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Enhancing the Port of Rotterdam's Container Forecast Model for Brazil using the Intranational Gravity Equation

by

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I am sure that this thesis experience will help me in the future as I grow into a prominent maritime professional.

Abstract

Port of Rotterdam (PoR), one of the shareholders of Port of Pecém in Ceará, Brazil, was surprised by the exceptional compound annual growth rate of 14% cabotage container volumes in the Port of Pecém in the past 13 years. This growth has affected the amount of container terminal investment needed in the Port of Pecém. This is one example of how important forecasting is for port developers. This research aimed to improve the Port of Rotterdam's container forecast model for Pecém. It is split into two parts, a review of PoR's model to see whether or not there was outstanding market circumstances and an intranational container forecast for Ceará in order to get more accurate throughput numbers.

The first part of this research involved a review of the PoR's forecast model for Brazil. PoR's Brazil model was based on the gravity equation, which was one of the most prominent economic trade models. The review showed that there was a market factor regarding cabotage trade volume. This thesis author decided to follow this approach and apply it to Ceará's cabotage container trade. This became the first academic instance that this economic model was applied in Brazil to quantify cabotage trade.

The second part was a linear regression analysis. It was found that the main drivers for cabotage container trade in Brazil were their Gross Domestic Product (GDP) and the population of the trading states, distances, coastline accesses, cabotage container fleets, and freight rates. The author came up with three scenarios to forecast the throughput until 2030. The most optimistic scenario forecasted a significant growth, from 176.000 TEUs in 2020 to nearly 412.000 TEUs by 2030 for both the in and outflows. The direct implication of this forecast is for the Port of Pecém to expand its existing capacity of 500.000 TEUs after 2030.

The main finding of this research is that this forecast did not perform well in comparison with the past couple of years' throughputs. In the academic realm, this research showed that the gravity equation is not the ideal method to find out the reason behind the cabotage container trade flow in Brazil.

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List of Abbreviations

ANP	Brazil National Petroleum, Natural Gas and Biofuel Agency
ANTAQ	Brazil National Waterway Transportation Agency
CAGR	Compound Annual Growth Rate
CEPII	Centre d'Etudes Prospectives et d'Informations Internationales
CIPP	Complexo Industrial e Portuário do Pecém
Clarksons' SIN	Shipping Intelligence Network
DWT	Dead-weight Ton
GDP	Gross Domestic Product
HSFO	High Sulfur Fuel Oil
IBGE	Brazil Geography and Statistics Institute
IPCA	Extended National Consumer Price Index
MSE	Mean Squared Error
OLS	Ordinary Least Squares
ONTL	Infra S.A.'s Brazil National Transport and Logistic Observatory
PoR	Port of Rotterdam
R$	Brazilian Real
RVO	Netherlands Enterprise Agency
S.A.	Sociedades Anônima, Brazilian limited liability company
TEU	Twenty-foot Equivalent Unit
UNCTAD	United Nations Conference on Trade and Development
VLSFO	Very Low Sulfur Fuel Oil

Brazil Federative States

AC	Acre		PB	Paraíba
AL	Alagoas		PE	Pernambuco
AM	Amazonas		PI	Piauí
AP	Amapá		PR	Paraná
BA	Bahia		RJ	Rio de Janeiro
CE	Ceará		RN	Rio Grande do Norte
DF	Distrito Federal		RO	Rondônia
ES	Espírito Santo		RR	Roraima
GO	Goiás		RS	Rio Grande do Sul
MA	Maranhão		SC	Santa Catarina
MG	Minas Gerais		SE	Sergipe
MS	Mato Grosso do Sul		SP	São Paulo
MT	Mato Grosso		TO	Tocantins
PA	Pará			

1. Introduction

1.1 Background

Ports are essential infrastructures for the economic growth of a region, but they are highly capital-intensive. They take a long time to build, and it takes even longer to see the return on investment, often spanning over at least 25 years (De Langen, Van Meijeren, & Tavasszy, 2012). Each port is different in shape and size as it depends on, among others, its hinterland needs, geographical characteristics, and available feedstock. Therefore, forecasting is very important for port developers, such as the Port of Rotterdam (hereafter this text will be abbreviated as PoR), to adjust and calculate the investment needed to serve the demand.

Brazil is one of the largest economies in the world, although it is still a developing country that is heavily reliant on goods trade. In 2022, they exported goods up to 334 billion USD to the top five export partners, including China, EU, USA, Argentina, and Chile. Merchandise import flow alone was 292 billion USD in 2022, with the top five partners being China, USA, EU, Argentina, and India (WTO, 2023). Approximately, 95% of their trade went via ships (Brazil Ministry of Foreign Affairs, 2023).

In that year, all Brazilian ports handled 1,2 billion tons of cargo that was split into four major commodity types (as shown in figure 1). Dry bulk mainly consisted of 360,6 million tons of iron ore and 99,4 million tons of soybeans. Liquid bulk was represented mostly by crude oil and derivatives, totalling up to 199,4 million tons. Meanwhile, 128 million tons of containers included 7,9 million TEUs of export and import flows, 1,8 million TEUs of cabotage, and 0,8 million TEUs of inland waterways trade. The cabotage here refers to the trade between seaports in Brazil using ships.

The historical numbers showed that from 2010 to 2023, the total container throughput grew from 6,6 million TEUs up to 10,4 million TEUs (as shown in figure 2). Within 13 years, the size nearly doubled with a CAGR of 3,57%. A breakdown of the CAGR between the type of container flows showed that cabotage grew at 9,53%, which

was faster compared to the growth of export-import (long haul) at 2,62% and the inland waterways at 4,34%.

Figure 1 Share of goods handled in Brazil ports year 2022
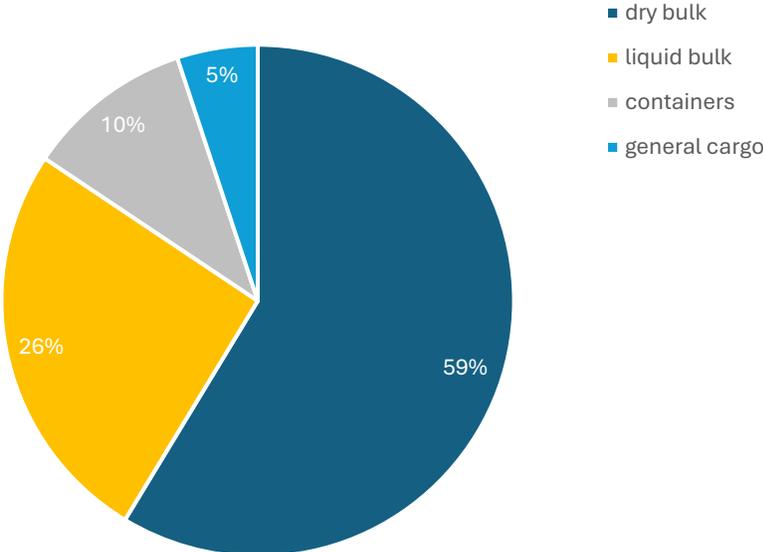
Source: (ANTAQ, 2024)

Figure 2 Brazil container throughput 2010-2023 (TEU)
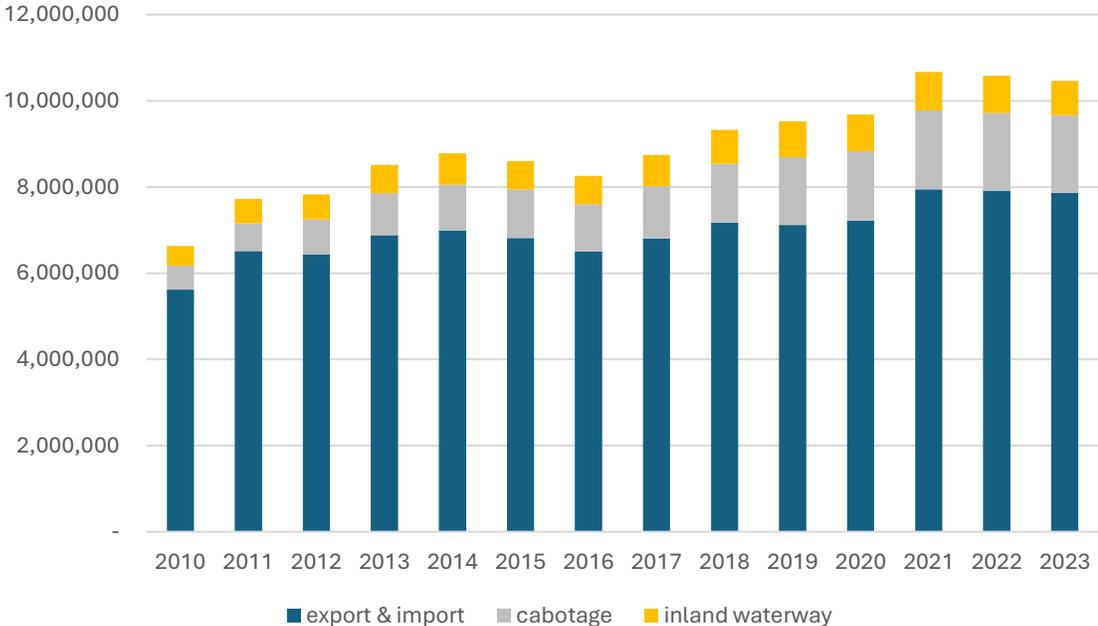
According to the Brazilian Law No. 8630 year 1993, there are two types of ports in Brazil: public and private. The difference lies in the ownership of assets and contracts. Private ports, mostly in the form of terminals, own everything, whereas public ports lease their assets and contracts to private parties through concession. There is no distinction by commodity type, but there is a factual split where containerized cargo is mainly handled by the public ports and bulk cargo by private ports. (RVO, 2020, pp. 11-14)

The Brazilian container market is primarily served by container ports located in the South and Southeast regions of the country, such as Santos, Itapoá, Paranaguá, and Navegantes (as shown in Figure 3). This prominence is in line with the population concentration in those regions. In contrast, ports in the North-East, including Pecém, represent a smaller share of the national container throughput.

Figure 3 Major Brazilian container ports by volume, 2020 (million TEU)
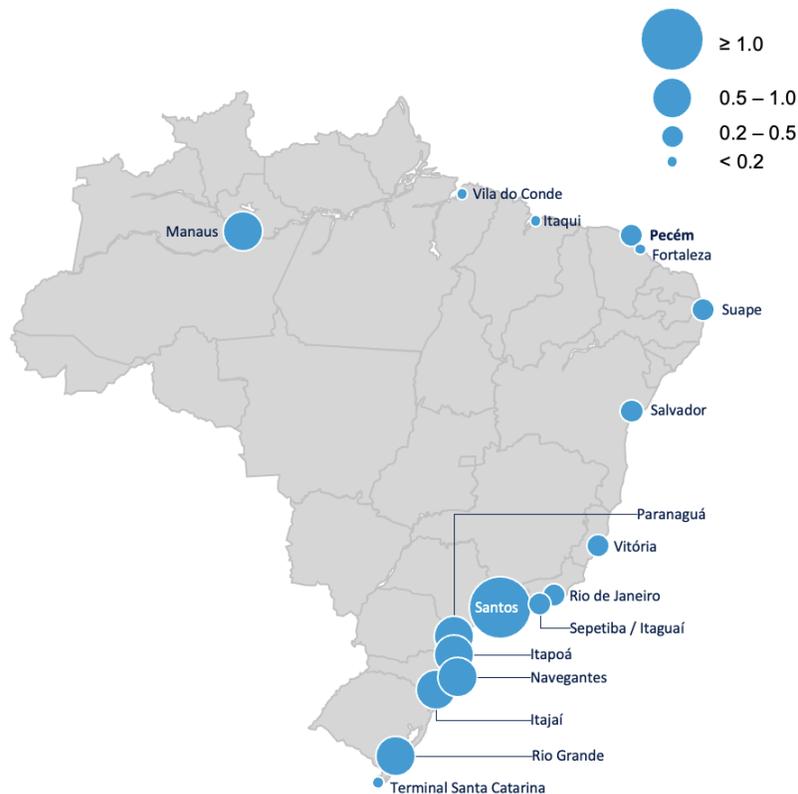
Outside of the Netherlands, PoR has been a shareholder of two ports: the Port of Sohar (Oman) since 2004 and the Port of Pecém (Brazil) since 2018. In Pecém, PoR owns a 30% share of a joint venture, together with the State Government of Ceará (70%), called CIPP (Pecém Industrial Port Complex). In terms of infrastructure, it has multiple terminals for all commodity types (as shown in Figure 4) with water depths up to 15,7 meters. It is supported by 19.000 Ha industrial areas and 6,8.000 Ha export processing zones directly behind it.

Figure 4 Port of Pecém aerial view

Source: (CIPP, n.d.)

