Brazilian agricultural product exportation with a concurrent increase in the use of fertilizer has put pressure on the country's already overtaxed transportation system and expanded the number and intensity of transportation bottlenecks, especially during the grain harvest and planting seasons. Problems with the transportation system have led to an increase in fertilizer transportation costs and a disproportionate increase in fertilizer's share of total agricultural production costs, highlighting the need to discover the most economic fertilizer transportation routes. Our research found a significant variance in fertilizer transportation costs among different Brazilian transport regions, referred to as transport corridors in this study. Literature on the subject has found that regional fertilizer shipping price variations are often contingent on the presence of shipping intensive industries, ports and storage centers. Using a comparative analysis based on an econometric model, this study examines the effect of intra-regional fertilizer transportation routes on shipping costs and clarifies the dynamics of fertilizer transport in Brazil.

Keywords: fertilizer, transport, econometric, freight
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1. Introduction and background

According to the Brazilian Ministry of Agriculture (MAPA, 2016), Brazilian agribusiness exports accounted for 45.9% of total Brazilian exports between December 2014 and November 2015. Brazilian agribusiness accounted for an average of 23.2% of the country's total gross national product between 2004 and 2013 (CEPEA, 2016). Over those 10 years, the agriculture sector was the largest contributor to both the country's balance of trade and its gross national product. The main destinations for these exports were the European Union, the United States, China, Russia, Argentina, Japan, Iran, and Venezuela. By weight, soybean and its derivatives are the most exported Brazilian agricultural products and are usually shipped from the ports of Paranaguá, Santos and Rio Grande do Sul (MAPA, 2016; Ribeiro *et al.,* 2009).

According to data published by the government's Companhia Nacional de Abastecimento (CONAB, 2016), the 2015/2016 Brazilian grain harvest was an estimated 210.5 million MT. The United States Department of Agriculture (USDA, 2016) estimated Brazilian soybean production from the 2015/2016 crop at 100 million MT, almost the half of the country's grain production, 50.4% higher than from the 2011/2012 crop and only 6.5% lower than soybean production in the United States, the world's principal soybean producer (CONAB, 2016).

The exportation of Brazilian agriculture products has significantly increased over the last 10 years. Soybean exports alone have risen over 600% since 1997. According to the Secretaria do Comércio Exterior (Brazilian Secretariat of Foreign Trade (SECEX), 2016), Brazil exported 8.3 million MT of soybeans in 1997; in 2015 Brazilian soybean exports reached 54.3 million MT. The increase is continuing: soybean exportation rose 18.9% between 2014 and 2015.

With the bulk of Brazil's soybean production located in the landlocked Centro-Oeste (Midwest) region (Izumi, 2012), the rapid rise in international sales has highlighted the country's logistic deficit, especially in the product transport segment. In June of 2015, 23.9% of the price of soybeans went to pay transportation costs. Each year, it takes more time and more money to transport grains from Brazil's Midwest to international markets (Oliveira, 2011), making logistic research extremely relevant.

The key to logistics success is managing difficulties, mainly brought about by inclement weather, poor infrastructure and seasonal flux. The logistics chain can be divided into many segments, such as transportation, storage, material handling, protective packaging, acquisition, planning, and information collection. The chain's objective is the efficient transport of the demanded product to the right place at the right time and in the right condition while minimizing the total cost of operation. During the harvest and post-harvest periods, inadequate transportation and loading services and ineffective product packaging often disrupt the shipping chain's dynamic, opening the door to significantly higher producer transportation costs.

For agricultural products and their inputs, efficient logistics is essential to the maintenance of a competitive pricing structure. Because agriculturally oriented products have low value, the cost of transportation is an important component of total product price, which differentiates them from high added-value products. To get a sense of the extent of the logistics component of Brazilian agricultural costs, this study will analyze fertilizer transportation pricing over the multi-year period of greatest agricultural product exportation.

The aim of this study is to better understand the dynamics of fertilizer logistics in Brazil and, with the aid of a multiple linear regression econometric model, to ascertain the impact of shipping route selection on fertilizer transportation pricing. In order to obtain greater adjustment of the model, explanatory variables other than the transport corridor were included. These additional variables represent the price of diesel, distance traveled (km), and binary variables for the periods when the fertilizer was transported. The estimated coefficients of these additional explanatory variables serve as complementary results without representing the central objective of this work.

It should be noted that this study does not aim to estimate the cost of fertilizer freight transport. The study makes use of a multiple regression model employing the ordinary least squares (OLS) estimation method to conduct a descriptive analysis of selected variables relating to the transport corridors.

2. Logistical context

The Council of Supply Chain Management Professionals (CSCMP, 2016) writes that 'Logistics management is that part of supply chain management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers' requirements.' Logistics includes all production handling activities and information processing to, from and between participants in a supply chain.

The goal of logistics is to make products and services available where they are needed and when they are desired (Bowersox and Closs, 2004: p. 13). Fulfilling this goal is an important part of controlling company costs and enhancing life in the country as a whole. The Council report reveals that total US business logistics activities represented 17.9% of US GDP in 1980 and 8.3% of US GDP ($1.45 trillion) in 2014. In Brazil, business logistics represented 11.5% of GDP in 2012 according the Brazilian Institute of Logistics and Supply Chain (ILOS, 2016).

The recognition of logistics as a component of business structure is recent. Modern logistics, which comprises the logistics of the transformation process in specific sector companies, began after the Second World War. The postwar period demanded that industry quickly fill the gap between increasing demand and reduced consumer supply by taking advantage of the idle capacity at industrial plants and innovating new production processes. This larger-scale production required tight and flexible integration between manufacturing segments and strategic planning so that stock could be quickly turned into key elements, from which arose standardization (Novaes, 2007).

Strategically designed logistics extends beyond punctual optimization; it includes the incorporation of competitiveness as a differentiator. A properly organized logistics structure gives coherence to the whole production system and, as such, has become essential to business success. Logistics determines what will be produced in what quantity, organizes the supply of raw materials, and ensures the successful, timely delivery of the product to the consumer: the key to sales success.

The complexity of logistics is addressed in the concept of total cost. All the processes involved in logistics should be analyzed in a unified way. Comprehensive analysis was made possible due to the development of sophisticated information technology and management acumen. Logistics decisions should cover the entire production chain and the market in which it operates, seeking the best balance between service, end user satisfaction, and process costs.

The growing relevance of logistics in total production cost and in the design of the production process makes investigation of the logistics dynamic underlying each product's production and sale essential. This is particularly true when it comes to agricultural inputs, such as fertilizer, in a country like Brazil, a country of continental proportions and high demand.

Fertilizer transportation

According to Michelon (2007), trucking does have some great advantages over other means of transport due to its scheduling flexibility and ease of cargo combination. The timing of freight pick-up and dispatch can usually be adjusted to meet the customer's needs much more easily when the freight is hauled over a road transport system than when moved by waterway or rail. If transported by road, cargo can be accepted for shipment, loaded, combined with other cargo, and expeditiously delivered, giving trucking companies an advantage over other transport modes when working in the spot freight market. The ability to combine cargos and make advantageous use of the spot market gives a roadway shipping company many opportunities to operate at full capacity on both outbound and return legs.

