

BRAZIL'S NORTHERN ARC PORTS AND THE FROZEN BEEF EXPORT CHAIN: BOTTLENECKS AND ECONOMIC BENEFITS

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ABSTRACT

Consumer demand for consistently high quality meats has exposed a series of problems in the Brazilian frozen beef agro-industrial logistics chain arising from a lack of adequate infrastructure to cope with export flows. Based on interviews with the sector's agents and on a comparative analysis of transportation costs, this paper aims to identify and evaluate infrastructure bottlenecks that affect the Brazilian frozen beef logistics chain and the economic gains that could be achieved by directing more frozen beef exports through the country's Northern Arc ports. Among the results obtained from analyzes of frozen beef export flows from the state of Mato Grosso, the Brazilian state with the greatest number of plants that process beef for export, the use of Northern Arc ports can bring road transportation cost savings of up to 43% for some localities. It was also found that the lack of maritime shipping capacity, whether from restricted port capacity or infrequent ship departures, is one of the main logistical problems impeding the flow of frozen beef from ports in Brazil's north.

Keywords: Northern Arc Ports; Export Flows; Beef;

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RESUMO

Os atributos de qualidade demandados pelo mercado consumidor impõem uma série de dificuldades à cadeia logística de carne bovina congelada. A falta de infraestrutura para o escoamento da produção eleva os riscos aos quais essa cadeia agroindustrial é exposta. Baseado na realização de entrevistas com agentes do setor e em uma análise comparativa de custos de transporte, o presente artigo analisa os gargalos e ganhos econômicos dos fluxos de exportação de carne bovina congelada pelo Arco Norte. Dentre os resultados obtidos com as análises, para o Mato Grosso, estado com a maior concentração de frigoríficos exportadores, a utilização dos portos do Arco Norte traz uma economia de até 43% para algumas localidades. Além disso, a baixa periodicidade dos navios e a baixa capacidade de movimentação dos terminais portuários estão entre os principais entraves logísticos para o escoamento da produção pelos portos da região norte do país.

Palavras-chave: Portos do Arco Norte; Fluxos de Exportação; Carne Bovina;

1 INTRODUCTION

Breeding cattle for the production of beef is an extremely important Brazilian agribusiness. The country has the world's second largest effective cattle herd, numbering about 170 million head (IBGE, 2006). Data from Brazil's most recent Agricultural Census show that the country's largest cattle herd is in the state of Mato Grosso do Sul (20.4 million head), followed by the states of Minas Gerais (19.9 million) and Mato Grosso (19.8 million) (IBGE, 2006). The number of cattle in the state of Pará increased the most between 1996 and 2006, around 119%. Over the same period, the herd in Brazil's northern region, which includes the states of Rondônia, Acre, and Amazonas, grew by 81%, and the herd in the state of Mato Grosso increased about 37%.

Table 1 lists the Brazilian states that showed the greatest increase in the size of their cattle herds between 1996 and 2006. These data indicate that cattle ranching in Brazil, which was once centered in Brazil's southern states, has been migrating to the country's North and Center-West regions (IBGE 2006).

Table 1 - States that presented the greatest increase in cattle population between 1996 and 2006

State	Accumulated Growth (%)
Pará	119.6
Rondônia	115.7
Acre	103.2
Amazonas	57.3
Maranhão	43.3
Mato Grosso	37.2
Roraima	20.2

Source: (IBGE, 2006)

Brazil exported a total of 1.1 million tons of frozen beef in 2006, with Russia, Egypt and other countries of the Middle East being the main destinations for these exports. Ten years later, data from Brazil's Secretariat of External Commerce (SECEX, 2016) shows that 920,000 tons of frozen beef was exported from Brazil, with Hong Kong, Egypt, China, Russia and Iran accounting for about 80% of these exports (SECEX, 2016).

Aspects such as a favorable climate, low production costs, genetic improvement, land availability, a more efficient and intensive production system, and technological innovation are pointed out as factors that have contributed to the growth in the number of livestock in Brazil, as well as for the increase in beef production (FRANCO, 2003). Other important changes spurred this growth: (i) productivity increased; (ii) investment in technology and professional training

was amplified; (iii) public policies that encourage animal monitoring were implemented; and iv) animal health and food safety awareness grew (FRANCO, 2003). Brazilian beef production and certification standards now meet those set in the world's most restrictive international markets, thereby increasing the product's market penetration.

Data from the Brazilian Association of Meat Exporting Industries (ABIEC, 2016) show that Brazil has a total of 83 export certified meat processing plants spread across 13 Brazilian states, with the Center-West state of Mato Grosso having the largest number of export units (18). Brazil's Center-West, Southeast and North regions have the country's highest concentration of these units, representing 44%, 25% and 19% of the total number of Brazilian export certified meat processors, respectively (ABIEC, 2016). The meat processing plants in Brazil's Center-West, North, and Northeast regions are the country's most active, accounting for 45.53%, 14.62% and 15.95% of the beef processed in Brazil, respectively (MAPA, 2016).