Unforeseen growth in container flows, surpassing even the optimistic scenarios forecasted by PoR, has brought attention to the container market of Port of Pecém. Figure 5 below shows that the container throughput growth for Port of Pecém was dominated by cabotage throughput (shown in shades of grey in Figure 5) from 2015 onwards. Cabotage's share began at 36% in 2010 and grew to 85% in 2023. The most optimistic scenario of PoR's Brazil Model stated that the expected throughput was around 314.000 TEUs in 2022. In reality, the volume increased to 417.000 TEUs (see Figure 6). The author was hired as an intern to better understand Brazil's container throughput flows and pinpoint the reasons for such unforeseen growth.

Figure 5 Port of Pecém container throughput 2010-2023
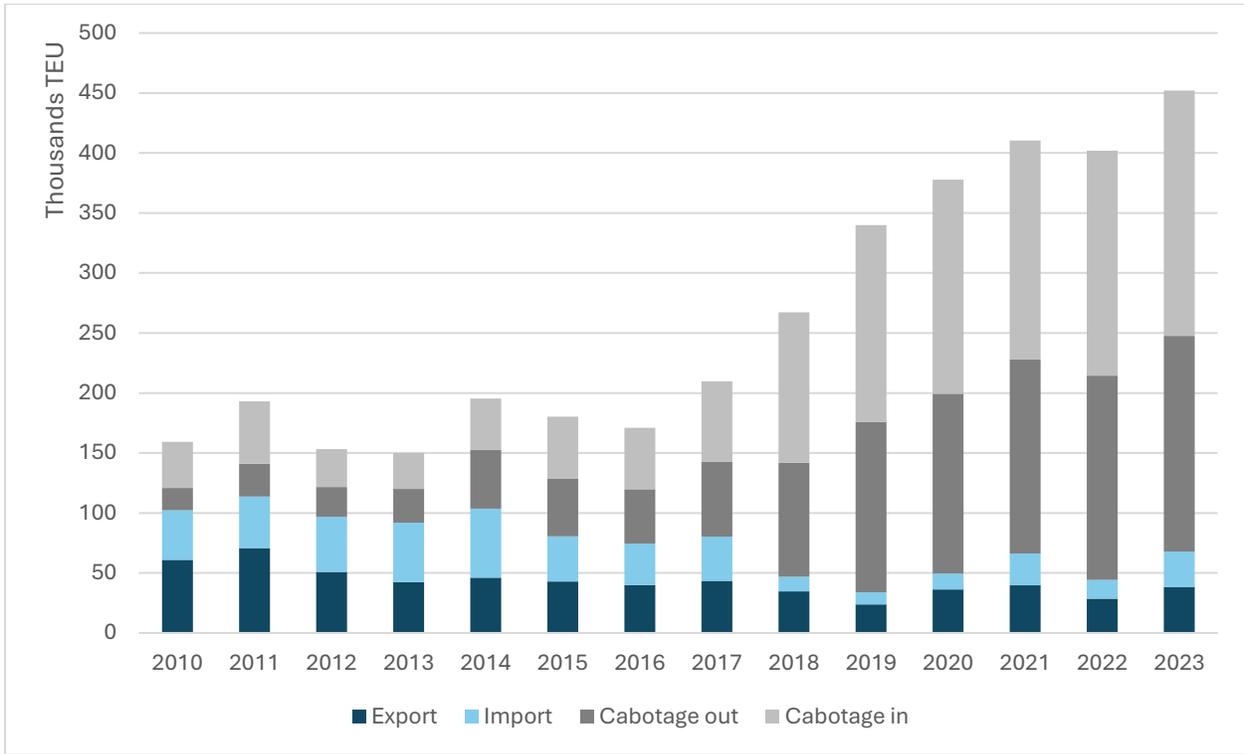
Source: (CIPP, 2024)

Figure 6 Pecém container throughput projections (2022) in K TEUs
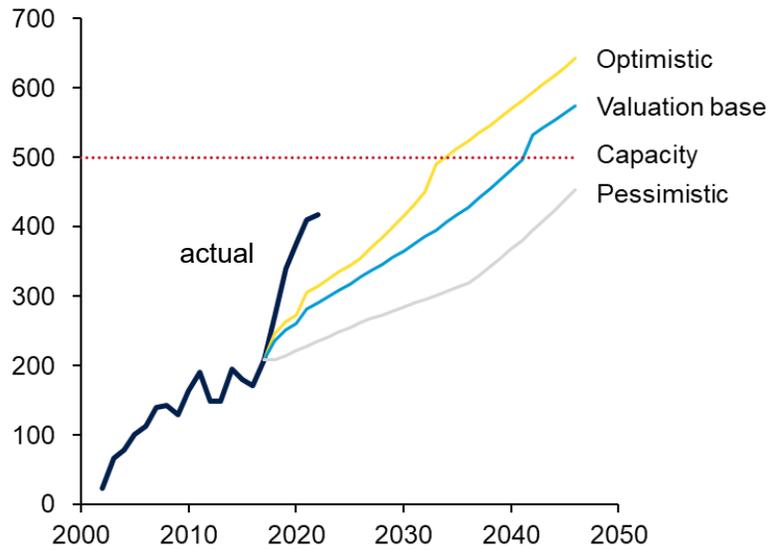
Source: PoR

1.2 Research Question

The overall research objective is to find out:

"How can Port of Rotterdam's container trade flow forecast model for Brazil be improved?"

Some sub-research questions that can help answer the question above are:

1. What is the forecasting methodology used by the Port of Rotterdam?
2. What are the strengths and weaknesses of the current model?
3. Was there a model failure or an outstanding market circumstance?
4. What are the drivers for cabotage volume?
5. How should the cabotage volume be modeled?
6. What is the result of the backcasting of the updated model?
7. What is the market share of Pecém Port in the updated forecast?
8. What is the 10-year forecast for Ceará and the Port of Pecém?

1.3 Research Design

The first part of this research was dedicated to reviewing PoR's latest forecast model for Brazil which was made in 2020 (hereafter this text will be stated as PoR Model). PoR Model was based on a basic gravity equation for the international trade flow and then followed by a simple regression based on GDP and population for the cabotage flow. The review was to determine whether all the necessary steps have been taken to ensure a working gravity model or it has considered unpredictable market circumstances.

The latter part of the research explained the backcasting and forecasting of the updated model to see whether factors of container growth can be identified. The author used a literature review and interviews with colleagues from PoR that either involved in container forecasting or worked in the Port of Pecém to identify the variables to be tested. The test was done using OLS, which then benchmarked to different models through the MSE method for the backcast and forecast results.

Regarding the technicalities of the research, the statistical programs used were Microsoft Excel and R. PoR's model was created using Microsoft Excel and the author also used the same program to construct data frames. R was used for regression analysis

and to create the predictions. Empirical data were obtained through desk research from publicly available information. Several interviews were also conducted with relevant stakeholders in the Port of Rotterdam office and the Pecém office to gain market insights and test hypotheses.

1.4 Limitations

There were two constraints of this research: the language and data quality. The author relied on Google Translate to translate the Brazilian government websites and Portuguese research papers into English. Lastly, it is only recently that the ANTAQ statistics improved their quality. Therefore, the data set available only began in 2010 and for several variables, multiple sources were needed due to the wide spectrum of the research subjects.

1.5 Thesis Structure

After the introduction, the next part described the literature review on three major topics: container forecast, gravity equation, and cabotage in Brazil. It is then followed by the methodology section, showing the updated model equation, data description, and research variables. The author later reviewed the PoR model and added the updated model regression analysis results, benchmarking, and drafted scenarios to present the new forecast results.

2. Literature review

This section's objective is to establish a proper understanding of this research's methodology and context. The literature was collected in May – July 2024 from the Erasmus University Library collection of books and papers and Google Scholar. Additional sources included reports from international organizations. Keywords used are similar to the sub-sections below because of the deductive approach that the author used: starting from the general concept of container forecast, then to one of the most used methods that was also used by the PoR which is the gravity trade model, and finally narrowing down on cabotage in Brazil.

No period limitation was placed, and only papers to which the Erasmus University has access, including those from journals and publicly accessible files, were collected. The first step of filtering the papers was by reading the title and abstract and the author successfully collected 125 papers. The author then created a literature review matrix to dissect the contents of these papers and narrowed it down to 38 titles that were published from 2000 to 2023. 7 of the papers were in Portuguese, especially on the topic of Cabotage in Brazil. These papers were translated into English using the Google Translate document translator.

2.1 Container Forecast

In the introduction, the importance of forecasting has been stated. According to Stopford, the first step to a forecast discussion is to accept that shipping forecasts are often wrong but, paradoxically, forecasts are still needed due to the uncertain nature of this world (Stopford, 2009, p. 700). Stopford properly explains the basic concepts of forecasting that starts from relevance, research, and rationale. Additionally, they mentioned various kinds of forecasts that are needed by different stakeholders throughout the maritime sector.

For this research, from the perspective of a port authority or developer, what is important for PoR is the cargo volume forecast for at least 5-10 years to establish a proper business plan and strategy (Stopford, 2009, p. 710). Therefore, the first part of the literature review is dedicated to understanding the multiple current ways to forecast and seeing which one is better for PoR. The author investigated various methods that were used to forecast container throughput.

The author observed thirteen journals regarding the topic of port container forecast. Only one of them used a qualitative model based on Delphi interview. The rest used quantitative models and sometimes even more than one method to determine which method works best. In total twenty three methods were mentioned, but the most commonly used was variations of regression, starting from a simple single variable regression, ARIMA, SARIMA, and a multivariate gravity model.

Jansen wrote in their thesis on forecasting container cargo that there are many techniques, and each has different effects depending on the type of port observed (Jansen, 2014). They assessed a few of them and concluded that a proper container forecast should be based on GDP as well as port competition and complemented with qualitative observations to modify input variables.

A similar approach from Jansen was also applied by Darabi and Suljevic where they discussed several forecast methods and then ultimately produced their own model to forecast the container throughput of a confidential shipping company. Moreover, they were also very structured in their approach, from identifying the strategic goals to applying their forecast results (Darabi & Suljevic, 2015).

Tsai and Huang's research was more challenging as it looked at more than one port throughput. They used the artificial neural network method to collect the trade flow information and then used a regression model based on general economic statistics. This method was accurate for large container terminals such as Hong Kong. Error factors were successfully identified due to the import and export value assumptions (Tsai & Huang, 2015).

There was also a doctorate dissertation written by Rashed on the same topic of container throughput forecast for ports. They started with a univariate time series model (ARIMA), added another regression dynamic time series with multiple variables, and finally applied scenarios to create a long-term forecast for 2050 for the Port of Antwerp. They also commented on the general forecasting practice which heavily depends on available data and market conditions of the port observed. (Rashed, 2016)

Gosasang et al. also used a regression analysis but complemented it with a vector error correction model. This method, which was newly applied to Bangkok Port, was used by observing 16 years of throughput. Later, the forecast result was translated into container terminal supra-structure investment requirements. (Gosasang, Yip, & Chandraprakaikul, 2018)

Meanwhile, Ducruet et al. created a massive global gravity model between 9000 ports and 4600 cities. The cities were categorized by their proximity to ports. They

concluded that ports and cities do depend on each other. They also confirmed the traditional insights from gravity regarding GDP and distance. (Ducruet, Itoh, & Berli, 2020)

Across the papers that the author found, there was only one (written by Matczak) that specified national-level forecasting. They came up with a simple short-term forecast method using throughput and TEU index based on the GDP and population of Poland. By comparing Poland's internal and EU28 trade data from 2008-2017, they managed to create a five-year forecast which showed that the 2018 forecast was 6% less than the actual numbers. (Matczak, 2020)

One of the latest papers by Shankar et al. became one of the firsts that utilized machine learning to forecast container volume. Long-short-term memory (LSTM) network also uses multiple variables in forecasting, considering external variables through a triple-bottom-line approach including environmental, economic, and social factors. The research object in this case is the Port of Los Angeles throughput from 1995 to 2018. The statistical tests for their proposed combined method of ARIMAX and LSTM technique provided higher accuracy compared to the commonly used ARIMAX and VAR. (Shankar, Punia, & Ilavarasan, 2021)

Forecasting could also be done using qualitative measures. Bathke et al. did so using the Delphi-based interview method to figure out future projections. Interviews were done with relevant stakeholders in the maritime container shipping experts, professionals, and academics. The initial 96 projections from desk research and a large number of interviews were narrowed down to the final 3 scenarios through workshops and discussions. The conclusion did not state the exact shipping volume but a recommendation for long-term strategies for shipping firms. (Bathke, Münch, von der Gracht, & Hartmann, 2021)

Nieto et al. incorporated a forecasting method from the air transportation industry, which is a combination of ARIMA, GARCH, and Bootstrap models. However, this model was not as accurate as the support vector regression model in forecasting container throughput for both the export and import flows. Cargo demand is primarily impacted by economic indicators, more so than cargo flow time series, which only represent trends, seasonality, and variability. (Nieto, Carmona-Benitez, & Martinez, 2021)

Stamer also used the machine learning method called the east absolute shrinkage and selection operator (LASSO) which is combined with the partial least squares model. It does require input data of ship AIS positions, but the result was accurate for 76 countries and regions. (Stamer, 2023)

PoR created their forecast together with Oxford Economics for the port complex up to 2050. They used a mix of quantitative and qualitative methods that were able to identify several cargo drivers. The eight drivers used were geopolitical stability, government spending, consumer behavior, climate change, energy transition, CSR, production cost, and transportation. A combination of these drivers was developed into four different scenarios with various throughput volumes ranging from 400 to 580 million tonnes of cargo and a diverse mix of cargo types in each scenario. (PoR, 2022)

In general, the author observed that there are two major groups of forecast methods: univariate based on only the throughput, and multivariate based on multiple other factors. Out of the twenty three methods discussed, regression was the most commonly used method. The author shall explain later in the methodology section which method would be the most ideal for PoR as a port developer.