There are many ways to transport final product and raw materials to and from Brazilian agriculture, but the predominant grain and agricultural input transport mode is via the country's road system (Scherer and Martins, 2004). Lima (2001) calculated that 2/3 of all freight in Brazil is carried over roadways. Unfortunately, road transportation in Brazil is hampered by limited infrastructure. For grains, this is especially evident during the peak harvest season.

The Brazilian road system's failings lead to seemingly contradictory transportation problems: serious congestion and a shortage of adequate vehicles. These difficulties are reflected in extremely high seasonal freight rates that are most evident in the spot market. Other forms of transport, such as railways and waterways, are in development in Brazil; but these lower cost alternatives are not yet available. At this time, the only way to reduce transportation costs is through efficient use of the road system.

Freight transport via a road system is also differentiated from most other freight transport modalities in that it has lower fixed costs and higher variable costs. Freight transport over long distances by roadway is quite a bit costlier than moving the same freight by train or waterway. Freight movement usually makes up about 60% of all logistics costs in developed countries (Rodrigues, 2007). The costs of moving freight linked with shipping distance are considered variable costs, and all costs that arise independent of shipping distance are considered fixed costs (Lima, 2001). Correa Jr. and Caixeta-Filho (2003) and Lima (2001) describe the main variables that influence freight rates, which can be divided into six categories, as shown in Table 1.

The fixed costs of freight transportation in Brazil may be less constant than in the developed world. First, there is the rather high rate of inflation that causes shipping costs to often change rather quickly and disrupt planning. Second is the environmental push: the Brazilian government is adding taxes and road use regulations to encourage the use of more sustainable transportation alternatives (Steadieseifi *et al.,* 2014). The variable costs depend on issues influenced by the differentiated price conditions in each region, such as seasonality, infrastructure, and the potential for 'return freight' (back loading). The following section gives

Table 1. The main variables that influence freight rates (adapted from Correa Jr. and Caixeta-Filho, 2003; Lima, 2001).

Variable costs related to travel and distance traveled	**Fixed costs related to shipping company operation**	**Product handling facilities and peculiarities**
• fuel • oil • tire • lubricants • washing • road-use taxes • tolls • other maintenance	• taxes • insurances • licensing • depreciation • facilities • staff (driver) • administration • business taxes • financing	• type and dimensions of cargo • load risk (flammable, toxic or theft prone) • operating costs • vehicle specificity (refrigerated, tanker, grain or fruit hauler)
Market conditions	**Infrastructure**	**Organizational**
• seasonality • possibility of return freight	• regional peculiarities that includes road conditions • traffic	• competition or synergy with other transportation modes • tolls and working scales along the route • lead time to delivery

a broad overview of transport dynamics in the Brazilian fertilizer sector and a more detailed discussion of the return freight concept.

Market conditions: seasonality and return freight

In this study, 'seasonality' refers to changes in freight rates as determined by seasonal transportation demand. Seasonal fluctuations in the demand for fertilizer transportation indicate that fertilizer freight logistics are very different from that of other agricultural products.

Fertilizer deliveries in Brazil never stop but oscillate within a narrow range and follow a different schedule relative to grains. Fertilizer shipments are at their lowest in April and highest in September. Deliveries of 1.1 million metric tons (MMT) of fertilizer were made in April of 2010, 3.9 MMT in September of 2014; and 1.4 MMT in April of 2015, the least monthly amount delivered that year.

The seasonal fluctuation in demand for soybean transportation is enormous: minimal in December and January, peaking in May and June. In April 2016 10.1 MMT of soybeans were exported, 26 times the January 2016 amount (394 thousand metric tons (TMT)). The disparity in the amounts of fertilizer and soybean transported and the timing of that transportation opens opportunities to transport fertilizer back to grain producing regions as return freight, which should benefit both the shipper and the shipping company.

Return freight is that cargo that returns to the shipping service's initial debarkation point. If a good is shipped from point X to point Y, the return freight would be that cargo that returns to point X from point Y. This return freight is also referred to as the 'backload.' When the soybean harvest in central west Brazil is at its height, the amount of freight to be shipped by roadway to export facilities exceeds the normal demand for freight to be shipped from those facilities back to the harvest area. This is a common occurrence at some stage of most of the country's grain harvests, soybean being used as an example because it is the most exported crop.

To secure the grain hauling truck's return from the export facility during the harvest, grain producers may be obliged to pay for transport of their outbound freight and the return of an empty truck to the harvest area. This translates into extremely inflated freight rates for the shipment of just harvested grains to export facilities, especially to the Brazilian ports of Santos and Paranaguá. Any additional payment received for the shipment of a return cargo is of benefit to the shipping company. Carrier agents consider return freight to be a compensation; and the price for grain transportation can be adjusted by the probability of return freight, which often leads to negotiation between both shipper and shipping company as a part of price formation (Oliveira *et al.*, 2010).

Fertilizer is a very good return freight candidate, giving it an important role in the return freight calculation. Fertilizer is bulky, relatively imperishable, necessary and imported into Brazilian ports in great quantity. Other products also lend themselves to this strategy: limestone, cement, soybean meal, wheat, bagged sugar, sorghum, citrus pulp, seeds, gypsum, industries' finished products and construction materials, such as bricks and tiles. The combination that occurs most frequently in Brazil is outbound with soybean and return with fertilizer (Michelon, 2007).

The Brazilian soybean harvest takes place from late January to May, with the first very small quantities exported in late January and early February. As noted earlier, as the harvest reaches its peak, there is an increase in demand for one-way grain transportation services. Although this is a time of low fertilizer use, it is also a time when scheduling fertilizer as return freight is most economically advantageous. At this point, the fertilizer shipper must decide if it is rational to make use of the return freight option or wait and ship during the planting season when the cargo will used almost immediately.

By taking advantage of the return freight option, shipping companies can reduce round trip expenses and grain producers and fertilizer suppliers can reduce shipping costs. When the shipping company is making a profit even if the truck returns to its point of origin empty, return freight is transformed into an opportunity to increase shipping company profits and lower the shippers' costs. Oliveira *et al.* (2010) note that return freight can be considered an opportunity cost. Product shippers seeking to minimize costs and shipping companies seeking to maximize profits are aligned in their desire to arrange a return freight.

Fertilizer market

According to Brazil's National Association for Fertilizer Promotion (ANDA, 2014), the country used 30.2 million metric tons of fertilizers in 2015, 23% more than used in 2007 (24.6 MMT), the first year ANDA compiled fertilizer utilization data. Since 2004, Brazil's fertilizer segment has experienced an average annual growth rate of 3.0%; although, the segment stagnated in 2005, 2008, 2009 and 2015, most likely due to an increase in international fertilizer prices and maritime freight costs in those years.

A survey conducted by the Brazilian Federal University of Rio de Janeiro (UFRJ) in conjunction with the Brazilian Chemical Industry Association (ABIQUIM, 2009) found that the products most imported into Brazil were raw materials used in fertilizer production. Between 2004 and 2015, fertilizer use in Brazil increased 32.7% while domestic production decreased 6.8% (ANDA, 2014). The gap between domestic production and consumption was filled by imports, with the importation of fertilizer and fertilizer components increasing by approximately 62.4% between the 2004 and 2015 (ANDA, 2014). Tavares and Haberli Jr. (2011) note that between 2007 and 2010, 95% of the potassium chloride used as fertilizer in Brazil was imported.