With 63% of Brazil's meat processors located in the country's Center-West and North regions and the country's main ports located in its South and Southeast regions, transportation of frozen beef for export results in expressive logistics costs that directly impact the Brazilian frozen beef exporters' revenue. Brazil has maritime export facilities in its northern regions, the Northern Arc ports, which could provide a means of reducing these logistics costs.

The present research has as its objective an analysis of the effect use of the Northern Arc ports would have on Brazilian frozen beef exporters' logistics costs, taking into consideration i) these ports radius of influence, and ii) the main bottlenecks restricting their use in the export chain. In addition, and as a complementary goal, this article employs a sensitivity analysis to draw transportation cost comparisons between use of the Northern Arc ports and traditional ports in Brazil's South and Southeast regions for the export of frozen beef.

Following this introductory section, the article's second section addresses the frozen beef logistics chain in Brazil. The third section details the methodology used in this analysis—interviews with meat export sector agents and a comparative analysis of transport costs. The fourth section presents results from this analysis, and section five contains our conclusions.

2 THE FROZEN BEEF EXPORT LOGISTIC CHAIN IN BRAZIL

According to Caixeta-Filho (2001), proper transportation logistics can be defined as the actions needed to deliver products to the right place, at the right time, under the right conditions while spending as little as possible. In agribusiness, logistics is important in all the productive chain's links, from transport of agricultural inputs to the farm through delivery to the final consumer. Among the agro-industrial logistic chains, the frozen beef export chain has very specific attributes that increase the product's final cost.

The need to control temperature, for example, is one logistic chain necessity that increases complexity in frozen beef export operations. In general, frozen meat for export must be kept at -20° C during transport, requiring the use of refrigerated vehicles. These vehicles have the function of storing and transporting the previously chilled cargo (SILVA, 2010).

The transport of frozen beef intended for maritime export may be carried out by road and rail. Transport by air, a less frequently used tool employed in the frozen beef transportation chain, is used when the product needs to be delivered in less than ten days (SILVA, 2010).

Brazil's highway network, fourth largest in the world, is the main artery used to move products within the country. According to data from CNT (2016), of the 1,720,756 km that make up the Brazilian highway network, only 12% (211,468 km) is paved. The lack of paved roads makes it difficult to consistently move products efficiently, especially over longer distances. This trans-

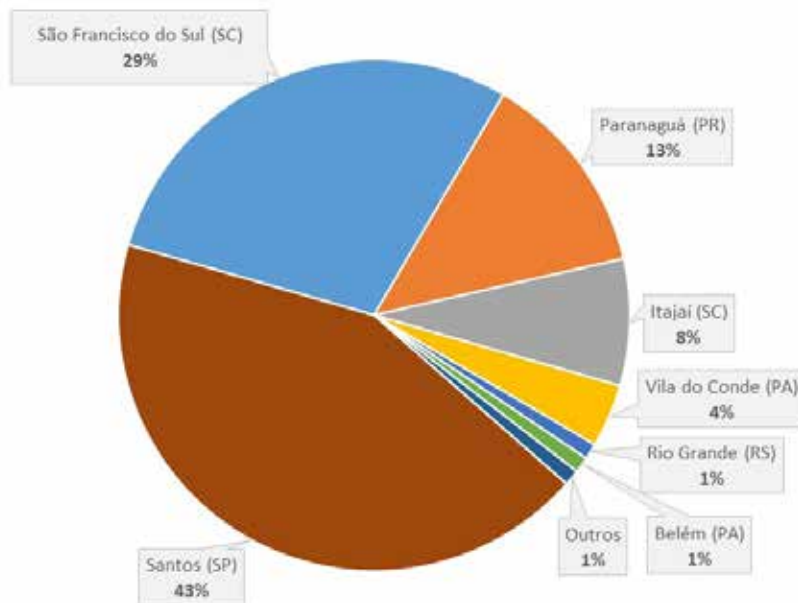
portation infrastructure inadequacy entails high logistics costs that reduce the ability of Brazilian products to compete in the international market (BARBOZA, 2014). Estimates from *Fundação Dom Cabral* (2016) indicate that logistics costs represent 11.73% of Brazilian companies' revenues. Additionally, data from the Brazilian *Instituto de Logística e Supply Chain* (ILOS, 2014) show that 11.9% of the national GDP in 2015 was consumed by logistics costs. It's important to highlight that in the agribusiness industry, the potential impact of logistics costs may be higher, given the product's generally lower value per volume shipped.