2.2 Gravity Equation

Particular attention was given to this topic because this was the base model that PoR's International department uses to forecast international container trade flow. It is also one of the most long-standing economic models that has been well-developed ever since the days of Tinbergen in the 1960s (Tinbergen, 1962). The traditional basic model was based on GDP, country size, and proximity as it was inspired by Newton's natural gravity theory (as shown in Equation 1).

Equation 1 basic economic gravity equation

$$X_{ij} = GS_i M_j \varphi_{ij}$$

X_{ij} = monetary exports value from country i to j

G = global factor that is irrelevant to each country, for example trade liberalization index

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S_i = exporter factors such as GDP, population, etc.

M_j = importer factors such as GDP, population, etc.

Φ_{ij} = ease off market access from I to j, the flip side of trade costs

Equation 2 is another way to write the gravity equation when it is utilized to analyze using OLS and normally applying a natural logarithm to reduce the skewness of GDP values.

Equation 2 gravity OLS format

$$\ln X_{ij} = \ln G + \ln S_i + \ln M_j + \ln \varphi_{ij}$$

Unlike most models, it was developed from empirical research rather than a theoretical background. The theoretical basis for this model came a bit later than the actual model. The first was done by Anderson in 1979 when they modeled goods by the origin country and consumer preferences. Larger countries import and export more because the national income is a sum of domestic and external demand for each unique good. (Anderson J. E., 1979)

Bergstrand also showed that the gravity equation could also be derived from Krugman's monopolistic competition trade model. In his model, countries with similar GDP and population characteristics trade different goods, which again shows the existence of customer preference (Bergstrand, 1985). Another economist who investigated this was Deardoff when they tried to use newer data inputs to check the theory. Deardoff also found that the gravity equation was able to explain trade based on factor endowments (Deardoff, 1998).

Besides distance, other factors are customarily used to derive trade costs, such as dummies for islands, landlocked states, common borders, language, former colonial relationships, and trade agreements (UNCTAD, 2012, p. 106). More and more research, including this thesis, explored other variables to gain a better performing estimate. Anderson and Van Wincoop added their take on trade costs that it should be weighted instead of merely relative (Anderson & van Wincoop, 2003).

A review of a gravity equation can be done using terms found by Baldwin and Taglioni. The gold medal mistake is when trade cost variables are omitted. The silver medal mistake is when reciprocal trade flows are averaged, and the estimated results are better if export and import flows are separately analyzed. Lastly, the bronze medal mistake is for inaccurate deflation of GDP and trade flow value. (Baldwin & Taglioni, 2006)

This next method has been used to forecast container trade in a couple of research. Back in 2006 Wilmsmeier et al., added port infrastructure condition, efficiency, private participation, customs delay, and connectivity as variables that captured port characteristics. The model was developed to calculate international maritime transport costs and they indeed highly impact trade costs (Wilmsmeier, Hoffman, & Sanchez, 2006). Again, Hoffman contributed to the same topic but focused more on another variable: liner shipping connectivity. They revised this variable and then tested it using the gravity model to see its impact on international trade. (Fugazza & Hoffman, 2017)

Regarding the territorial scope, intranational trade has also been a subject of research since a while back. Wolf investigated commodity flow between USA states and found that there is a home bias. It means that it traded three times more between themselves compared to international trade with Canada (Wolf, 2000). More recently, Fujii used intra-Japan trade flow to simulate no-artificial-trade restriction and then compared it with international trade to explain the "trade openness" variable in the context of the gravity equation. (Fujii, 2019)

Based on the literature that the author has observed, this thesis would be one of the first to use the gravity equation in a country-specific setting, specifically on container cabotage cargo flow.

2.3 Cabotage in Brazil

The author managed to collect eleven papers on this topic. The majority of them were written originally in Portuguese, which the author then translated into English using Google Translate. One can say that cabotage is gaining popularity as a research topic since five of them were published in 2021 and 2022. None of these papers used gravity equation or economic trade model analysis as a method.

Four papers described the cabotage context from desk research. It is best to start with Casaca & Lyridis who gave an overview of global cabotage regulations. They classified countries around the world based on the strictness of their regulation, policy instruments, and rationale. Brazil falls under the definition of "controlled protectionist" because it allowed foreign vessels under certain conditions (Casaca & Lyridis, 2018, p. 229).

ANTAQ, Brazil's national waterway transport agency, defined cabotage in Law no. 10,893/04 as navigation carried out between Brazilian ports, using maritime and/or inland routes. This, for example, includes the route from Fortaleza to Manaus that partly goes through the Amazon River and partly by sea. This definition was written the same way between Fonseca (Fonseca, 2015), Machado (Machado, Souto, & Carvalho, 2021), and Röhm (Röhm, 2022). The content of these three papers was quite similar as they talked about the history of cabotage, how cabotage had a small share (between 11-15% in the past decade) and then the benefits of cabotage in price, safety, sustainability, etc.

The benefits of cabotage were then more clearly defined by three other papers that utilized interviews as qualitative research methods. Novaes' research, which used stated preferences or utilities and multinomial logit, concluded that fare and reliability are the most important aspects when selecting different modes of transport according to shippers (Novaes, Gonçalves, Costa, & Santos, 2006). Bender et al., building upon previous research by also adding the Nested Logit model to the survey, found that for shippers in Rio Grande do Sul, fare and reliability were the most important attributes (Bender, Uriarte, & Tapia, 2021). Lastly, Junior and Nunes employed the Multicriteria Decision Aid method in their survey and scored the evaluation of container cabotage past activities. Security scored highest at 9,1 out of 10 and other parameters (service level, route, cost, reliability, and information quality) scored close to 7 out of 10. (Junior & Nunes, 2022)

A few of these papers used quantitative methods to derive the cabotage drivers. Yoshizaki et al. used a linear programming model to examine how a container shipping company should combine international and cabotage container volumes. They concluded that combining these two types of container flows on a single ship will increase utilization

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and productivity (Yoshizaki, Hino, & Chebat, 2013). Another research was done by Sousa and Leopoldino by utilizing a case study on a metal-producing company. A cost-benefit analysis was used to see how the company decided to transport using cabotage instead of other modes of transport (Sousa & Leopoldino, 2018).

In 2020, Brazil published a new law called BR do Mar that had the objective of increasing the number of cabotage services. This rule allowed Brazilian shipping companies to also bareboat charter a foreign vessel while before, only Brazil-flagged ships may be used to serve cabotage services. ANTAQ mentioned that they hoped for an increase in fleet capacity by 40% and 30% per year volume growth. (ANTAQ, 2020)

One more forecast that should be highly noted is from Brazil's Ministry of Infrastructure. They drafted a very comprehensive national logistics plan for 2035 back in 2021. The report encapsulated all aspects of transportation, for both goods and persons, through all modalities from land, sea, and air. They used origin-destination matrices of both freight volume and value. They came up with 9 different scenarios based on different growth assumptions, infrastructure projects, and policies. (Ministry of Infrastructure - Brazil, 2021)

3. Methodology

Decisions on which forecast method to use should start from the perspective of the beneficiary. In the present case, it is for the Port of Rotterdam as an international port developer. Stopford mentioned that for port authorities and port developers, volume is the main aspect that interests them the most (Stopford, 2009, p. 706). The reason for this is that the volume would enable them to ascertain how much and what kind of investments are needed.

The Model for Brazil was based on a PoR study back in 2020 which investigated the potential container growth in Southeast Asia. They required a forecast of container growth by the partner country to decide where to concentrate their marketing efforts. Based on the author's observation of PoR's own 2050 forecast, their interest lies more in the hinterland conditions rather than operational efficiency since they do not operate the

cargo terminals. Therefore, a multivariate analysis is ideal for them. The author decided to focus on containers because of their proven relation with general economic indicators rather than the business-specific nature of the other cargo types, liquid bulk, dry bulk, and breakbulk.

The decision of the author to apply the gravity equation to Brazil's intranational trade followed PoR's perspective on this model. The gravity equation has an intuitive nature that can be easily explained. The theory behind it is well established by hundreds of researchers who used this model to explain various trade conditions. It gives a comprehensive view of multiple countries or regions and can be used to check the relationship between trade and other sectors, and it has proven consistency in the prediction of goods and services trade (WTO-UNCTAD, 2016). Even though most of the research was directed to international trade, intranational gravity equation research was also done by many researchers, as written in the literature review above, to justify its usage for the present research.

An apparent disadvantage of this model is its inability to capture future disruptions due to its high reliance on economic growth. One way to adjust to this was to craft a proper scenario similar to what the Port of Rotterdam did in their 2050 forecast which included major changes in the sustainability policies of the Port and the world.

3.1 Intranational Gravity Equation

The author followed the forecast method by PoR but applied and modified it to fit the internal container trade flow in Brazil. The multivariate approach is ideal in this case to answer one of the questions asked by PoR to the author, which is to identify which variable(s) affected the cabotage growth in Pecém. The gravity equation would be able to produce a generally acceptable forecast and, at the same time, test other variables. For each data frame, the author ran the regression two times: the first one with only the traditional gravity variables such as GDP, population, distance, landlocked, and remoteness, and the second time with similar variables with the addition of other variables which might affect cabotage throughput. Identification of these variables was done through literature review and short interviews.

A literature review, which was done in the previous chapter, has identified factors such as price, safety, distance, etc. Interviews were done between March and August 2024 involving several people from the PoR organization, including colleagues working in the Port of Pecém. It was conducted one by one with a short list of open questions on either container forecast in general or the market situation in Brazil, depending on the person's expertise. A full list of interview details is available in the appendix of this thesis.

3.2 Data Description

3.2.1 Port of Rotterdam Model

PoR's forecast model for Brazil's container trade flow (hereafter this text will be stated a PoR Brazil Model) was created by Carlos Zepeda, Senior Port Economist from the International Department, back in 2020. The model was created in the format of Microsoft Excel. It forecasted the total container trade flow, international, and cabotage between Brazil and its top 100 countries' trade partners, which represented 98% of its container flow, from 2021 up to 2050. Their analysis was done by considering the historical data from 2000-2020.

The PoR Brazil Model formula is split between international container flow and cabotage container flow. For the international flow, it was based on the market characteristics, distance, and a few other factors. The market characteristics included access to coastline from CEPII, country GDP at constant 2010 prices obtained from World Bank and IMF, country population data from World Bank and UNCTAD, market share of manufactured goods from the total export value developed by PoR from Seabury data, export product diversification also from PoR own calculations using the Herfindahl-Hirschman Index (HHI) formula based on Seabury data, and the Human Development Index (HDI) from UNCTAD. The distances used were weighted geodesic in kilometers, depending on the economic centers of the countries, also acquired from CEPII. CEPII also provided other factors, such as Free Trade Agreement dummies, landlocked dummies, and common language dummies. The cabotage container flow was projected using Brazil's GDP and population growth.

Following the format from Equation 2 above, coefficients were acquired from regression analysis (see Table 3 below). PoR's Brazil Model used different coefficients depending on the country region as using the global coefficient caused a mismatch in the backcasting process. Due to the limited amount of time, this process was only done for important trade partner regions for Brazil, which were Europe and Northeast Asia.

Coefficients acquired were used to forecast future container throughput based on three scenarios that are affected by 2 groups of drivers: first is economic statistics, such as population and GDP growth, and second is the export diversification and manufacture export share. The low scenario is when low economic growth and regionalization of trade happen. Meanwhile, the high scenario is when high GDP, population growth, and continued globalization take place. The base scenario is somewhere in between these assumptions.

Finally, after the calculation of container trade volumes for Brazil, PoR then narrowed it down to Pecém using port market share assumptions acquired from extrapolating the historical growth, which stated Pecém had a 2% share in 2010 to 4% share in 2020.

3.2.2 Intranational Gravity Variables

The author created the data frame based on the literature review and input from PoR colleagues. Various sources were used due to the many types of parameters observed. There are two different data frames created: one for cabotage container flows coming into Ceará, the state in which Port of Pecém operates, and the other for the outflows. Transhipment of cabotage containers was not properly recorded and only data from 2018 to 2023 were available. The transhipment throughput for Ceará was quite small, between 2.000 to 9.000 TEUs each year, therefore it was not observed in this research. For each flow, 286 observations between Ceará and 26 other Brazilian states were created.