Figure 1 shows the seasonal changes in fertilizer delivery, domestic production and importation. Brazilian fertilizer shipments begin to increase during the second half of the first semester, when planting of the summer grain crop begins, with greatest overall demand in the second semester. Considering that imported fertilizer and fertilizer components make up such large percentage of Brazilian fertilizer consumption, it is hard to overstate the importance of the transportation infrastructure responsible for moving these goods in the final cost of agricultural products (Teixeira, 2013).

Seasonality also affects most agricultural products. Figure 2 shows the seasonal fluctuation in soybean exportation. While fertilizer importation and consumption are concentrated in August, September and October, soybean exportation is shown to be concentrated in April, May and June.

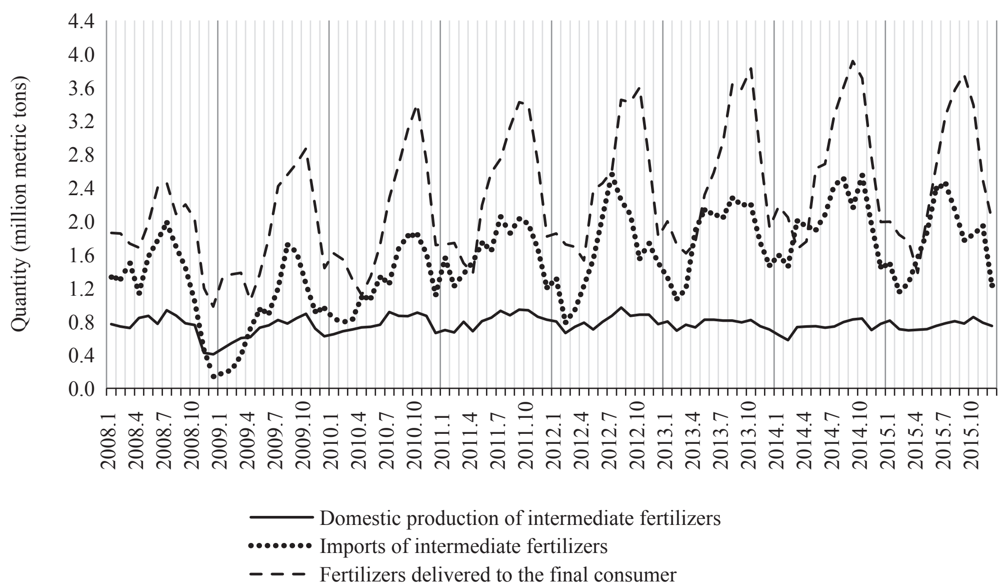

Figure 1. Fertilizers delivered to the final consumer, domestic production of intermediate fertilizers, and imports of fertilizer production inputs in million metric tons (ANDA, 2014).

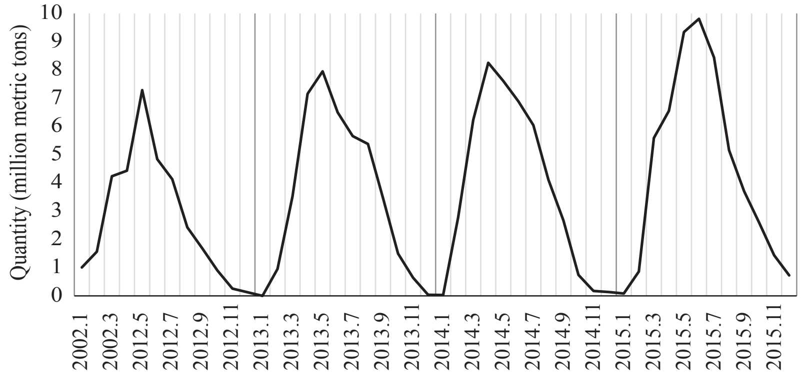

Figure 2. Million metric tons soybeans exported (SECEX, 2016).

3. Econometric approaches in the transport sector

According to Correa (2001), mathematical modeling is widely used in studies addressing transport issues. Econometric analysis has been particularly useful to identify key factors influencing freight rates and to estimate transportation demand functions. Thompson (1960), for example, found that the cost to ship chemicals in the United States was directly related to the distance traveled. The same author highlights the logarithmic form log-log as a good alternative when modeling the non-linear relationship.

Kerr (1972) used OLS analysis via multiple regression techniques to study railway freight rates for products with different characteristics in the United States. The author considered miles driven, the overflow rate, and load weight as explanatory variables.

Binkley and Harrer (1981) analyzed the determinants of marine grain shipping prices using two linear models estimated by OLS. One of their models examined the average effect of the following explanatory variables on the freight rate: travel distance and travel distance squared, ship's size, and the size of the ship to the square of the distance, the transported volume, and binary variables to reflect the season of shipment, types of transport contract ('free discharge' and 'gross terms'), and if the carrier was a US-flagged vessel.

Hauser (1986) derived a single road shipping function using an OLS regression dealing with ten functions related to the producer's cost to transport by roadway and length of route in the United States. The author concluded that due to intense competitiveness within the grain road transport industry, the freight rate is equivalent to shipping company operating costs plus a 2% profit margin.

Prentice and Benell (1992), on the other hand, used a multiple linear regression model to estimate the utility of American transportation companies when transporting loads with different attributes (origin, need for refrigeration, destination, loading/unloading duration). They note that the transportation of red meat from Canada to the United States was the 'desirable' return freight.

Beilock *et al.* (1996) developed a study to identify the determinants of the road freight rate for the flow of international goods in Europe and Western Asia. The factors, identified as rate determinants, were number of borders crossed, road conditions, and the use of ferries to cross waterways. The authors point out that although loading ability is an important factor in determining the freight rate, this was not considered in the study because the data refer to a category of carriers that do not seek return cargo.

Garrido and Mahmassani (2000) developed a predictive model of transport demand using the variability of demand as a function of time and space. The authors employed a multinomial probit model and a Monte-Carlo simulation to evaluate the likelihood of the multinomial probit model. The model developed by the authors considered the demand for shipping as a stochastic process, identified by an econometric model with a probability distribution function and interaction between the alternatives considered.

Many of the key explanatory variables and mathematical approaches used in the cited studies are similar. Multiple regression models, OLS models, and autoregressive models are particularly evident among the more often used mathematical techniques, and are most probably selected according to data characteristics and the methodological predilection of those involved in research. The inference here is that there is no preferable technique but that researchers must use methodology that best suits the study's characteristics and their own preferences. Some factors that appear more frequently in freight transportation studies are distance traveled, characteristics of the cargo's point of origin and destination, loading and unloading times, load type and the value of the product carried.

It was decided that our study would employ a multiple linear regression model estimated using the OLS method to evaluate variables that affect fertilizer freight rates, especially trip routing through selected transport corridors. Variables were selected based on related literature and data availability.

It is noteworthy that multiple linear regression is a statistical tool that has wide application in the social sciences, especially in fields related to management, economics, and sociology (Hoffmann, 2015). This technique is concerned with the study of the dependence of a variable, the 'dependent variable,' on other variables; the 'independent variables,' with the objective of evaluating and/or predicting the average (population) or the average value of the dependent variable in terms of the known values of the explanatory variables (Oliveira, 2014). However, it should be clarified that while a regression analysis considers the dependence of one variable in relation to another, it need not imply a causal relationship. The success of any multiple linear regression analysis depends on the relationship between the dependent variable and explanatory variables as well on the availability of appropriate data and an adequate, suitable theoretical construction.