The problem of logistics in Brazil lies not only in its highways, inadequacies are also observed in its rail and port infrastructures. The main challenge regarding these two transportation chain links is maintenance of the "cold chain" to ensure that perishable products remain suitable for exportation. In the case of Brazilian ports, a lack of adequate infrastructure makes the export of frozen beef from many of the country's ports impracticable—for example, port terminals must include container holding areas that allow the cold chain to be maintained, usually by providing electric outlets and cold-storage warehouses.

The largest volume of frozen beef exported from Brazil is loaded at the Port of Santos in the southeastern state of São Paulo. In 2015, this port handled approximately 409 thousand metric tons of frozen beef, which represented around 43% of the country's total frozen beef exports (SECEX, 2015). The more southern ports of São Francisco do Sul (SC), Paranaguá (PR) and Itajaí (SC) also presented quite significant amounts of frozen beef exports in 2015: 29%, 13% and 8% of the country's total frozen beef exports, respectively (SECEX, 2015).

These ports have adequate infrastructure to receive and load refrigerated cargo but are located far from the large beef producing centers. The Northern Arc ports, on the other hand, are located closer to the majority of Brazil's frozen beef producing centers and present a potential for the reduction of Brazilian agribusiness logistics costs and an increase in the volume of Brazilian exports. The ports of Vila do Conde and Belém, located in the northern state of Pará, stand out among the ports in this export corridor. Both ports together handled approximately 12% of the total cargoes exported by Brazil in 2015 (SECEX, 2015) but a much smaller percentage of its frozen beef exports. Figure 1 shows the percentage of Brazilian frozen beef exported through individual Brazilian ports in 2015 (SECEX, 2015).

Figure 1 - Brazilian ports export of frozen beef in 2015 by percentage of total frozen beef exports



Source: (SECEX, 2015)

These data show that a significant percentage of the frozen beef exported from Brazil travels long distances over domestic infrastructure before reaching a port embarkation terminal due to the limited availability of more advantageously located, adequate port infrastructure. In total, the port of Santos (SP) has approximately 7,179 power outlets needed to maintain temperatures in offloaded refrigerated containers¹ and 5 cold chambers with 24,000 m³ of storage capacity (Porto de Santos, 2016). The port complex of São Francisco do Sul (SC), which includes the Itapoá private port, has 2,690 power outlets for refrigerated containers and a 20 ton capacity cold chamber, which is used primarily for load inspection (LABTRANS, 2016). The port of Paranaguá (PR) has 3,100 power outlets, plus a specific terminal for frozen products with a capacity of 7,000 tons (APPA, 2016). The port of Itajaí (SC) has 2,382 power outlets for refrigerated containers and a cold chamber with capacity of 6,000 tons. At that port, construction has begun on another cold chamber with a 1,500 ton capacity for inspections and three refrigeration terminals with cold maintenance capacity for more than 2,400 twenty-foot units (Porto de Itajaí, 2016). The presence of this type of infrastructure contributed to these ports positions as the main export channels for Brazilian frozen beef.

On the other hand, the Northern Arc ports have substantially less capacity to receive, store, and inspect refrigerated loads. The Northern Arc port of Belém, for example, has 56 power outlets that can be connected to refrigerated containers and a cold chamber that permits the simultaneous monitoring and inspection of two 40-foot refrigerated containers (CDP, 2016). The Northern Arc port of Vila do Conde's leased area contains a 100 m² cold chamber, which allows up to four simultaneous operations, and 50 power outlets that can be connected to refrigerated containers (CDP, 2016). Exports of frozen beef from the ports of Vila do Conde and Belém increased 189% and 629% (SECEX, 2015), respectively, between 2012 and 2015, but between them, they exported only somewhat more than 32 thousand metric tons of frozen beef at the end of that period. To restate, 409 thousand metric tons of frozen beef was exported from the port of Santos in 2015.

Data presented in this section have shown the discrepancy between Brazil's southern ports and its Northern Arc ports in terms of operational capacity and volumes exported. It is

¹Reefers containers: are refrigerated containers, which allow the accomplishment of the transport with the control of temperature.

worth mentioning that some agribusiness sector products, such as soybean and corn, are increasingly exported in relatively large volumes through the Northern Arc ports, given that the use of these ports reduces transportation costs and the environmental impacts from these products' exportation (VETTORAZZI, 2017). If export capacity and infrastructure at the Northern Arc ports were to be expanded, the frozen beef export chain could realize similar transportation cost and negative environmental impact reductions.

3 MATERIAL AND METHODS

As discussed previously, the analysis carried out in this paper aims to identify the Northern Arc ports' potential to reduce logistic costs associated with the transportation of frozen beef to the external market, specifically those generated by the increasing amounts of processed beef being produced in the northern and mid-western Brazilian states of Mato Grosso, Pará, Acre and Roraima. Two complementary methodologies were employed to achieve this objective, : an analysis of data gathered through interviews and a comparative analysis of freight rates.