Table 1 Sample data frame cabotage flow from São Paulo into Ceará

| Exporter	Importer	Year	In	DP_export	DP_import	pop_export	pop_import	distcap	landlocked	GDP_brazil	remoteness	fleetcapTEU	gasoline	diesel	bunker	emission	truckfleet	cidents_ro	cidents_wa	trucktheft
SP	CE	2010	12155	1,29E+09	79336299	41262199	8452381	2357,97	0	3,89E+09	115492	26436	1,53611	1,19848	473,2396	168,5	40830,89	1,83E+08	968	880
SP	CE	2011	29133	1,44E+09	89695828	41476762	8496333	2357,97	0	4,38E+09	115048,6	34594	2,730583	2,025917	648,8271	184,6267	57774,64	1,92E+08	870	920
SP	CE	2012	17014	1,56E+09	96973753	41692442	8540514	2357,97	0	4,81E+09	117073,5	34594	2,736333	2,086833	667,3313	201,6301	56701,03	1,85E+08	863	960
SP	CE	2013	12879	1,72E+09	1,09E+08	41909242	8584925	2357,97	0	5,33E+09	115298,9	53538	2,854	2,319	618,1833	208,0259	48911,09	1,87E+08	886	1000
SP	CE	2014	16955	1,86E+09	1,26E+08	42127170	8629567	2357,97	0	5,78E+09	108100,9	69192	2,975	2,512	559,6938	212,7273	53430,99	1,69E+08	942	1000
SP	CE	2015	24931	1,94E+09	1,31E+08	42346232	8674440	2357,97	0	6E+09	108228,6	82222	3,343	2,827	284,6167	198,9468	57740,81	1,22E+08	999	1120
SP	CE	2016	24943	2,04E+09	1,38E+08	42566432	8719547	2357,97	0	6,27E+09	106795,4	82222	3,68	3,013	223,4771	196,761	40680,31	96000000	906	1360
SP	CE	2017	24868	2,12E+09	1,48E+08	42787777	8764889	2357,97	0	6,59E+09	104977	82222	3,767	3,112	315,8417	198,5459	40217,23	90000000	907	1570
SP	CE	2018	36301	2,21E+09	1,56E+08	43010274	8810467	2357,97	0	7E+09	105934,2	82222	4,409	3,448	415,85	188,8567	49404,55	69000000	779	1470
SP	CE	2019	49325	2,35E+09	1,64E+08	43233927	8856281	2357,97	0	7,39E+09	106515,8	84922	4,378	3,589	395,3021	190,1384	54517,76	67000000	1043	1400
SP	CE	2020	50080	2,38E+09	1,67E+08	43458744	8902334	2357,97	0	7,61E+09	107499,3	84922	4,279	3,423	360,4375	179,941	37079,67	64000000	904	1250

Source: Author compilation

Dependent

The only dependent variable is the internal container trade flow. The source of this data was from ANTAQ, which the author downloaded in July 2024. The earliest data available was from 2010, therefore, the author used the annual container cargo flow recorded in TEU from 2010-2020 to create the model and left the data for 2021-2023 as reference points to test the prediction numbers.

Figure 7 shows that in 2020, the most relevant trade partner for Ceará is São Paulo. However, the trade partner share changed erratically in the past for both trade flows, as seen in Figures 8 and 9.

Figure 7 Map of Ceará's cabotage container trade partners
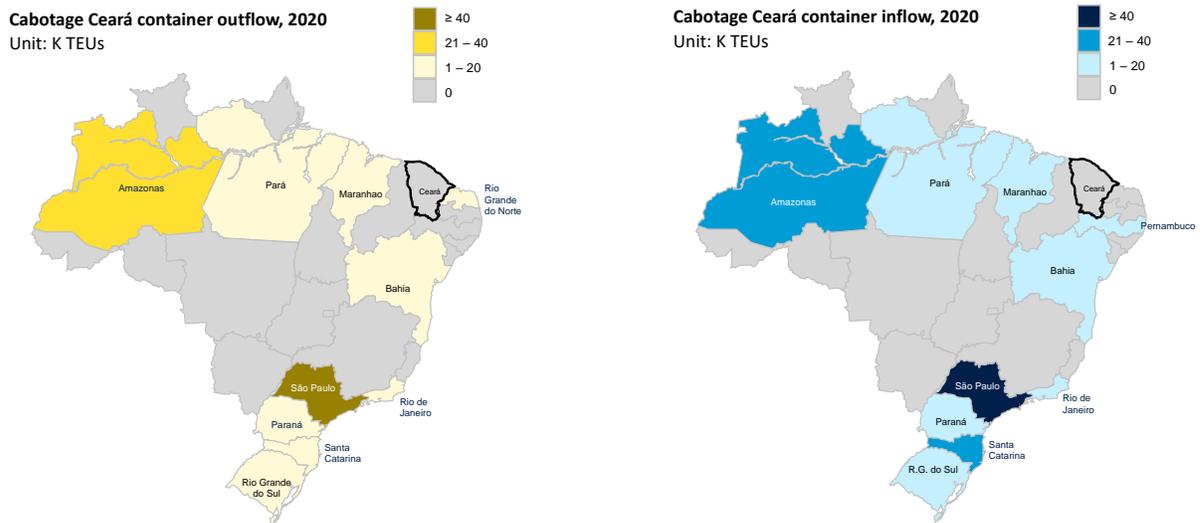
Source: Author compiled from (ANTAQ, 2024)

Figure 8 Cabotage container throughput share into Ceará by trade partner state
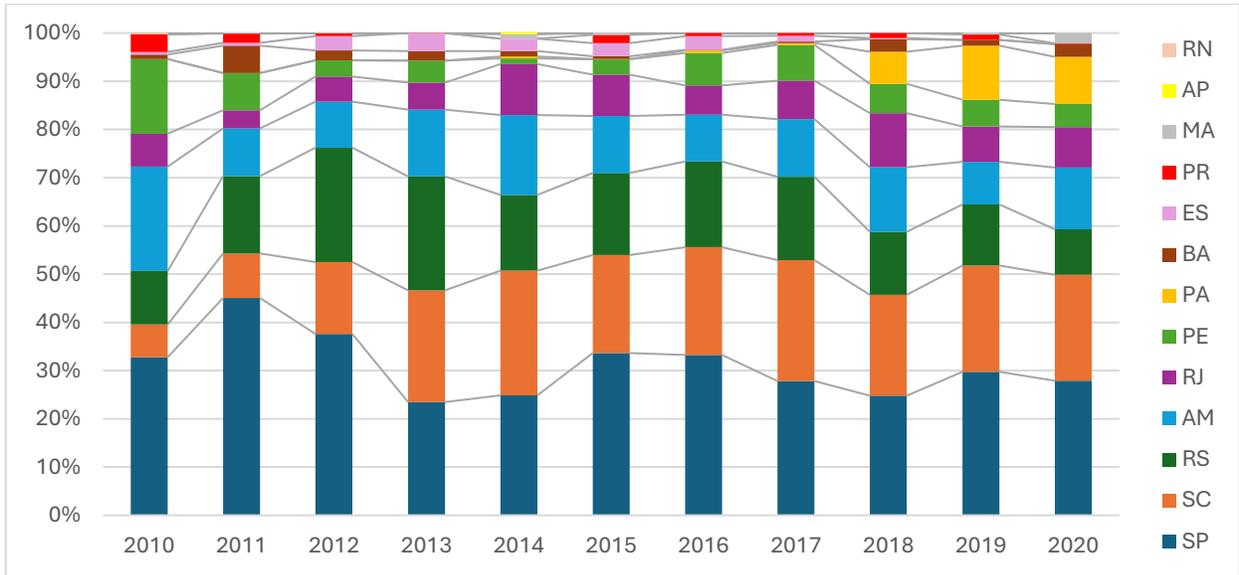
Source: Author compiled from (ANTAQ, 2024)

Figure 9 Cabotage container throughput share out of Ceará by trade partner state
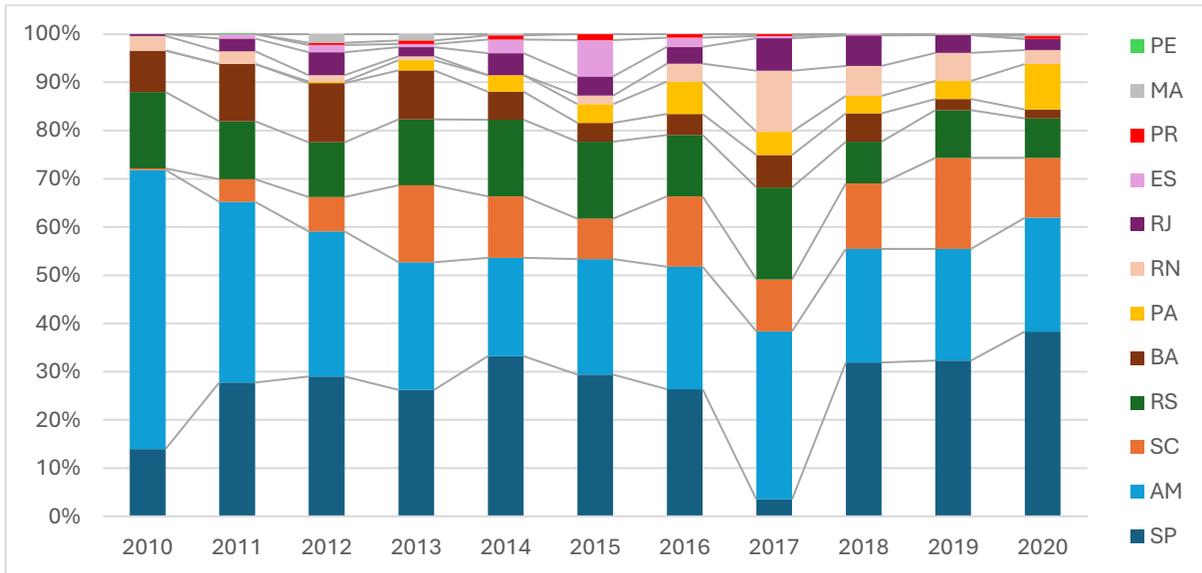
Source: Author compiled from (ANTAQ, 2024)

The author decided to calculate the gravity based on the trade between states in Brazil to be able to focus on Port of Pecém, but still capture the trade overview. Trade between municipalities would require a much larger trade matrix and potentially disrupt

the research focus. The trade between seven regions in Brazil could simplify the trade matrix but subsequently, it would be more difficult to calculate the port market share.

The data was arranged by ANTAQ in a way that it could only show the container flows into a certain state and not directly show as trade flow between states. However, the data itself is not complete. There were 13.131 TEU container flows into Ceará which were categorized as indeterminate, 12,5.000s of which was from the year 2010. However, this is a very small percentage (0,008%) compared to the overall recorded flow, thus, it should not greatly affect this research. The indeterminate flow coming out of Ceará was not recorded. The author also manipulated the data for trade between Ceará and nine landlocked states, which was also not recorded, into zero.

One more issue regarding the data is the difference, between the total cabotage throughput data that was used in the PoR Brazil Model downloaded in 2021 and the currently available data, by a factor of approximately two times, as seen in Table 2 below. To adjust to this, the author later divided the previous calculations by two to check the accuracy of the PoR Brazil Model.

Table 2 Brazil Cabotage Throughput in TEU

Year	Downloaded 2024	Downloaded 2021	2021:2024
2010	551.721	1.111.860	202%
2011	641.189	1.310.457	204%
2012	814.350	1.756.770	216%
2013	973.943	2.082.061	214%
2014	1.059.961	2.290.228	216%
2015	1.125.052	2.341.375	208%
2016	1.093.350	2.250.882	206%
2017	1.207.804	2.498.610	207%
2018	1.364.167	2.769.842	203%
2019	1.576.255	3.169.095	201%
2020	1.612.951	3.256.925	202%
2021	1.833.685	3.686.205	201%

Source: (ANTAQ, 2024)

Independent

In total, the author observed 20 independent variables. Some of them are conventional gravity equation variables such as GDP, population, distance, access to sea, and remoteness. Other variables were discovered from literature review and interviews. Data collection was done in July 2024. It also took some time due to various data quality that mostly came from the Brazilian government or private institutions. The data downloaded were annual data from the year 2010 up to the most recent year available.

GDP data was obtained from IBGE. The available numbers were the current prices in Brazilian Real from 2010 to 2021. This data was quite detailed, reaching up to the annual municipality level, therefore, the author made a summary for each Brazilian state and the whole country (IBGE, 2021). The prices were then adjusted into the constant prices of 2010 based on Brazil's national consumer price index (IPCA) (IBGE, 2024).

Population data was also downloaded from IBGE. IBGE conducted a population census in 2010 and 2022 that is available at the state level in Brazil. The author assumed a steady growth between those years with a CAGR of 0,52% (IBGE, 2023).

Distances in kilometers were collected from Google Maps. The author tried geodesic straight-line distance in the first regression and then updated it with the actual road distance between the capitals of each state in Brazil to capture further road access for routes without highways.

The landlocked variable dummy was input by the author based on observation from Google Maps. This was quite straightforward, depending on whether or not the state had any access to the sea, but an exception was made for the state of Amazonas. The author decided that it is not landlocked due to the large size of the Amazon River that allows access for container ships with the size of up to 3000-4000 TEUs depending on its draft conditions (Maersk, 2024).