4. Methodology and specification of data

This study examines road freight rates when fertilizer is shipped through different Brazilian regions, represented by transit corridors, and evaluates the impact of four variables on these rates. The main criterion for the choice of regions was that the selected routes in the region's road transportation corridor attend to significant fertilizer supply and demand. This entails that routes connect cities serving as hubs for fertilizer blending operations, shown in Table 2, ports, which are often adjacent to fertilizer blending industries, and grain production areas, shown in Table 3. The differences among the five corridors' freight rates will also give an indication of the effect of return freight on fertilizer transportation costs.

This study uses multiple linear regression to determine the impact of variables related to five Brazilian regions on the fertilizer freight rate. The five regions are represented by five different transportation corridors.

Table 2. Number of fertilizer manufacturing operations in or near cities located in the transport corridors (RAIS, 2012).

State[1]	City	Fertilizing manufacturers	State	City	Fertilizing manufacturers
PR	Paranaguá	27	SP	Campinas	8
MT	Rondonópolis	20	SP	Ribeirão Preto	8
MG	Uberaba	18	SP	Cubatão	7
GO	Catalão	12	PR	Maringá	6
PR	Curitiba	10	MG	Uberlândia	6
SP	São Paulo	10	GO	Anápolis	6

[1] MT = Mato Grosso; MG = Minas Gerais; GO = Goiás; PR = Paraná; SP = São Paulo.

Table 3. Cities centered in Brazil's biggest maize and soybean producing areas by megaton of production in 2012 (IBGE, 2012).

City	State[1]	Maize[2]	Soybean[2]	City	State	Maize	Soybean
Sorriso	MT	1.998.402	1.961.880	Itiquira	MT	642.600	615.000
Jataí	GO	1.221.000	863.100	Querência	MT	558.780	629.640
Rio Verde	GO	1.070.000	907.500	Campo Verde	MT	284.272	882.126
Sapezal	MT	817.004	1.130.326	Campos de Júlio	MT	494.712	590.700
Nova Mutum	MT	775.720	1.107.481	Sidrolândia	MS	521.515	563.565
Lucas do Rio Verde	MT	1.089.710	716.550	Dourados	MS	611.850	358.800
Campo Novo do Parecis	MT	597.000	1.063.800	Ipiranga do Norte	MT	606.600	280.000
Maracaju	MS	918.000	615.000	Santa Rita do Trivelato	MT	388.500	494.748
Nova Ubiratã	MT	608.405	890.988	Montividiu	GO	413.400	466.095
Primavera do Leste	MT	588.748	744.000	São Gabriel do Oeste	MS	489.000	368.880
Diamantino	MT	447.400	873.600	Vera	MT	474.800	349.800

[1] MT = Mato Grosso; GO = Goiás;. MS = MatoGrosso do Sul.

[2] Quantity in million metric tons.

The dependent variable (FREIGHT) was defined as the average price in Brazilian Reais per metric ton (R$/MT) charged by transportation companies to transport bulk fertilizer by roadway over routes in our selected transport corridors and is contingent on the cargo's origin and destination, the period of fertilizer flow (month and year), and the length of the route (km). These data are based on a set of information consisting of 14,878 observations from January 2010 through March 2014. The observations are grouped by freight origin and destination into five sets, with each set indicative of routes in one of the transport corridors. Table 4 lists the corridor classification details. Each observation relates to one route, and a particular route may be used by different shipping companies.

These data came from the Information System for Freights (SIFRECA), a monitoring and freight price data collection system under the direction of the Agroindustrial Logistics Research and Extension Group (ESALQ-LOG) from the Escola Superior de Agricultura Luiz de Queiroz/USP. SIFRECA is specifically concerned with road freight rates for the transport of Brazilian agricultural and agri-business products and collects data using periodic surveys of producers, processors, and traders. It should be noted that data used to calculate the average and nominal cost for bulk fertilizer road transport excludes information from self-employed carriers and tax and insurance figures and that 'cost' is the value paid to the transportation company by the agent in need of transportation services. For reasons of confidentiality, the ESALQ-LOG research group does not provide information broken down by transportation company, nor does their available database contain data more current than the period covered by our study. It was not possible to update the data.

In addition to the freight rate over a particular route (R$/t) and the pairs of origin-destination cities that make up that route, the SIFRECA database also provided a measure for distance covered linked with each observation, represented by the variable (KM) in the model. It should be noted that in one month, for example, the same route can be observed with different freight rates for fertilizer transport because the transportation was provided by different carriers.

The purpose of this study is to assess the impact of road transport corridors on the price of fertilizer shipping. For a better specification and robustness of analysis, other explanatory variables were included: distance, diesel price and period the fertilizer was transported.

Table 4. Routes classification according to fertilizer transport corridors (ESALQ-LOG, 2014).

Corridor A (COR_A)	Origin	Routes connecting Paranaguá (port) and the city of Curitiba (fertilizer industries in close proximity to Paranaguá) to
	Destination	grain producing areas in Brazil's Midwest: State of Mato Grosso: Sorriso, Sapezal, Nova Mutum, Lucas do Rio Verde, Campo Novo do Parecis, Nova Ubiratã, Primavera do Leste, Diamantino, Querência, Campo Verde, Campos de Júlio, Ipiranga do Norte, Santa Rita do Trivelato, Brasnorte, Sinop, Tapurah, Santo Antônio do Leste, Itiquira, and Vera; State of Mato Grosso do Sul: Maracaju, Sidrolândia, Dourados, São Gabriel do Oeste, Ponta Porã and Rio Brilhante; State of Goiás: Jataí, Rio Verde, Cristalina, Montividiu and Chapadão do Céu
Corridor B (COR_B)	Origin	Routes connecting Paranaguá (port) to
	Destination	fertilizer industries in the State of Paraná: Curitiba and Maringá; State of Mato Grosso: Rondonópolis; State of Goiás: Catalão and Anápolis; State of Minas Gerais: Uberaba and Uberlandia; State of São Paulo: São Paulo, Campinas, Ribeirão Preto and Cubatão
Corridor C (COR_C)	Origin	Routes connecting Santos (port), Guaruja (port) and Cubatao (12 km from Santos and home to fertilizer industries) to
	Destination	grain producing areas in Brazil's Midwest: State of Mato Grosso: Sorriso, Sapezal, Nova Mutum, Lucas do Rio Verde, Campo Novo do Parecis, Nova Ubiratã, Primavera do Leste, Diamantino, Querência, Campo Verde, Campos de Júlio, Ipiranga do Norte, Santa Rita do Trivelato, Brasnorte, Sinop, Tapurah, Santo Antônio do Leste, Itiquira, and Vera; State of Mato Grosso do Sul: Maracaju, Sidrolândia, Dourados, São Gabriel do Oeste, Ponta Porã and Rio Brilhante; State of Goiás: Jataí, Rio Verde, Cristalina, Montividiu and Chapadão do Céu
Corridor D (COR_D)	Origin	Routes connecting Santos (port), Guarujá (port) and Cubatão (fertilizer industries and adjacent to the port of Santos) to
	Destination	fertilizer industries in the State of Paraná: Paranaguá, Curitiba and Maringá; State of Mato Grosso: Rondonópolis; State of Goiás: Catalão and Anápolis; State of Minas Gerais: Uberaba and Uberlândia; State of São Paulo: São Paulo, Campinas, Ribeirão Preto and Cubatão
Corridor E (COR_E)	Origin	Routes connecting fertilizer industries in the State of Goiás: Catalão and Anápolis; State of Minas Gerais: Uberaba and Uberlândia to
	Destination	grain producing regions in Brazil's Midwest: State of Mato Grosso: Sorriso, Sapezal, Nova Mutum, Lucas do Rio Verde, Campo Novo do Parecis, Primavera do Leste, Diamantino, Querência, Campo Verde, Campos de Júlio, Brasnorte, Sinop, Tapurah, and Vera; State of Mato Grosso do Sul: Maracaju, Dourados, and Rio Brilhante; State of Goiás: Jataí, Rio Verde, Cristalina, Montividiu and Chapadão do Céu