The study began with construction of a pre-defined questionnaire that was used during telephone interviews with agents representing meat processing plants certified for export located in the region of interest to gather the following information:

- i. The Brazilian ports through which the plant exports frozen meat;
- ii. Information about the type of transport and contracts used in the plant's logistics operations;
- iii. The main logistical bottlenecks linked specifically with frozen beef export.

Employees representing eight meat processing companies were interviewed. All the companies were qualified for product export and are responsible for managing the production from twenty-two cattle processing plants. The interviews were conducted with people responsible for contracting frozen beef transportation services.

A comparative analysis of road freight rates for the transport of frozen beef was also performed. In this methodological procedure, the ports of Santos (SP), São Francisco do Sul (SC), Paranaguá (PR), Vila do Conde (PA), Belém (PA), Santarém (PA) and Itacoatiara (AM) were defined as frozen beef export sites. The first three ports, located in the South and Southeast regions of Brazil, were selected for the analysis because they are responsible for approximately 85% of the exports from this productive chain. Vila do Conde and Belém were included in the analysis because they are currently the Northern Arc ports that already operate in the export of frozen beef. Finally, Santarém and Itacoatiara were included in the analysis because they are Northern Arc ports where other agribusiness products are exported.

Once the ports were defined, an "origin-destination" matrix was built. The matrix has all 358 *municípios* (municipalities)² in the states of Mato Grosso, Pará, Acre and Rondônia as cargo origination points and seven Brazilian ports as destination points. The matrix of 358 municipalities and seven ports considered in the analysis yielded 2,506 origin-destination (OD) combinations, for which respective origin to destination kilometer distances were obtained using the Guia Quatro Rodas platform (2016).

Distance transported over the Brazilian highway system were used to calculate freight costs (R\$/t) for each origin-destination combination. This calculation was made by structuring a

2 *Municípios* are analogous to counties in other countries in that they are government designated and can be made up of both rural and urban areas; but as they are named for a city in its territory (or visa versa), in this article *municípios* will be henceforth referred to as municipalities. In total, the analysis included the 143 *municípios* of Pará, the 141 *municípios* of Mato Grosso, the 22 *municípios* of Acre and the 52 *municípios* of Rondônia.

linear regression model that has as its dependent variable the 2016 freight rate in the particular market with the route's extension (km) as the independent variable. Freight rate information was obtained from the Brazilian Freight Information System (*Sistema de Informações de Fretes*, [SIFRECA], 2016) database, with data referring to export flows of frozen meat from Brazil's Central-West and North regions in refrigerated containers in 2016. Equation 1 presents the regression model³ used in this data analysis and applied to the calculation of freight road transportation costs of each analyzed OD combination, with variable x being the distance (km) and y the estimated transport cost (in R\$/t)

$$y = 0.169 \cdot x + 62.093 \quad \text{Equation 1}$$

Comparative analyzes were carried out to identify the least expensive logistics solutions for road transportation to export ports.

4 RESULTS AND DISCUSSION

The first set of results to be discussed deals with the interviews carried out with frozen beef export sector agents. The interviews showed that the logistical bottlenecks that often prevent exports of frozen beef from Northern Arc ports are related to infrastructure and logistics problems.

The main limitation set out by exporters is the periodicity of ships used for exportation purposes from the Northern Arc ports of Belém and Vila do Conde, both in the state of Pará. According to the information obtained, ships for the export of refrigerated containers depart from these ports every two weeks. Such periodicity restricts their use for the export of frozen meat because meat processors, normally having very limited static capacity to stock production, must rapidly and continuously release their product. Not only does the reduced supply of maritime transport services at these ports affect their importance as embarkation sites for frozen beef exportation, it also magnifies the impact of the small number operators at these terminals and exacerbates the prices paid for all services, especially refrigeration services.

Port infrastructure was much emphasized in the interviews. The ports of Belém and Vila do Conde have a very limited number of electrical outlets, which are necessary to maintain the containers' refrigeration capabilities. It is worth highlighting that there are no secondary options for the storage of containers near these ports' facilities, which increases the dependence equipment at the port terminals.

Low operational productivity at Northern Arc ports was also noted by the interviewees. It often takes four days to load containers on ships docked at either Belém or Vila do Conde, considerably increasing the logistic costs of transport to the ships, especially since a fee must be paid to keep the containers in the loading area. In addition, the time needed to offload vehicles at port terminals increases the risk of product quality loss, given the difficulty and cost associated with maintaining the cold chain.