Remoteness is a variable that was suggested (UNCTAD, 2012) to better capture the trade restriction. It was calculated by dividing the distance between the states by the ratio of the partner state's GDP and the whole country's GDP. The larger the number, the farther the partner state is from the society.

Fleet capacity in TEUs was downloaded from the Clarkson SIN Database in July 2024. We added the capacity of ships under the Brazilian flag registry, because only Brazil-flagged ships may operate cabotage services in Brazil. The earliest ship was built in 2005 and then ships added were under the assumption that it could operate for up to 25 years since being constructed. (Clarksons, 2024)

Freight rates per ton-kilometer were acquired for both truck and cabotage from Infra S.A. Infra S.A. is a state-owned company that works in planning, engineering, and innovation for Brazil's transportation sector (Infra S.A., 2022). There is a missing cabotage freight data for the years 2010-2012, therefore, the author assumed that the price for 2010 is an average of the 2013-2018 price and so on to fill in the gaps. This was done because the correlation analysis between the 2010-2020 freight rate with bunker price and fleet capacity did not provide an acceptable r-squared to justify the linear equation as seen in figures 10 and 11 below.

Figure 10 Cabotage freight rate and bunker price linear analysis
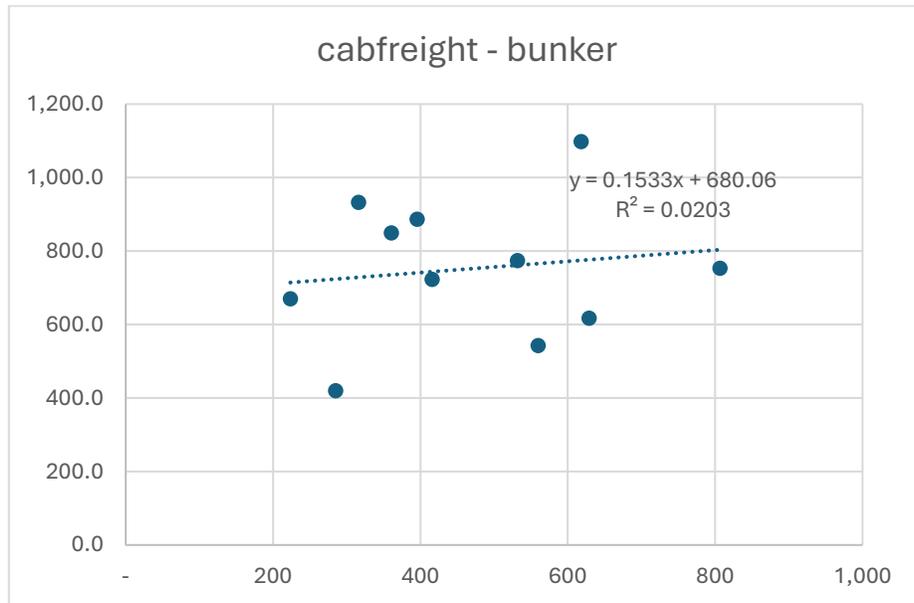
Source: Author

Figure 11 Cabotage freight rate and fleet capacity linear analysis

cabfreight - fleet capacity

$y = -0.0072x + 1325.6$
$R^2 = 0.1378$
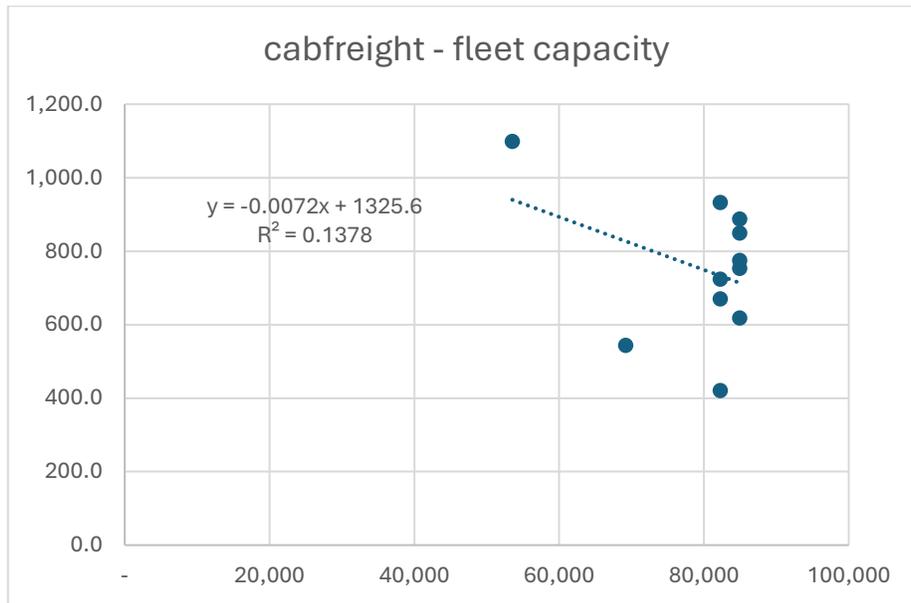
Source: Author

Fuel prices were also considered, especially gasoline for general use, diesel for trucks, and heavy fuel oil for ships. ANP published a database for monthly consumer prices for gasoline, diesel, and other fuels. Ship fuels database was obtained from Clarksons' SIN. HSFO bunker price was from Panama, which was the closest to Brazil, and it changed to VLSFO from 2020 onwards due to IMO MARPOL Annex VI that Brazil has ratified. (Clarksons, 2024)

Truck-related variables were considered because trucks are the most direct competition in terms of container delivery modality in Brazil. Trains were not considered since they were mostly used for freight transport of bulk materials instead of containers. Trucking in Brazil is highly privatized, similar to the US trucking industry. Truck capacity is a total of trucks licensed obtained from ANFAVEA (National Association of Automotive Vehicle Manufacturers) combined with the container truck share obtained from ANFIR (National Association of Road Implement Manufacturers), with the assumption of 11 years of average operational age for trucks of that decade (Araujo, 2021).

A time variable was added to account for the longer transport time for cabotage compared to trucks. Travel time is distance divided by the average travel speed, 29 km/h

for cabotage (CE Delft, 2016) and 60 km/h for trucks (Brazil, 2015). However, the cabotage time is added with the average stay hours of containers in ports in Ceará recorded by ANTAQ, which was 86,8 hours. (ANTAQ, 2024)

Social-related factors were observed using quantitative variables such as accidents and emissions data from Infra S.A. (Infra S.A., 2022) and truck cargo theft lost value (NTC & Logistica, 2022), which were then updated to capture a closer connection with container trade by applying the average external cost of transport per ton-kilometer that was obtained from CE Delft (CE Delft, 2019). CE Delft's report observed transportation in the Netherlands and Europe and consequently, the author multiplied the numbers by two to reflect the cost in a developing country, such as Brazil. This assumption was made because there was no previous study for Brazil and comparison of such detailed external costs that included emissions, congestion, noise, and accidents.

4. Analysis and Results

4.1 Port of Rotterdam Forecast Review

This review started by comparing the predicted volumes with the actual numbers. We were able to use the numbers from 2021 to 2023 to check the PoR Brazil Model's performance. At the state level, the model was able to perform well with the recent data, although matching different scenarios depending on the flow.

Figure 12 PoR Brazil Model Export
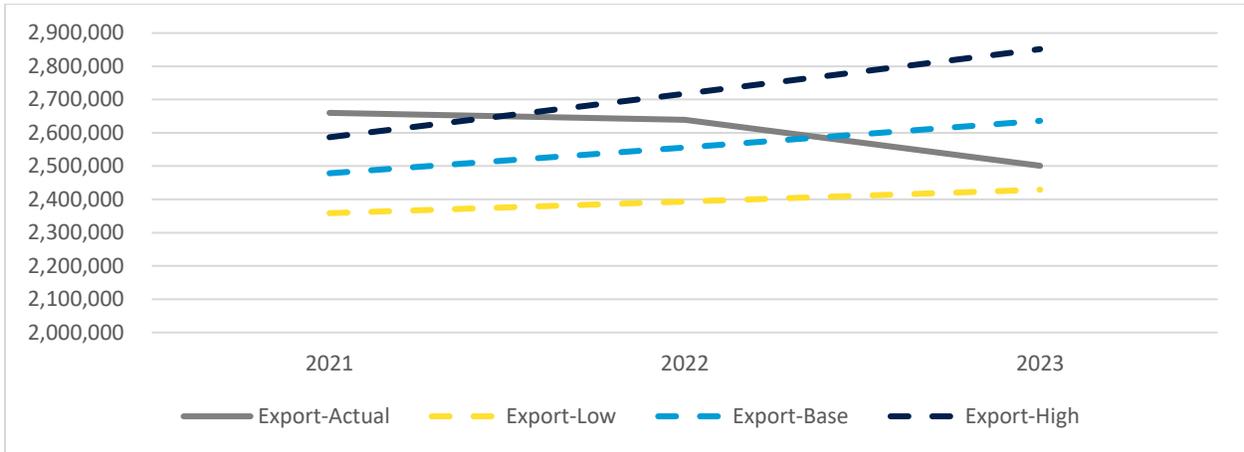
Source: Author compiled from Seabury and PoR

Figure 13 PoR Brazil Model Import
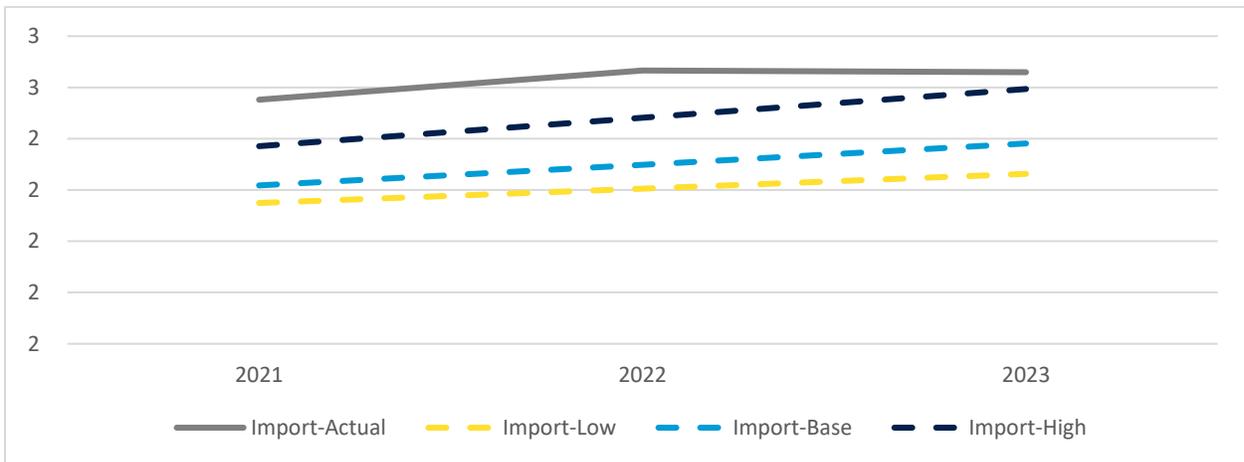
Source: Author compiled from Seabury and PoR

Figure 14 PoR Brazil Model Cabotage

Source: Author compiled from ANTAQ and PoR

The statistics of these models proved that there should not be an issue with the forecast. For the import regressions, the coefficients input was changed into export coefficients for the countries that PoR has analyzed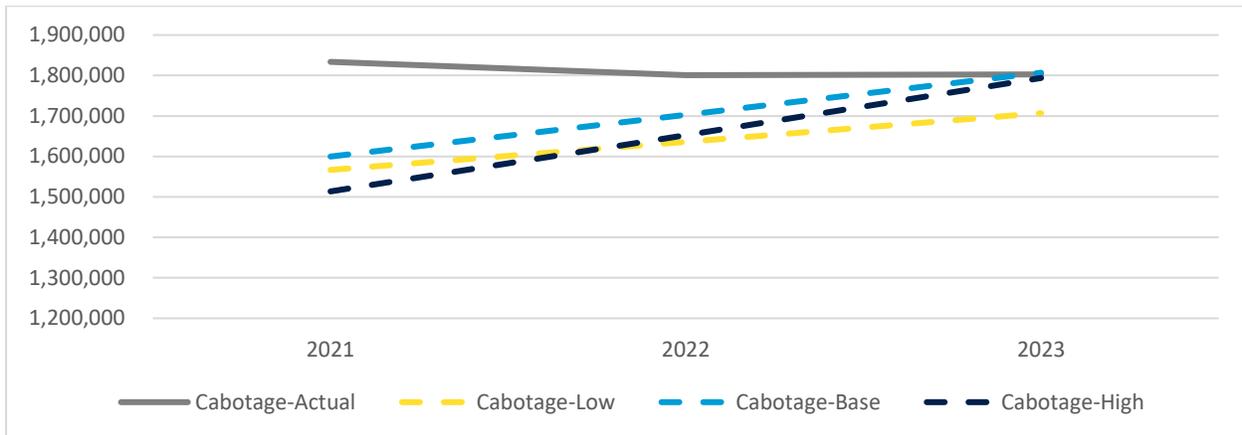 previously. Here, the PoR Brazil Model was able to avoid the traditional mistakes mentioned by Baldwin & Taglioni in their research (Baldwin & Taglioni, 2006). Trade flow deflation is irrelevant in this case due to the focus on container trade flow and it also ran different regressions depending on the flows.