Description of variables

In the empirical model used in this study, the fertilizer freight rate (R$/t)[1] was considered to be function of the following variables:

- Five binary variables associated with the five selected road transportation corridors: COR_A, COR_B, COR_C, COR_D, and COR_E. These corridors are used to transport the great majority of fertilizer used in Brazil. Data regarding fertilizer flow in the five corridors' and nominal[2] freight transportation prices were provided by ESALQ-LOG (ESALQ/USP). The corridors are defined in Table 4.

[1] The fertilizer freight rate used in the model is in R$/MT not in US$/MT because the behavior of the Real$ is more relevant to freight rates in Brazil than the US$ when trying to understand the Brazilian fertilizer freight market's dynamic.

[2] The rationale for this is due to the absence of a specific deflator for freight and little influence from inflation (given by general price inflation) on freight values, since a considerable part of these values correspond to previously contracted amounts and therefore are fixed for a period.

- Three binary variables, T1, T2 and T3, associated with periods of fertilizer transport. T1 represents the three month period of March through May; T2 represents the seven month period of June through December and T3 represents two month period of January through February (the whole year was considered).
- Mean distance (km) of travel, described as variable (KM); source: ESALQ-LOG (ESALQ/USP).
- Mean diesel price – Brazil (R$/liter)[3], described as variable (DIESEL); source: Agência Nacional de Petróleo (ANP).

The variables' descriptive statistics

The figures in Table 5 show that approximately 61% of the observed fertilizer freight traffic was in Corridor A, that the mean price of diesel (R$/ltr) was R$ 1.84 or US$ 0.562[4], that the mean distance traveled over the observed routes was 1,521 km and that period when the most routes were traveled (53%) was from June through December (T2).

During the T2 period, from June through December, vehicles transporting fertilizer traveled over 53% of the designated routes, the highest percentage of the three transit periods. This was certainly to be expected as the T2 period is both the longest period, seven months, and encompasses the grain planting season: the time of greatest fertilizer demand. 28% of the routes were used to transport fertilizer during the three month March through May T1 period. These are the soybean harvest months and would be the most economically advantageous months for fertilizer to be used as return freight. Fertilizer was transported over 18% of the routes during the January through February T3 period, a period of few grain shipments and the least advantageous for the use of fertilizer as return freight.

Empirical model

A multiple linear regression equation employing the OLS method is used to estimate the coefficients of the previously described variables (Koutsoyiannis, 1972). These coefficients are then used to capture the influence of each of the five transit corridors on the price to ship fertilizer. The additional explanatory variables (diesel price, period of fertilizer flow, kilometers traveled) were included to achieve better model performance and improve its robustness.

[3] The diesel price used in the model is in R$/liter not in US$/liter because the Brazilian government sets diesel prices in the Brazilian domestic market.
[4] Real$ to commercial dollar conversion, July 12, 2016: 1 US$ = R$ 3.2750 (Banco Central do Brasil, 2016).

Table 5. Description of the exogenous variables and descriptive statistics (data from 2014).

Variables	Description	Mean	Standard deviation
COR_A	1 if route belongs to corridor A, 0 if it does not	0.61319	0.48704
COR_B	1 if route belongs to corridor B, 0 if it does not	0.11964	0.32455
COR_C	1 if route belongs to corridor C, 0 if it does not	0.09699	0.29595
COR_D	1 if route belongs to corridor D, 0 if it does not	0.04934	0.21657
COR_E	1 if route belongs to corridor E, 0 if it does not	0.12085	0.32596
DIESEL*	Average diesel price (R$/liter), per month	1.84	0.22
KM*	Distance in km, from each fertilizer route	1,521.34	625.53
T1	1 if the route occurred in the months between March and May, 0 if it does not	0.28687	0.45231
T2	1 if the route occurred in the months June and December, 0 if it does not	0.53212	0.49898
T3	1 if the route occurred in the months January and February, 0 if it does not	0.18100	0.38503

* Continuous variables

The proposed model follows the functional form,

$$\ln Y = \alpha + \sum_{i=1}^{5} \beta_i X_i + \sum_{j=6}^{8} \beta_j X_j + \beta_9 \ln X_9 + \beta_{10} \ln X_{10} + \varepsilon \quad (1)$$

where

- lnY corresponds to the natural logarithm of the fertilizer freight rate in R$/MT;
- i corresponds to the corridor in which the routes are classified – Corridor A (i=1); Corridor B (i=2), Corridor C (i=3), Corridor D (i=4) or Corridor E (i=5);
- j refers to the period of fertilizer transportation – T1 (j=6); T2 (j=7) e T3 (j=8).
- α, β_i, β_j, β_9, β_{10} are the estimated model parameters;
- X_i refers to the binary variable corresponding to the *i-th* type of Corridor;
- X_j refers to the binary variable corresponding to the *j-th* fertilizer transport period;
- ln X_9 refers to the natural logarithm of the average diesel price in Brazil (R$/liter);
- ln X_{10} refers to the natural logarithm of the distance of each fertilizer route (km); and
- ε corresponds to the random error (distribution N (0,1) was assumed.

The E-Views 6.0 (IHS Global Inc., Irvine, CA, USA) statistical program and the 'R-Studio' program (RStudio Inc, Boston, MA, USA) were adopted to estimate the regression parameters, to carry out tests, and to create graphics useful when analyzing the results.

5. Results and discussion

'Soybean price' was initially one of the explanatory variables added to improve the estimated model's robustness but was excluded from the final model due to the presence of endogeneity, which is discussed in the following section.

Presence of endogeneity

The use of instrumental variables allows consistent estimations when the explanatory variables are correlated with a linear regression's error term. In this situation, the linear regression can produce biased and inconsistent estimations. However, consistent estimates may also be obtained when an instrumental variable is available. As part of this analysis, each explanatory variable was tested for endogeneity using the test developed by Hausman (Gujarati, 2006: p. 605; Wooldridge, 2010: p. 495;).

The following structural model was used to carry out this test:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + u \quad (2)$$

where

- Y refers to the fertilizer freight rate;
- X_1 diesel price (in Brazil);
- X_2 distance of each route considered in the data (km);
- X_3 soybean price; and *u* model error term.