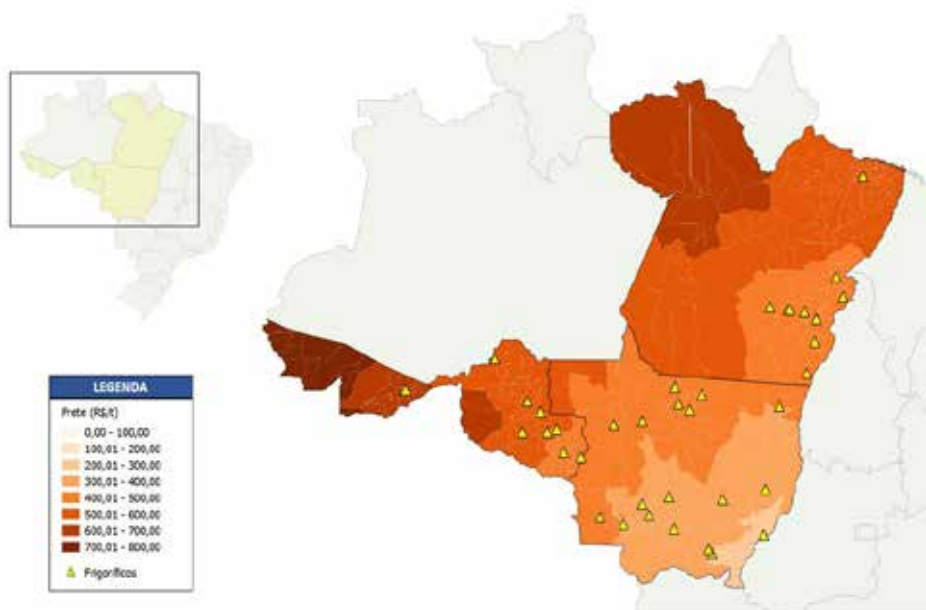
In sum, investments in additional infrastructure and increased service by maritime shippers would permit greater use of the ports at Belém and Vila do Conde in the exportation of frozen beef. The next step in the analysis is to determine if increasing the capacity and productive efficiency of the Northern Arc ports would reduce logistics costs for companies producing Brazilian frozen beef for export.

Information obtained from the interviewees and from the SIFRECA database (2016), shows that frozen beef from processors in the Brazilian states of Mato Grosso, Rondônia and Pará

³ The coefficient of determination (R^2) obtained in the model was 0.9392.

is normally routed to the country's southern and southeastern ports of Santos (SP), Paranaguá (PR) and São Francisco do Sul (SC) for export. Figure 2 shows the estimated lowest frozen beef road transportation costs in R\$/t from all origin municipalities analyzed in this article to these three ports. Darker shades indicate higher transportation costs. Data was gathered from SIFRECA and the Brazilian Association of Meat Exporters (*Associação Brasileira das Indústrias Exportadoras de Carnes* [ABIEC], 2016)

Figure 2 - Minimum cost of road transportation for export flows to the ports of Santos (SP), Paranaguá (PR) and São Francisco do Sul (SC).



Source: Authors, based on data from SIFRECA (2016) and ABIEC (2016).

Frozen meat for export from Acre, the state most distant from the three southern ports, showed the highest logistics costs. The estimated average cost to transport frozen meat from the export certified meat processing plant in the municipality of Rio Branco, Acre's capital, to the port of Santos was R\$ 668.68 per ton. Frozen meat transport costs from the Acre municipality of Acrelândia to Santos was the lowest in the state, R\$ 654.63 per ton.

In the state of Rondônia, the lowest transportation costs were to the port of Santos and are associated with the municipalities of Vilhena and Colorado do Oeste—R\$ 463.78 and R\$ 478.16, respectively per ton. For both municipalities, the port of Santos presented the least expensive logistics solution among the three ports.

In the state of Pará, frozen meat transport costs to the port of Santos from the municipalities of Santa Maria das Barreiras, Santana do Araguaia and Conceição do Araguaia were R\$ 405.61/t, R\$ 409.31/t and R\$ 421.43/t, respectively. These municipalities are all located in the micro-region of Conceição do Araguaia.⁴ The lowest costs for frozen meat transport from Pará's micro-regions were from the aggregated municipalities in this micro-region to the Port of Santos (SP).