Table 3 PoR Brazil Model general coefficients

	Export	Import	Cabotage
(Intercept)	-74798.20	129229.84	-26013306.58***
	(p = 0.48)	(p = 0.31)	(p = 0.00)
Area(i)	NA	0.00 ***	
		(p = 0.00)	
Area(j)	0.00 ***	NA	
	(p = 0.00)		
Pop(i)	264.43	30.68***	
	(p = 0.69)	(p = 0.00)	
Pop(j)	-23.53 ***	-211.69	

27

	(p = 0.00)	(p = 0.80)
GDP(i)	0.00	0.01***
	(p = 0.33)	(p = 0.00)
GDP(j)	0,03***	0,02*
	(p = 0.00)	(p = 0.01)
HDI(i)	55716.46	14824.97*
	(p = 0.87)	(p = 0.01)
HDI(j)	11762.97 *	-262029
	(p = 0.01)	(p = 0.53)
Share(i)	1184792.41*	1221421***
	(p = 0.01)	(p = 0.00)
Share(j)	-132712.40 ***	-567428
	(p = 0.00)	(p = 0.31)
Div(i)	-130781.79	3903.78
	(p = 0.54)	(p = 0.42)
Div(j)	-10916.56**	-160408.92
	(p = 0.01)	(p = 0.54)
Dist(ij)	-0.59***	-2.18***
	(p = 0.00)	(p = 0.00)
Lang(ij)	4189.79	1586.08
	(p = 0.12)	(p = 0.63)
FTA(ij)	37449.05***	34503.77***
	(p = 0.00)	(p = 0.00)
Contig(ij)	19679.70 ***	4913.96
	(p = 0.00)	(p = 0.09)
Landlock(ij)	-15157.86***	1812.69

	(p = 0.00)	(p = 0.63)	
BrazilGDP			1.39
			(p = 0.07)
BrazilPop			122668.24***
			(p = 0.00)
nobs	2100	2100	11
r.squared	0.78	0.77	0.96
adj.r.squared	0.78	0.77	0.95

All continuous predictors are mean-centered and scaled by 1 standard deviation.
The outcome variable is in its original units. *** p < 0.001; ** p < 0.01; * p < 0.05.

Source: Author compiled from PoR

   The adjusted r-squared for these models was considerably high, which was close to one. The p-values showed that statistics of the trade partners of each flow are more important than those of Brazil's itself. Limited data and timeframe caused limited variables for cabotage volume regression, but it already had the highest adjusted r-squared. Then, the issue of PoR's Brazil Model fell on the Port Market share assumption. It was calculated by extrapolating the total container volume of Pécem in comparison with the total of Brazil's. It was unable to capture the high growth of container cabotage flow that was mentioned in the introduction. Therefore, the author decided to forecast the intranational container trade flow.

Figure 15 Port of Pécem Container Market Share Growth
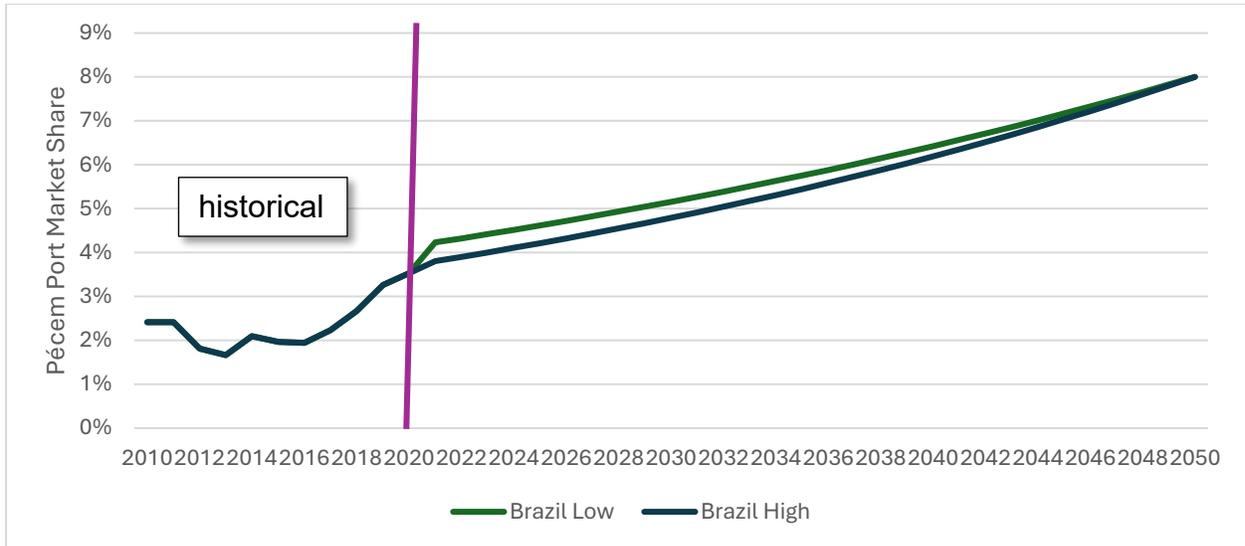
Source: Author compiled from PoR

4.2 Intranational Container Trade Forecast

4.2.1 Regression and Backcasting

Inspired by the PoR Brazil Model, regression was run separately between the inflow and outflow of cabotage containers, just as how it was done for the import and export flows. Each regression was done twice to compare the basic gravity equation and the updated equation, which included additional variables based on the insights that we found.

Table 4 First trial Ceará cabotage inflow regression coefficients

	Basic1	Updated1
(Intercept)	5701.57 ***	5701.38 ***
	(p = 0.00)	(p = 0.00)
GDP_exporter	7561.62 ***	7494.41 ***
	(p = 0.00)	(p = 0.00)
GDP_importer	-6395.69 *	-20305.17
	(p = 0.02)	(p = 0.48)

Pop_exporter	-3465.68 ***	-3403.74 ***
	(p = 0.00)	(p = 0.00)
Pop_importer	6561.73 **	9822.69
	(p = 0.01)	(p = 0.35)
distcap	11808.86	15117.74 *
	(p = 0.05)	(p = 0.03)
landlocked	-6367.09 ***	-6366.57 ***
	(p = 0.00)	(p = 0.00)
remotenessE	-9514.39	-12828.04
	(p = 0.12)	(p = 0.07)
fleetcapTEU		15084.32
		(p = 0.55)
gasoline		28057.83
		(p = 0.59)
diesel		-36527.53
		(p = 0.59)
bunker		6748.30
		(p = 0.51)
emission		1749.34
		(p = 0.71)
truckfleet		-1064.83
		(p = 0.65)
accidents_road		-9315.24
		(p = 0.59)
accidents_water		2714.66
		(p = 0.57)
nobs	286	286

r.squared	0.65	0.66
adj.r.squared	0.64	0.64

All continuous predictors are mean-centered and scaled by 1 standard deviation. The outcome variable is in its original units. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

The adjusted r-squared was only slightly different between the two, with the basic model to be higher by 0,002. It meant that the basic model could better explain the changes of cabotage inflow into Ceará over the last decade. However, in general, 0,64 is considered to be a good enough value to judge the model (as long as it is higher than 0,5, although there was still some distance to 1). These two models are similar in regard to their relevant variables with low p-values, the GDP and population of the exporters, and whether or not the state is landlocked. It was unfortunate to see that the other variables in the updated model were not relevant based on a linear analysis.

Table 5 First trial Ceará cabotage outflow regression coefficients

	Basic1	**Updated1**
(Intercept)	4200.39 ***	4200.16 ***
	(p = 0.00)	(p = 0.00)
GDP_exporter	-1158.79	-30297.51
	(p = 0.64)	(p = 0.25)
GDP_importer	5856.06 ***	5770.11 ***
	(p = 0.00)	(p = 0.00)
Pop_exporter	1391.27	12620.34
	(p = 0.54)	(p = 0.19)
Pop_importer	-3210.16 ***	-3130.93 ***
	(p = 0.00)	(p = 0.00)
distcap	5357.22	9321.17

|		
	(p = 0.33)	(p = 0.15)
landlocked	-4734.24 ***	-4733.55 ***
	(p = 0.00)	(p = 0.00)
remotenessE	-3848.74	-7817.77
	(p = 0.48)	(p = 0.23)
fleetcapTEU		25287.61
		(p = 0.27)
gasoline		48593.89
		(p = 0.31)
diesel		-64359.15
		(p = 0.30)
bunker		10189.03
		(p = 0.27)
emission		4379.21
		(p = 0.31)
truckfleet		-1836.19
		(p = 0.39)
accidents_road		-16548.84
		(p = 0.29)
accidents_water		4584.32
		(p = 0.30)
nobs	286	286
r.squared	0.51	0.52
adj.r.squared	0.50	0.49

Source: Author

Just as with the inflow model before, the basic model had a higher adjusted r-squared. However, it is quite low compared to the inflow numbers. Relevant variables are similar to the inflow regression, indicating that the partner state's statistics are more relevant than the Ceará's GDP and population. Here, the other variables in the updated model were also irrelevant due to their high p-values. We then checked the models with the actual numbers using backcasting. Only the total annual backcast was relevant and comparable, as the detailed flow backcast resulted in negative container flow, which is impossible.

Figure 16 First Ceará cabotage inflow back-casting
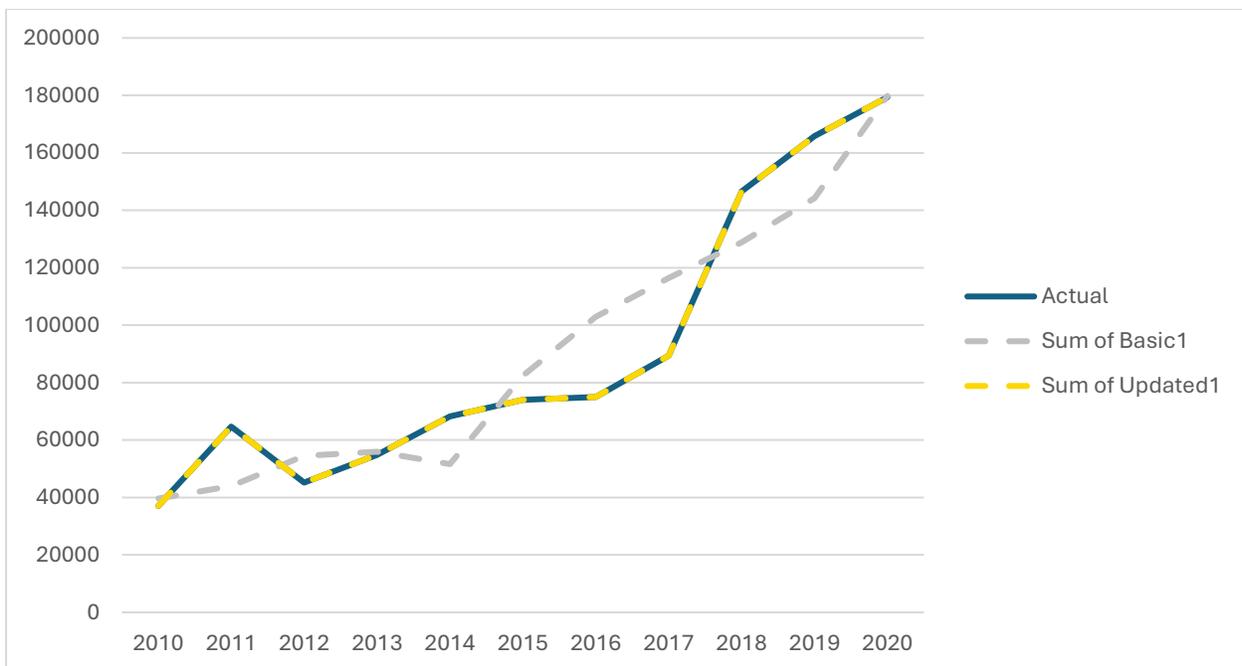
Source: Author