The following variables are considered exogenous and not included in the model above: the binary fertilizer transport periods (T1, T2 and T3), and the binary representing each corridor (Cor_A, Cor_B, Cor_C, Cor_D, Cor_E). Even in this context, for each individual assessment of the explanatory variables (X_1, X_2 and X_3) in Equation 2, the other explanatory variables are considered exogenous. Thus, for the assessment X_1 as endogenous, X_2 and X_3 are considered exogenous; for the assessment of X_2 as endogenous, X_1 and X_3 are considered exogenous, and for the assessment of X_3 as endogenous, X_2 and X_1 are considered exogenous. To analyze whether the diesel price variable (X_1) is endogenous, the reduced form of X_1 (the regression of X_1 against any exogenous variables or predetermined variables including exogenous variables that were not considered in the structural model (Equation 2)) is estimated, yielding residual $\hat{u}_1$. Then, $\hat{u}_1$ will be added as an explanatory variable in the structural model that includes X_1, and the significance of the coefficient of $\hat{u}_1$ is checked. The coefficient was obtained from a t test using the OLS method. If the coefficient of $\hat{u}_1$ is statistically different from zero, i.e. significant at a specific level of significance, the null hypothesis that the coefficient of $\hat{u}_1$ is equal to zero is rejected; and it follows that X_1 is endogenous. The same individual analysis is repeated for variables X_2 and X_3.

'Regression 1,' 'Regression, 2,' and 'Regression 3' correspond to regressions obtained by regressing the fertilizer freight rate (R$/t) against exogenous variables in the structural model (Equation 2), which are X_1, X_2 and X_3 with their residuals $\hat{u}_1$, $\hat{u}_2$ and $\hat{u}_3$, respectively.

It can be highlighted that:

- $\hat{u}_1$ corresponds to the residual vector obtained from the estimation of regression model 1 with X_1 being the dependent variable against the explanatory variables X_2, X_3, the binary corridor variables Cor_A, Cor_B, Cor_C, Cor_D and Cor_E and the binary shipping period variables T1, T2 and T3;
- $\hat{u}_2$ corresponds to the residual vector obtained from the estimation of regression model 2 with X_1 being the dependent variable against the explanatory variables X_1, X_3, the binary corridor variables Cor_A, Cor_B, Cor_C, Cor_D and Cor_E and binary shipping period variables T1, T2 and T3;
- $\hat{u}_3$ corresponds to the residual vector obtained from the estimation of regression model 3 with X_1 being the dependent variable against the explanatory variables X_1, X_2, the binary corridor variables Cor_A, Cor_B, Cor_C, Cor_D and Cor_E and binary shipping period variables T1, T2 and T3.

The residual coefficients considered as explanatory variables of regressions 1, 2 and 3 are shown in Table 6.

According to the values shown in Table 6, the coefficient of $\hat{u}_3$ was statistically different from zero, i.e. significant at 1% significance; therefore, the null hypothesis that the coefficient of $\hat{u}_2$ is equal to zero is rejected and that X_3 (soybean price) is endogenous. The coefficients $\hat{u}_1$ and $\hat{u}_2$ are not significant, indicating that the null hypothesis that the coefficients are equal to zero is not rejected and that variables X_1 and X_3 are exogenous (diesel price and distance, respectively).

For the chosen instrumental variable to be considered adequate it needs to be correlated with the explanatory variable and not correlated with the error term (Wooldridge, 2010). When the variable 'soybean price' was found to be endogenous, various instrumental variables were analyzed; but no statistically significant results were generated. As an example, the 'volume of exported soybeans' and 'volume of imported fertilizers' were selected as acceptable instrumental variables correlated with soybean price. When comparing the adjusted coefficient of determination (adjusted R-square) of regressions containing either of these instrumental variables with results from the model without these variables, i.e. the model with only the variables diesel price, length of transited routes and the binary variables fertilizer transport period (T1, T2 and T3,) and corridor (COR_A, COR_B, COR_C. COR_D and COR_E), it was found that the model lacking an instrumental variable was the more significant in terms of higher values for the explanatory variables' adjusted R-square coefficients and the direction of their signals, indicating that the model lacking instrumental variables was the more

Table 6. Residual estimates $\hat{u}_1$, $\hat{u}_2$ and $\hat{u}_3$, as explanatory variables of regressions 1, 2 and 3, respectively with data from 2016.

Residual estimates	Coefficient (estimates)	Statistic t	*P*-value[1]
$\hat{u}_1$ (Regression 1)	-5.28	-1.23	0.2176[#]
$\hat{u}_2$ (Regression 2)	6.2×10^{-4}	0.987	0.3237[#]
$\hat{u}_3$ (Regression 3)	-1.97	-18.83	0.0000[*]

[1] * denotes significance at 1%; # not significant (significance higher than 10%).

robust. For this reason, the endogenous variable 'soybean price' and all related instrumental variables were excluded from the specified model.

It should be noted, that the focus of this research is to quantitatively describe the impact of the region (represented by fertilizer transportation corridors) on the fertilizer freight rate. The variables 'soybean price,' 'fertilizer price,' length of route' and the binaries referring to 'period of fertilizer transportation' were only considered to make the model more robust and accurate.

Analysis of residuals

White's test was applied to check for data heteroscedasticity. The null hypothesis that the variance is constant (homoscedasticity) was rejected at a 1% significance level, verifying the existence of heteroscedasticity for the initial estimated model. White's robust correction was used because it adjusts the standard errors from model heteroscedasticity when, in practice, one does not know the pattern of heteroscedasticity. In addition, a successful corrective procedure (the natural logarithm) was used to modify the price of fertilizer transportation, the route length and the average price of diesel. White's test was reapplied after these procedures, and the absence of heteroscedasticity was verified. The test resulted in a non-significant value (or significant at much higher than a 10% level) making it impossible to reject the null hypothesis that the residuals are homoscedastic. Table 7 shows the test statistic after correction procedures.

Although not commonly used for cross section data, the Durbin Watson test was applied to check for the presence of residual autocorrelation (Gujarati, 2006), which was originally statistically calculated as 1.87. Inserting an autoregressive component freight rate (AR (1)), which was significant at 1%, resulted in a Durbin Watson test value of 2.05. The lower (dL) and higher (dU) limits found in the Durbin Watson Table of Critical Values (Gujarati, 2006) were 1.57 and 1.78, respectively. As the region between dU and (4-dU) is the region of no autocorrelation and the calculated value of 2.05 is within this region's boundaries (1.78 and 2.22), the finding that there is no autocorrelation of residuals is confirmed.

After assessing the variance inflation factor, the presence of multicollinearity between the estimated model's explanatory variables was discarded. Following procedures proposed by Gujarati (2006), the calculated variance inflation factor values were below 10, as is shown in Table 8.

Analysis of Figure 3A shows that there is no evidence that the errors are not following the normal distribution. The red line represents the normal. The higher the adhesion values of the series to the red line, the greater the evidence that the residuals' distribution is normal. Figures 3B and 3C are histograms of residual values, with 3B being the frequency of the residual values in the 10 to 100 range and 3C the frequency of residual values in the 1000 to 8,000 range, the histogram limit.

Table 7. White test result with research data from 2016.[1]

Observation × R-square	Prob. chi-square
21.10	0.9090*

[1] After applying the continuous variables' natural logarithm and using White's robust correction; the prob. Chi-square is not significant (significance higher than 10%).

Table 8. Values of variance inflation factor to evaluate multicollinearity between the explanatory variables with research data from 2016.