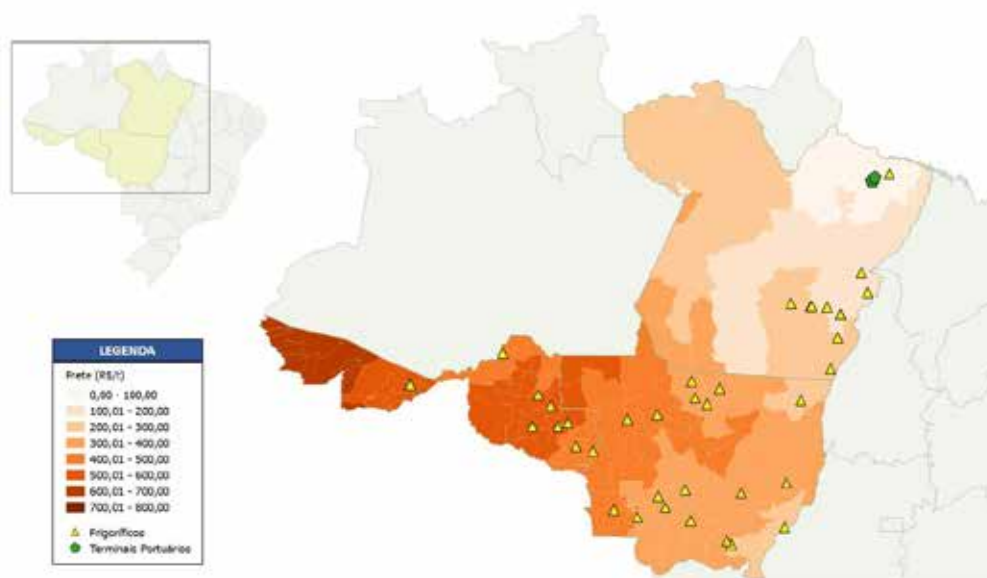
Among the four analyzed states, Mato Grosso presented the scenario's lowest transport costs, with frozen beef transport from the municipalities of Alto Taquari, Alto Araguaia and Alto Garças, located in the state's south, to the Port of Santos being the lowest in the state: R\$ 253.82,

⁴ In Brazil, a microregion is a legally defined area consisting of a group of municipalities (*municípios*).

R\$ 265.37 and R\$ 275.04, respectively. In the state's north, frozen beef shippers in the municipality of Alta Floresta paid an estimated R\$ 470.00 to transport frozen beef to the same port. The Port of Santos was the least costly logistics solution among the southern port options considered for frozen meat exporters in Mato Grosso.

As mentioned above, the ports of Belém and Vila do Conde, despite having limitations in terms of export capacity, are already active in the export of frozen beef. Figure 3 expands the logistics cost comparison beyond the three southern ports noted in Figure 2 to include the Northern Arc ports of Belém and Vila do Conde.

Figure 3 - Minimum road transportation cost to the ports of Santos (SP), Paranaguá (PR), Vila do Conde (PA), and São Francisco do Sul (SC).



Source: Authors, based on data from SIFRECA (2016) and ABIEC (2016).

Estimates show that use of the ports of Belém and Vila do Conde would result in lower road transport logistics costs for the export of frozen beef than would the use of Brazil's southeastern ports for all municipalities in the states of Acre and Pará, and for a number of the municipalities in the states of Rondônia and Mato Grosso.

Taking as an example the municipality of Rio Branco in Acre, by exporting frozen beef from the ports of Belém or Vila do Conde, road transport costs would be reduced by approximately R\$ 100 per ton (15% of total road transport costs) when compared to exporting through the port of Santos. Similar economic gains are estimated for processors in all this state's municipalities, showing the significant impact use of these Northern Arc ports would have to reduce logistics costs for frozen meat exporters in Acre.

A different situation is observed for the municipalities of Vilhena (RO) and Colorado do Oeste in Rondônia (RO). In these cases, the port of Santos remains the least expensive logistics solution, with an estimated economic benefit of R\$ 74.00 and R\$ 61.87 per ton over use of a Northern Arc port, respectively.

Relative to all the studied municipalities, the municipalities of Pará would achieve the greatest economic gain if able to consistently export through the two Northern Arc ports, achieving estimated savings of up to 90% in road transport costs when compared to export flows through the

Port of Santos. Municipalities in Pará's micro-regions of Santarém, Óbidos and Belém in Pará are the most benefited by exporting from the ports of Belém and Vila do Conde rather than Santos.

In the state of Mato Grosso, Northern Arc ports offer cheaper logistics solutions for 48 municipalities (34% of the state's municipalities). The municipalities of Vila Rica (MT), Santa Terezinha (MT) and Confresa (MT) showed the greatest estimated cost reduction by exporting through the northern rather than southern ports—up to a 41% savings in road transport costs. The northern ports are also considered the most economical logistics solutions for the municipality of Alta Floresta (MT). On the other hand, shipping frozen beef for export to the port of Santos rather than a Northern Arc port is most the competitive logistics solution for the state's central and southern municipalities of Alto Taquari (MT), Alto Araguaia (MT) and Alto Garças (MT).

The estimates point to logistics cost savings that can be achieved in many parts of the analyzed regions if the ports of Belém and Vila do Conde were more active in the export of frozen beef. Investments that would enable greater flows through these ports would bring clear benefits to this productive chain, especially to producers in the municipalities of Pará and the northern region of Mato Grosso. Table 2 presents the logistics cost reductions possible through use of the ports of Belém and Vila do Conde rather than Santos for the export of frozen beef. In Table 2, municipalities have been aggregated into micro-regions.