Figure 17 First Ceará cabotage outflow back-casting
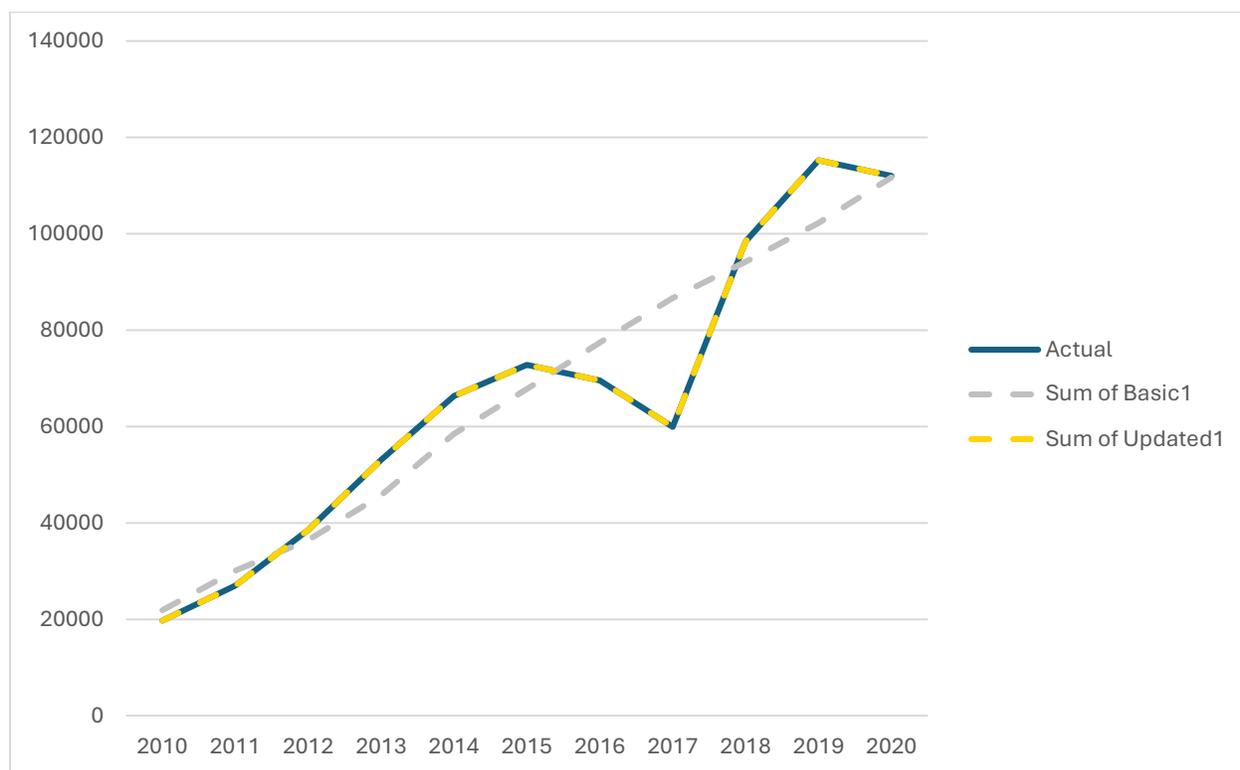
Source: Author

The first backcasting results for both in and out flows were quite surprising due to the high level of accuracy of the annual numbers from the updated model, which had lower r-squared. This showed that the relationship between the numbers might not be linear, but the model was able to perform well in backcasting the results. The basic model had a higher adjusted r-squared, but was unable to follow the throughput growth movement. This confirmed the paradox in forecasting, where there is an inverse relationship between accuracy and explainability. Therefore, the author tried to use other variables to be able to better explain the forecast results later.

The author was advised by his supervisor to use variables that could show that cabotage is more interesting later in the forecast scenario. Therefore, we included cabotage freight rate in comparison with trucking and considered external costs per ton-kilometer to connect better between the social and environmental effects to freight transport and travel time. GDP was adjusted to the constant price of 2010. The distance was also adjusted here, from a geodesic straight line to road distance, to better capture

the effect of road conditions in Brazil. The Updated 2.1 model had fewer variables because some of them were removed for being irrelevant and unable to forecast.

Table 6 Second Ceará cabotage inflow regression coefficients

	Basic2	Updated2	Updated2.1
(Intercept)	5567.98 ***	5567.47 ***	5566.39 ***
	(p = 0.00)	(p = 0.00)	(p = 0.00)
GDP_exporter	7632.37 ***	7634.18 ***	7611.99 ***
	(p = 0.00)	(p = 0.00)	(p = 0.00)
GDP_importer	-2489.82	-1232.13	-899.11
	(p = 0.26)	(p = 0.67)	(p = 0.71)
Pop_exporter	-3617.40 ***	-3612.44 ***	-3598.07 ***
	(p = 0.00)	(p = 0.00)	(p = 0.00)
Pop_importer	3280.29	3358.34	3231.10
	(p = 0.14)	(p = 0.24)	(p = 0.17)
distcap	2939.01 ***	2770.22	2939.10 ***
	(p = 0.00)	(p = 0.05)	(p = 0.00)
landlocked	-5981.16 ***	-5983.92 ***	-5976.58 ***
	(p = 0.00)	(p = 0.00)	(p = 0.00)
remotenessE	-1049.53 **	-1046.48 **	-1048.06 **
	(p = 0.00)	(p = 0.00)	(p = 0.00)
fleetcapTEU		678.04	-2044.96
		(p = 0.83)	(p = 0.23)
cabfreight		-64.78	-518.03
		(p = 0.96)	(p = 0.57)
truckfreight		946.95	

		(p = 0.46)	
cabext		-2766.98	
		(p = 0.30)	
truckext		-1095.25	
		(p = 0.72)	
cabtime		2325.80	
		(p = 0.37)	
nobs	286	286	286
r.squared	0.67	0.68	0.67
adj.r.squared	0.66	0.66	0.66

All continuous predictors are mean-centered and scaled by 1 standard deviation. The outcome variable is in its original units. *** p < 0.001; ** p < 0.01; * p < 0.05.

Source: Author

Compared to the first trial, the adjusted r-squared increased by 0,02. This was due to the distance between capitals that were adjusted, hence, the distance relevance increased in the Basic2 and Updated2.1 models. This affected the relevance of the remoteness variable because it was calculated from distance. The highest adjusted r-squared is found in the Updated2.1 model at 0,662, which was a 0,001-point difference from the other models. The relevant variables were the same as the previous models where the partner state statistics were the most relevant. The other variables, even though changed, remained unable to show their cause and effect in linear regression.

Table 7 Second Ceará cabotage outflow regression coefficients

	Basic2	Updated2	Updated2.1
(Intercept)	4207.94 ***	4203.58 ***	4206.23 ***
	(p = 0.00)	(p = 0.00)	(p = 0.00)
GDP_exporter	-877.96	-1165.13	-48.84
	(p = 0.65)	(p = 0.65)	(p = 0.99)

GDP_importer	5373.03 ***	5380.26 ***	5472.99 ***
	(p = 0.00)	(p = 0.00)	(p = 0.00)
Pop_exporter	1394.39	2141.47	1293.24
	(p = 0.47)	(p = 0.40)	(p = 0.68)
Pop_importer	-2912.72 ***	-2915.55 ***	-3008.98 ***
	(p = 0.00)	(p = 0.00)	(p = 0.00)
distcap	2430.50 ***	2307.29	2417.44 ***
	(p = 0.00)	(p = 0.07)	(p = 0.00)
landlocked	-4756.04 ***	-4748.96 ***	-4751.11 ***
	(p = 0.00)	(p = 0.00)	(p = 0.00)
remotenessE	-850.40 **	-841.31 **	-851.31 **
	(p = 0.01)	(p = 0.01)	(p = 0.01)
fleetcapTEU		-640.70	-1308.48
		(p = 0.82)	(p = 0.42)
cabfreight		-678.85	-724.87
		(p = 0.53)	(p = 0.37)
truckfreight		616.47	
		(p = 0.59)	
cabext		-1720.10	
		(p = 0.47)	
truckext		-1646.84	
		(p = 0.55)	
cabtime		1463.41	
		(p = 0.53)	
nobs	286	286	286

|			
r.squared	0.56	0.56	0.56
adj.r.squared	0.55	0.54	0.55

All continuous predictors are mean-centered and scaled by 1 standard deviation.
The outcome variable is in its original units. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

Source: Author

Regarding the outflow regression, the r-squared improvement is higher than the inflow improvement at 0,05 points. Between the latest regression analysis, the basic model had the highest adjusted r-squared with a 0,002 difference from the Updated2.1 model. The relevant variables were again similar in characteristics as the inflow regression, where the trade partner's GDP and population is more relevant.

Then again, we backcast these models to check. Updated2 models were not backcasted due to their overfit since the added variables had low relevance, and only fleet capacity and freight rate were kept because they could help add insight for the forecast. For both the backcast and prediction, only the results from the non-landlocked locations were used.

Figure 18 Second Ceará cabotage inflow back-casting
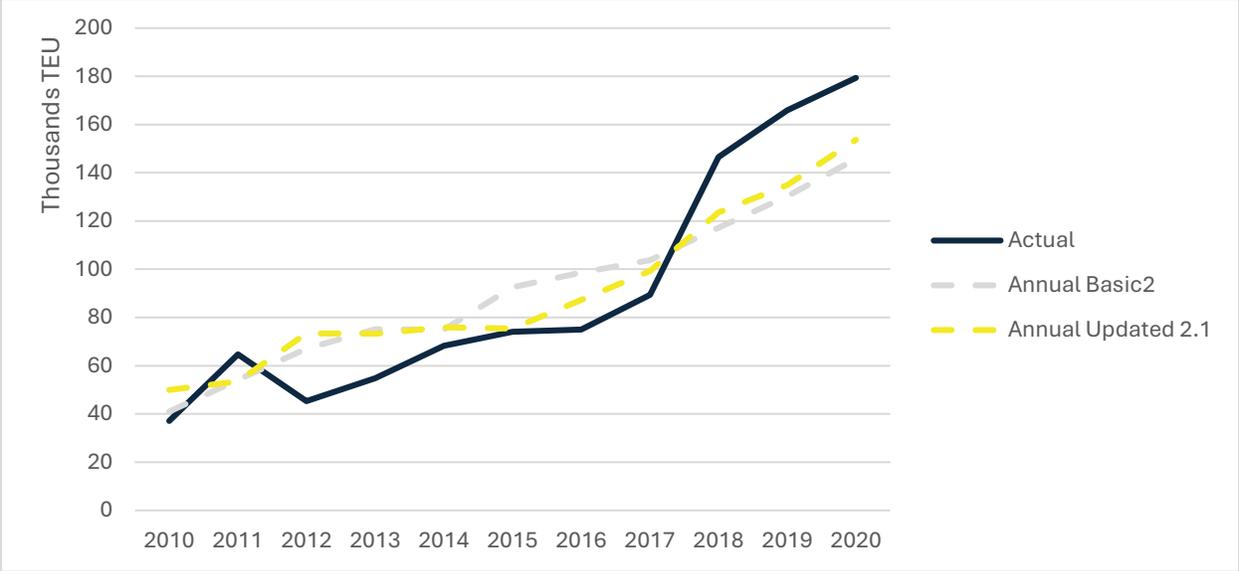
Source: Author

Figure 19 Second Ceará cabotage outflow back-casting
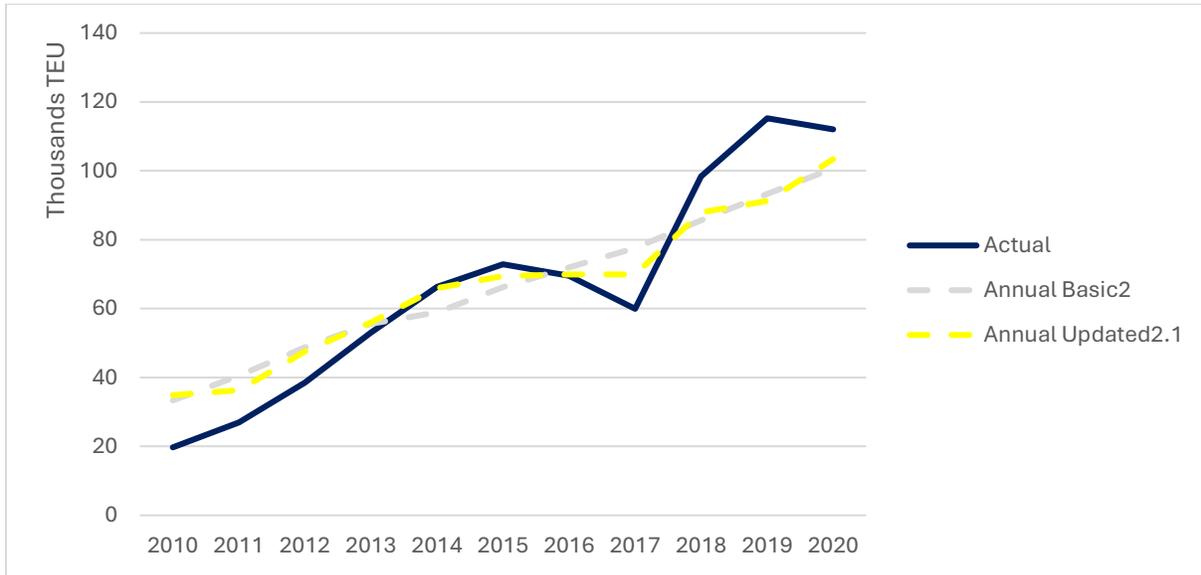
Source: Author

Table 8 Second back-cast results mean-squared error

Model	Mean-Squared Error
IN Basic2	2,04 x 10^7
IN Updated2.1	2,02 x 10^7
OUT Basic2	1,60 x 10^7
OUT Updated2.1	1,59 x 10^7

Source: Author

Figures 18 and 19 above showed that the Updated2.1 model performed better in following the actual annual numbers on both flows. We also tested the models by calculating the mean squared error between the backcast and the actual numbers, and it showed that the Updated2.1 results were better because they were closer to zero (as seen in Table 8). This showed that the relationship between the dependent variable and the other variables, cabotage fleet capacity and freight rate, might not be linear.