Diesel price	km	Freight
1.25	3.25	2.36

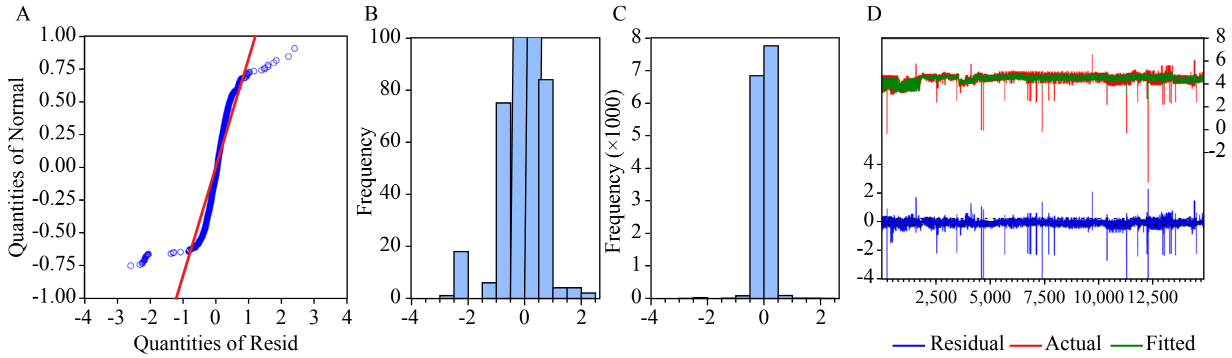

Figure 3. (A) Q-Q Normal Probability Plot of the residuals; (B) and (C) histograms of the residuals; (D) behavior of estimated series x compared with observed values. Based on research data from 2016.

Figure 3D shows the fit of the regression values with the observed fertilizer freight rates (green and red lines) and with the regression residuals (blue line). The figure's uppermost graphic indicates that the regression data are a good fit for most of the reporting period. The more the green line overlaps the red, the better adjusted the estimated equation is shown to be, i.e. the better its linkage with the observed data. The blue line in Figure 3D also represents the residuals and is used to show the difference between the observed series and adjusted series. The more this line 'oscillates,' the greater the evidence that what is not explained by the model is extremely random and of minimal importance.

It can be seen in Figure 3B and 3C that the residuals have a normal distribution. Although the Jarque Bera test, which is an asymptotic normality test (Jarque and Bera, 1987), led to rejection of the null hypothesis of normality of errors (because the skew values=-8,839; kurtosis=282,109; sample size (n)=14,878; statistical JB=48,486,376 with a probability of zero significance, rejecting the null hypothesis). According to Oliveira (2014), even if this hypothesis is not validated, it is still possible to correctly infer when there is a large enough sample to bring the law of large numbers into play (Judge *et al.,* 1988). Our study used a relatively large sample of 14,878 data points.

It should be noted that routes were excluded when freight rates charged for shipments over these routes showed them to be discrepant (outliers). To determine if a route's data were to be excluded, a simple arithmetic average of all the different routes fertilizer freight rates was calculated. If the freight rate for a route exceeded one standard deviation from the average, data for that route were disregarded. Data from economically relevant routes were not discarded. Relevancy was determined by frequency of use and volume of traffic. These specific values were not gathered for this research but were derived from the informed opinions of researchers, data provider groups, and market players. In addition, some of the data came from previously included contracted freight values, which justified some apparent dispersion

Results

The results from the final model's multiple linear regression are presented in Table 9. The table shows the coefficient values and the respective t-statistic figures for each explanatory variable. Values for the variable Corridor C (Cor_C) and the January through February fertilizer transportation period (T3) are omitted from the table as that corridor and period were chosen to be control variables for specification purposes and for analysis of the model's results.

Table 9 shows that the F statistic has a fairly high value, indicating that at least one of the estimated coefficients is different from zero, which consequently indicates that at least one of the selected independent variables is significant. The significance of the F test was expected, since, at the least, the distance variable KM has a very clear relationship with freight rates (Corrêa Jr. and Caixeta-Filho, 2003). It is noteworthy that the coefficient of determination, R^2, performed satisfactorily (0.62 approximately) indicating that the variables

Table 9. Coefficients estimation for the regression model's explanatory variables with research data from 2016.[1,2]

Explanatory variable	Coefficients	t-statistic	Standard error	*P*-value
constant	0.733722*	15.00025	0.048914	0.0000
COR_A	0.145553*	19.52019	0.007457	0.0000
COR_B	0.377956*	42.95309	0.008799	0.0000
COR_D	0.222336*	15.81382	0.014060	0.0000
COR_E	0.046231*	3.887272	0.011893	0.0001
T1	-0.075630*	-9.331273	0.008105	0.0000
T2	-0.033489*	-4.456568	0.007515	0.0000
lnDIESEL	0.094049*	4.121097	0.022821	0.0000
lnKM	0.510943*	78.44784	0.006513	0.0000
AR(1)[3]	0.241275*	7.320571	0.032958	0.0000
R-Squared	0.6157			
adjusted R-squared	0.6154			
observations	14,878			
F-statistic	2,634.390*			
prob (F-statistic)	0.0000			
Durbin-Watson	2.05			

[1] * denotes significance at 1%.

[2] The coefficients are valid for any monetary unit. The fertilizer freight price, the diesel price and the distance are in natural logarithm from and result in elasticity values.

[3] Insertion of the autoregressive term (AR (1)) to correct residual autocorrelation. Further interpretation of its coefficient was not conducted as its significance value was below 1% (Gujarati, 2006).

explain about 62% of the observed variation in freight rates. The R^2 is equal to 0.62, which is considered a high R^2 in economics and a sign that the model is properly designed.

Relatively to the control Corridor (Cor_C) and keeping the other explanatory variables constant, fertilizer producers would find shipping through Cor_A to be 14.55% more expensive, shipping through Cor_B would be 37.79% more expensive, shipping through Cor_D would be 22.23% more expensive, and shipping through Cor_E would be 4.62% more expensive. Corridor C (origin at Cubatão and the ports of Santos and Guarujá with destinations in the grain producing regions of Brazil's Midwest) was shown to be the lowest priced fertilizer transport corridor. This can be explained by the fact that this corridor is well positioned for fertilizer transport economically contracted as return freight due to the overabundance of grain being delivered from Brazil's grain growing region to the two major ports.

Relative to the fertilizer freights rates found during the 'T3' period (January thru February) and keeping the other explanatory variables constant, the freight rate for fertilizer transported in the T1 period (March thru May) would be 7.56% less and the freight rate for fertilizer transported in the T2 period (June thru December) would be 3.34% less (Table 9). The largest amount of fertilizer transported was during the grain harvest period (T1), followed by the grain planting period (T2).

It seems reasonable that the fertilizer freight rate is lowest during the T1 period because this period sees the shipment of soybeans and soybean meal at its greatest; the number of trucks that need to be returned from ports to the Midwest's vast producing region at its peak; and the demand for return freight is at its highest. Fertilizer transported in the T2 period will be less like to form part of a return freight scheme than in the T1 period as fewer soybeans are being transported to export facilities; however, soybeans are still being harvested and shipped during the period leaving the fertilizer as return freight option available, just to a lesser extent. Fertilizer freight rates are their highest in the T3 period. During this period, almost no soybeans are harvested or shipped and the fertilizer as return freight option is, for the most part, unavailable.

Although the T2 period was the period with the highest frequency of actual route utilization (about 53%), attention should be paid to the fact that the number of routes utilized need not translate to amounts of product shipped as many routes traversed may not include large grain handling and export facilities or may offer only limited return freight opportunities. The T1 period has a lower value for route utilization than the T2 period, but during the T1 period more routes are likely to be carrying cargo as return freight from export facilities relative to the T2 period, which would translate to the use of fewer routes to transport large amounts of fertilizer.