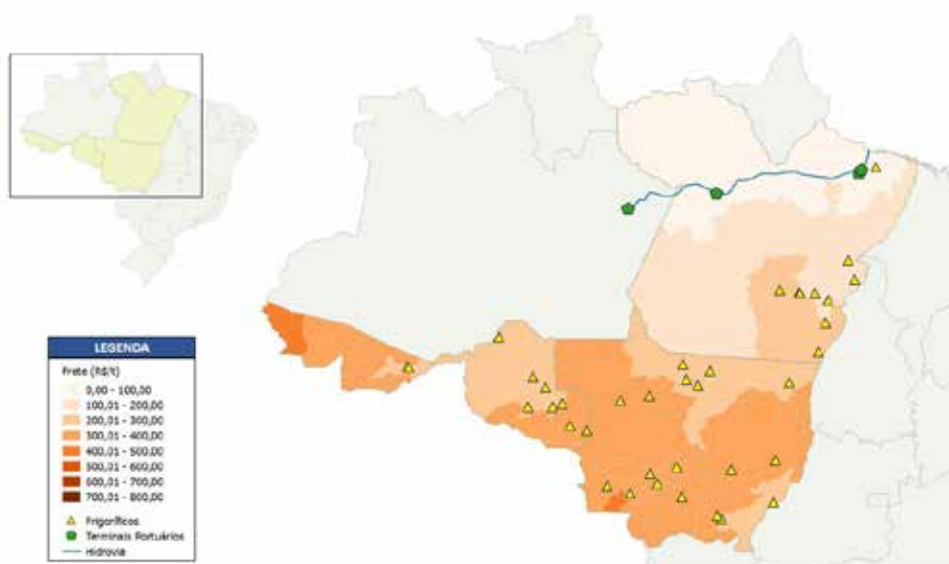
Table 2 – Micro-regions that presented greater savings from the flow of production through the ports of Belém (PA) and Vila do Conde (PA) rather than the port of Santos (SP).

State	Micro-region	Potential savings	Most competitive port
AC	Cruzeiro do Sul	22%	Belém (PA)
	Rio Branco	15%	Vila do Conde (PA)
	Brasiléia	15%	Vila do Conde (PA)
RO	Porto Velho	17%	Vila do Conde (PA)
	Ariquemes	16%	Vila do Conde (PA)
	Guajará-Mirim	16%	Vila do Conde (PA)
PA	Santarém	90%	Belém (PA)
	Óbidos	90%	Belém (PA)
	Furos de Breves	89%	Belém (PA)
MT	Norte Araguaia	41%	Vila do Conde (PA)
	Colíder	22%	Vila do Conde (PA)
	Alta Floresta	19%	Vila do Conde (PA)

Source: Research results.

The Northern Arc ports of Santarém (PA) and Itacoatiara (AM), currently grain export sites, have attracted investments to increase operational capacity. Figure 4 illustrates results of an analysis of frozen beef export costs after adding these two Northern Arc ports to the set of five ports already considered as frozen beef export sites.

Figure 4 - Minimum cost of road transportation to the ports of Santos (SP), Paranaguá (PR), São Francisco do Sul (SC), Belém (PA), Vila do Conde (PA), Santarém (PA) and Itacoatiara (AM)



Source: Authors, based on data from SIFRECA (2016) and ABIEC (2016).

The estimates show that the use of the ports of Santarém (PA) or Itacoatiara (AM) for the export of frozen beef would also reduce transportation costs for exporters located in some of the areas analyzed. Frozen meat exporters located in many municipalities in the state of Acre could reduce their road transportation costs up to 49% by using the Amazonian port of Itacoatiara (AM) rather than the port of Vila do Conde (PA), which prior to the addition of Itacoatiara to the analysis was the least expensive of the road transport destination port considered.

In the state of Rondônia, road transport logistic cost reductions of up to 56% are estimated for the municipalities of the Porto Velho (RO) micro-region if they were to export from the port of Itacoatiara (AM) rather than Santos, and only slightly less impressive reductions if using the port of Santarém (PA). Road transport cost reductions of approximately 29% from their previously lowest cost option (Santos) are also estimated for the municipalities of Vilhena (RO) and Colorado do Oeste (PA) if they were export from the port of Itacoatiara.

In the state of Pará, the potential benefits brought by the use of the ports of Santarém and Itacoatiara are even higher—up to a 78% savings over the cost of road transport to the port of Santos from localities near the port of Santarém. On the other hand, the port of Vila do Conde provides the most cost effective alternative for frozen beef shippers in the municipalities of Conceição do Araguaia (PA), Santa Maria das Barreiras (PA) and Santana do Araguaia (PA).