The estimated diesel coefficient, given by β_9, is the elasticity of the fertilizer transportation price relative to the mean price of diesel. The coefficient's value indicates that when the price of diesel (R$/liter) increases by 1%, the cost to transport fertilizer (R$/MT) increases by 0.094% if all other variables remain constant. The Department of Operating Costs, Technical, and Economic Studies of the Brazilian National Association of Transportation and Freight Logistics (DECOPE), which represents the Brazilian cargo transportation business, reported that the impact of a 1% change in diesel's price could lead to increases of 0.1 to 0.34% in freight rates (NTC-Logistica, 2015). This minimal impact in 2014 may be related to slowdown in the Brazilian freight market that year. NTC-Logistica (2015) noted that there was excess shipping supply for most of 2014, causing some lag in freight pricing.

Finally, the coefficient of the variable that measures distance traveled in km (β_{10}) indicates that when the distance traveled (km) increases by 1%, the cost to transport fertilizer (R$/t) increases by 0.51% if all other variables remain constant. A large number of studies dealing with the structure of freight cost consider that distance transported is the main factor for determining transportation costs, regardless of the transportation mode employed.

According to Correa Jr. and Caixeta-Filho (2001), increased shipping costs are an inherent result of increased distance transported as variable operating costs, such as fuel, oils, lubricants, and driver time, increase with an increase in distance traveled. Oliveira (1996) and Martins (1998) identified a close direct relationship between distance traveled and the cost of grain transport in the Brazilian state of Paraná. Figure 4 shows a direct relationship between distance transported and fertilizer transport costs. Although the relationship is not one to one, shipping cost tend to be higher the greater the distance transported.

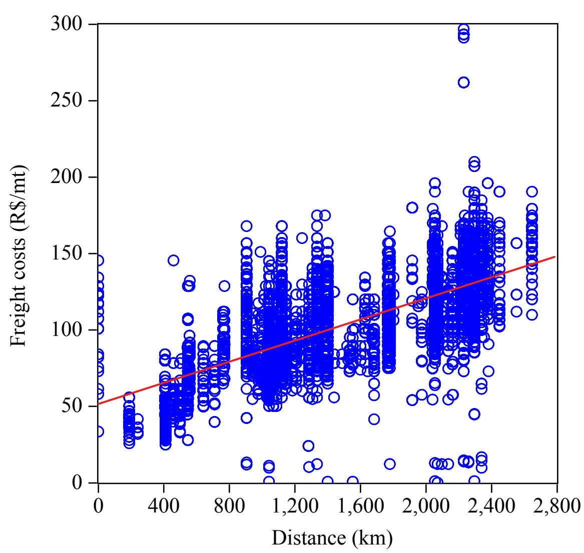

Figure 4. Fertilizer freight costs (R$/MT) × distance (km) from research data of 2016.

6. Final considerations

This study's results show the effect of price variation in several shipping inputs on the final Brazilian fertilizer shipping costs paid by the agent that hired the transportation company and the relative cost difference when shipping fertilizer over different road transport corridors. The study also examined the shipping complex's dynamic and noted the significance of return freight (backhauling) in the control of shipping costs.

It was found that shipping fertilizer though transport corridors linking major Brazilian ports with grain growing regions showed a significant annual average cost advantage over transport corridors linking ports with inland fertilizer industries. This finding most likely indicates the positive benefits of fertilizer as return freight after grain delivery.

Although it appears that the availability of return freight between ports and grain growing regions generates average annual transportation savings, there is no reason to assume this cost savings is spread evenly throughout the year. Fertilizer use and crop harvesting are not concurrent. Transportation price spikes often occur during peak harvest season when shippers must deal with vehicle shortages and transportation, loading, and unloading bottlenecks. It certainly appears that both grain and fertilizer storage facilities should be a priority for any large grain producer wanting to reduce transportation costs.

Corridor C showed the lowest freight rate (R$) among the corridors and was used as the benchmark when comparing the different corridors' freight rates. Routes in this corridor connect the ports of Santos and Guarujá and the fertilizer industries in Cubatão, 12 km from Santos, to Brazil's most important grain growing region, the Midwest. The option to ship fertilizer as return freight through this corridor during the grain harvest should be readily available.

Corridor E showed the second least expensive fertilizer freight rate, 4.62% above Corridor C's. Corridor E is made up of routes between Brazilian fertilizer industries and the country's large grain producing Midwest region. Interestingly, return freight should have had only a minor impact in lowering Corridor E's freight rate, less than in all the other corridors, as none of the routes in corridor E pass near major soybean processing or direct international export facilities. It is assumed that Corridor E's freight rate was greatly influenced by the transport of other products, which would have helped lower its freight rate in general. In addition, all the other corridors involve shipping to and from Brazilian ports. Freight rates in these corridors may have been negatively affected by logistical bottlenecks in the form of an overloaded transport system and congestion at the ports during the grain harvest, thereby reducing the impact of the return freight option relative to Corridor E.

In contrast, Corridor B, which covers the routes connecting the port of Paranaguá with inland fertilizer industries, showed the highest fertilizer freight rate, 37.79% above control corridor C. The high freight rate may be due to a lack of the return freight option as this corridor is out of all grain shipping patterns, and there are relatively major infrastructure inadequacies throughout the corridor and at the port. Although the availability of return freight and infrastructure inequality are two justifiable rational for this rather large transportation cost divergence, there is certainly room for further study to better isolate its causes.

Fertilizer freight rates in Corridors A and D were somewhat similar, 14.5 and 22.23% higher than corridor C, respectively. Corridor A connects the port of Paranaguá and fertilizer manufactures in the nearby city of Curitiba with cities in the grain producing region. Corridor D connects the ports of Santos and Guarujá and the fertilizer industries in Cubatão with inland fertilizer industries.

The methodology applied to complete this study has been found to be valid and can be used to expand the analysis to other transport corridors, other modes of transportation, and other products. The methodology could be further developed through the use of a longer series, more current data, and the separation of freight rates by shipping company. In this context, further studies to capture the impact each company has on generalized fertilizer freight rates could be carried out using the methodology applied in this study with the inclusion of fixed or random effects methods of analysis.

Our study does have one rather significant caveat: since interactions between the demand and supply of grain transportation services are contingent on factors that may have different levels of effect from one year to the next, its results may not be applicable if future conditions, particularly climatic or economic conditions, change appreciably from those in effect during the study's period.

In order to more fully understand and manage the Brazilian transportation system's cost structure, there is a need for further study to examine factors that have been barely touched on in this study. The more obvious of these factors involve logistical deficiencies, such as in the loading and offloading of goods at Brazilian export facilities and in the maintenance and design of Brazil's roadway system. Other factors for future analyses could focus on the state of the Brazilian fleet of transport vehicles and the effect of highway privatizations on transportation costs. The Brazilian transportation system functions, goods move from one place to another, whether they are moved in a timely or efficient manner is a question still to be answered.

By identifying the effect of various shipping variables on the cost to ship fertilizer, this study should help agricultural product producers and fertilizer manufactures plan the most economically advantageous product transportation schedule and determine the actual economic benefit of storage facility investments. The authors of this study hope that our results assist those who depend on the Brazilian transportation system control their transportation costs.

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