The ports of Santarém (PA) and Itacoatiara (AM) also contribute to the reduction of frozen beef road transportation costs from municipalities in northern Mato Grosso. The port of Santarém (PA) has significant influence on export costs for frozen meat exporters in the municipalities of Guarantã do Norte (MT), Matupá (MT) and Peixoto Azevedo (MT), providing an estimated freight cost reduction on the order of R\$ 100 per ton, about 22 % less than transport to the second best option—the port of Vila do Conde. A similar level of cost reduction is also observed for frozen beef exporters in the municipality of Alta Floresta (MT). For the municipalities of Alto Araguaia (MT), Alto Garças (MT) and Alto Taquari (MT), in the state's south, the ports of Santarém (PA) and Itacoatiara (AM) do not influence logistics costs associated with the road transport of frozen beef.

Table 3 lists the micro-regions of each state that showed the greatest transport cost reduction if exported frozen beef departed Brazil from the ports of Santarém (AM) or Itacoatiara (AM) rather than the more southern ports considered in Table 1.

Table 3 – Micro-regions that presented the greater savings from the flow of production through the ports of Santarém (PA) or Itacoatiara (AM) rather than the port of Santos (SP).

State	Micro-region	Potential savings	Most competitive port
AC	Rio Branco	49%	Itacoatiara (AM)
	Brasiléia	46%	Itacoatiara (AM)
	Sena Madureira	44%	Itacoatiara (AM)
RO	Porto Velho	56%	Itacoatiara (AM)
	Ariquemes	52%	Itacoatiara (AM)
	Ji-Paraná	51%	Itacoatiara (AM)
PA	Santarém	78%	Santarém (PA)
	Almeirim	78%	Santarém (PA)
	Itaituba	78%	Santarém (PA)
MT	Aripuanã	43%	Itacoatiara (AM)
	Alta Floresta	33%	Santarém (AM)
	Colíder	32%	Santarém (AM)

Source: Research results.

The results discussed above show that investments to increase operational capacities at the ports of Vila do Conde (PA) and Belém (PA) can significantly contribute to increase the exportation of frozen beef by northern and mid-western Brazilian meat processing companies by reducing their domestic road transport logistics costs and improving their position in the international market. These ports already handle export flows from this agro-industrial chain, but their terminals' limited capacities are major factors restricting these flows. As a consequence, the great majority of frozen beef originated in Brazil's northern regions and destined for export is transported to ports in the country's south and southeast regions, entailing much higher logistics costs. In a hypothetical scenario, there would significant additional transport cost reductions for this product's producers in the four states considered if investments were made to open the Northern Arc ports of Santarém (PA) and Itacoatiara (AM) to the export of frozen beef.

5 FINAL CONSIDERATIONS

The analyzes presented in the previous sections shows that inadequate and limited cargo handling capacity at Brazil's Northern Arc ports makes it difficult to use them to increase export flows and reduce Brazilian frozen beef prices in the international market. In addition, the infrequent ship arrivals and departures scheduled by the few shipping companies serving the two Northern Arc ports where noteworthy frozen beef exportation currently occurs, Vila do Conde and Belém, and the two ports minimal static capacity for receiving and storing refrigerated containers create other major bottlenecks restricting these ports use for frozen beef exportation. This set of problems makes ports in Brazil's South and Southeast regions the ports of choice for the country's frozen beef exporters, despite being much farther from many of the country's main frozen beef processing plants than ports in the country's North region.

Estimates presented in this paper show the potential road transportation cost reductions that expansion of Northern Arc ports could bring to Brazilian frozen beef exporters. These

estimates should be of aid to frozen meat exporters when determining where to locate future meat processing plants in the states of Mato Grosso, Acre, Pará and Rondônia and in discussions with other stakeholders regarding Brazilian transportation infrastructure improvements.

Our study made clear that investment to increase utilization of Brazil's Northern Arc ports would significantly reduce logistics costs for domestic frozen beef exporters and increase their competitive position in the international market. Policies to promote development should therefore prioritize increasing these ports' operational capacity, and government representatives should encourage maritime shipping companies to serve them more frequently.

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Contribution of authors

Contribution	[Author 1]	[Author 2]	[Author 3]	[Author 4]
1. Definition of research problem	√	√	√	
2. Development of hypotheses or research questions (empirical studies)	√	√	√	√
3. Development of theoretical propositions (theoretical work)	√	√	√	
4. Theoretical foundation / Literature review	√	√		
5. Definition of methodological procedures	√	√	√	
6. Data collection	√	√		
7. Statistical analysis	√	√	√	
8. Analysis and interpretation of data	√	√	√	
9. Critical revision of the manuscript	√	√	√	√
10. Manuscript writing	√	√		
11. Other (please specify)				