4.2.2 Scenario Drafting

After finding relevant variables from the previous chapter, we then investigated the historical growth pattern of those variables and gained market insights on how these shall change in the future. The four identified drivers for cabotage from the best-performing models were GDP, population, fleet capacity, and cabotage freight rate. Distance and landlocked criteria were highly relevant too, but these variables are assumed constant

due to their nature. These drivers were then transformed into three scenarios by the author: **Pessimistic**, **Status Quo**, and **Exceptional Growth**.

Analysis of Brazil's GDP started on the national level. The high rate CAGR, from 2010 to 2020, of 6% doubled the numbers in 2020 compared to 2010 (as seen in figure 20). Figure 21 shows that this growth is mostly contributed by the South-East region. However, as time passed, their share was decreasing and the other regions increased slowly.

Figure 20 Brazil Historical GDP at constant (2010) prices in R$ (2010-2020)
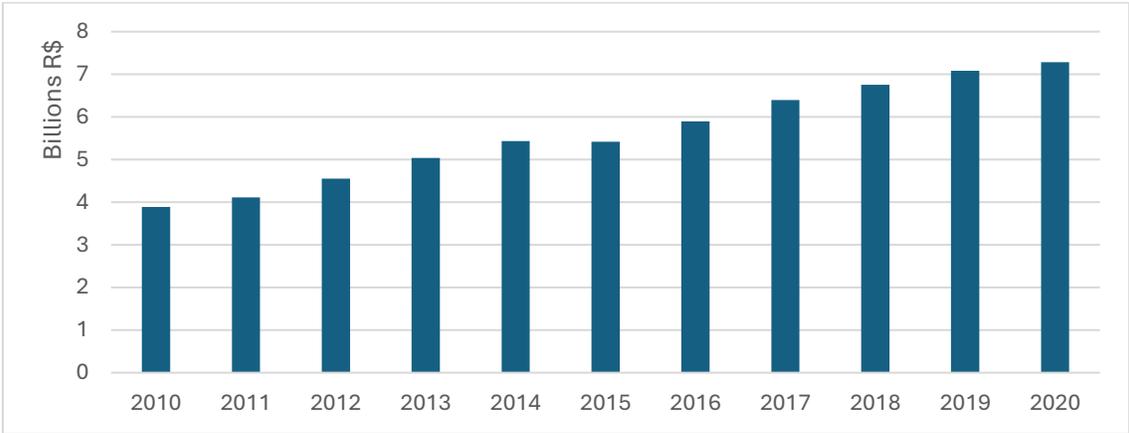

Source: (IBGE, 2021)

Figure 21 Brazil GDP share per region

Source: Author compiled from (IBGE, 2021)

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By using the analogy of Brazil states as a private company's portfolio, we examined how these states performed in the past 10 years. High-income states in the South region had low growth compared to other states, but São Paulo was way ahead in their GDP share. Best performances were attributed to the South region, represented by the above-average growth rates. Smaller states in the rest of the regions had high growth as well. In an optimistic scenario, these states could move to the right as star performers to catch up with the South and Southern region states. Circle size represents their relative GDP size in comparison to each other, with São Paulo (SP) being the largest.

Figure 22 Brazil states GDP growth-share matrix
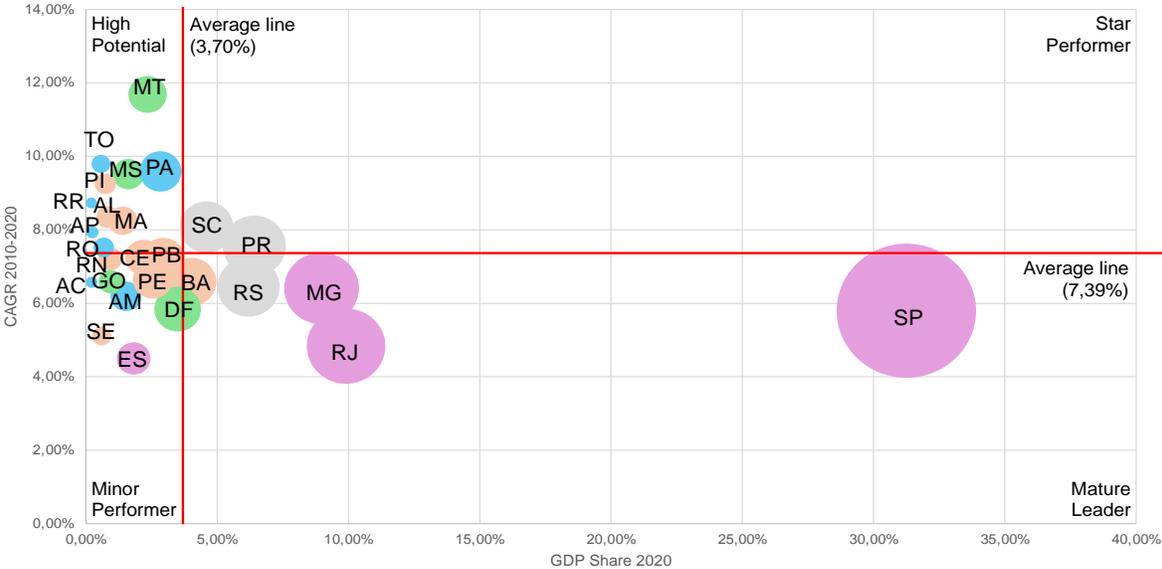
Source: Author inspired by (BCG, n.d.)

Therefore, we came up with the forecast assumption in Figure 23 below.

In the status quo scenario, with the assumption of a similar growth pace in the past 10 years. Exceptional growth scenario had the North, North-East, and Central-West states growing even faster than before by taking the highest growth rate of each region, and the South and South-east regions stayed the same. The pessimistic scenario is when all regions grow slower as we used the slowest-growth states as the assumption for all.

*Figure 23 GDP growth rate forecast assumptions per region*
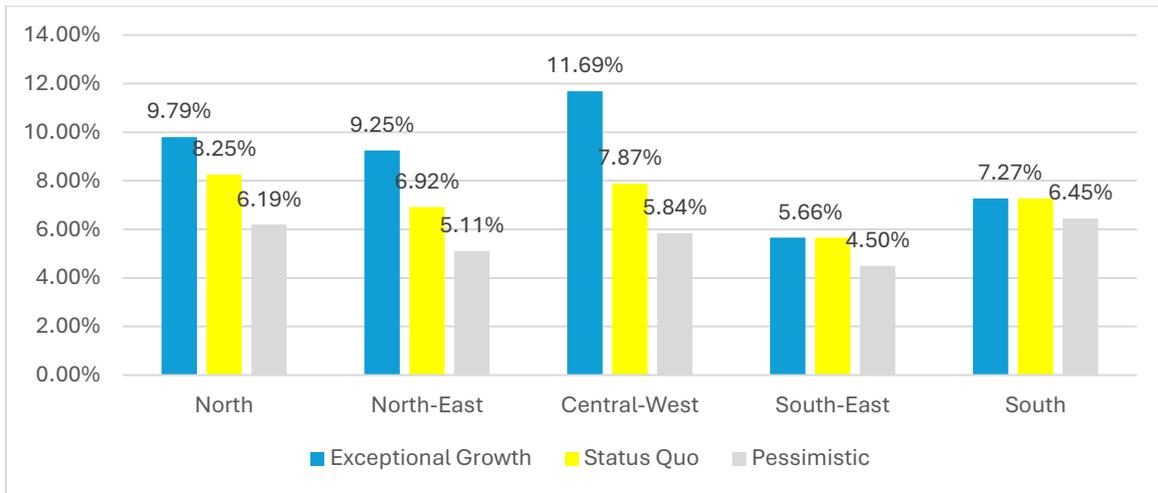
Source: Author

For the population, it is quite straightforward. The average population CAGR from 2010-2022 was at 0,52% per year, based on IBGE's census (IBGE, 2023). Brazil had its projection made in 2010 to 2060 with a slightly higher growth at 0,76%. These numbers confirmed UNCTAD's population projection that had three scenarios, with the low at 0,28%, middle at 0,52%, and high at 0,8% (UNCTAD, 2022). Therefore, the author decided to follow the UNCTAD projections and assumed the same growth rate for all states.

Fleet-size growth assumption was first checked based on the GDP growth. Historical correlation analysis showed that it does have a high correlation and is supported by a high r-squared as well (as seen in Figure 23). However, when we used Brazil's GDP to forecast fleet growth, it was much higher compared to the actual capacity in 2024.

<figure>Figure 24 Fleet size and Brazil GDP correlation analysis

$$y = 2E\text{-}05x - 40420$$
$$R^2 = 0.8678$$
</figure>
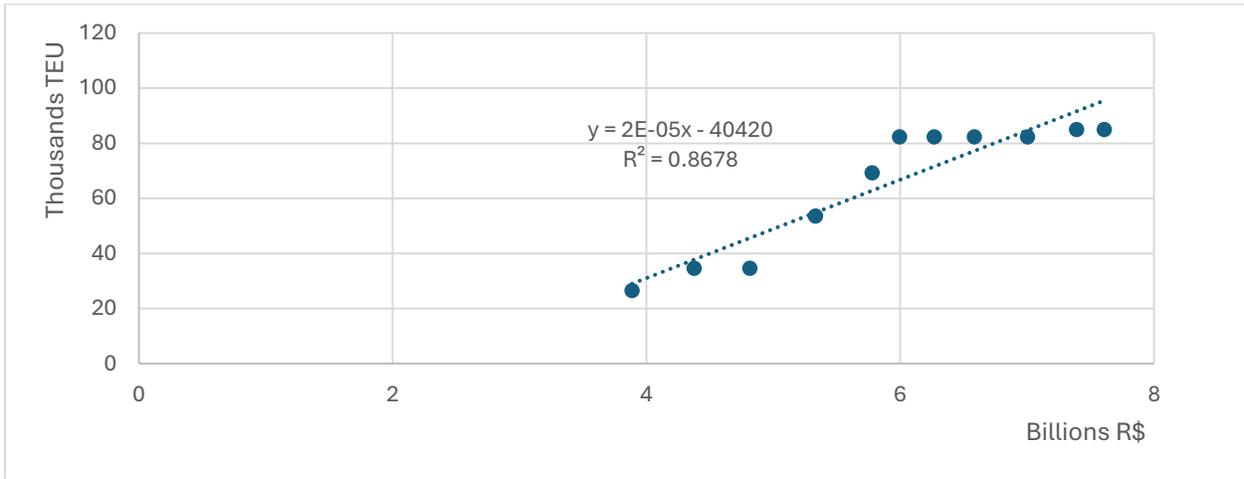
Source: Author

We added a forecast assumption based on the BR do Mar policy mentioned previously, which had the objective of increasing cabotage fleet capacity by 40% from the 2020 capacity. We assumed this would happen in 2030, and the prediction in Figure 24 showed that it is not far from the actual numbers in 2024. Therefore, we chose to base the scenarios on this policy with the 40% increase by 2030 as the exceptional growth, a 20% increase for the status quo, and no additional fleet for the pessimistic scenario.

Figure 25 Fleet capacity forecast assumption
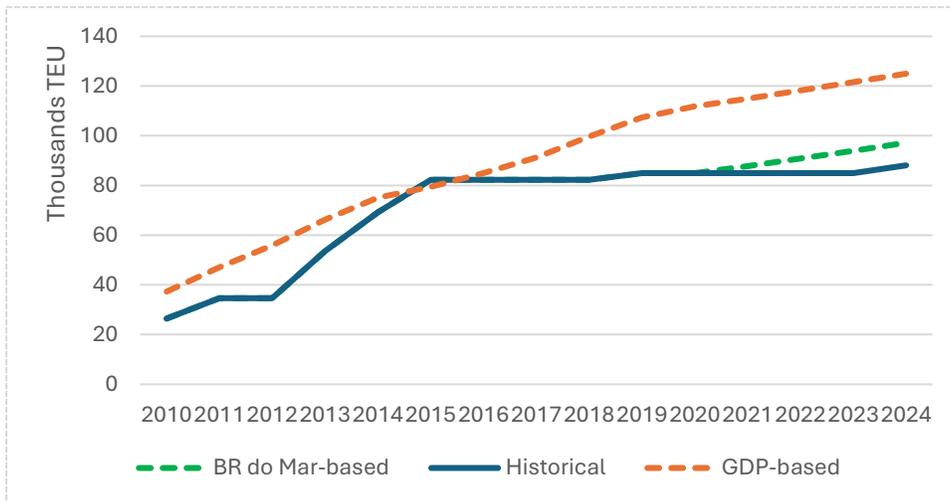
Source: Author & (Clarksons, 2024)

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*Figure 26 Fleet capacity forecast assumptions*

Source: Author

The last driver for cabotage is freight rate in R$ per ton per kilometer. For the historical analysis, the first 6 years (2010-2016) were removed due to them being outliers. Our own average calculation, as we mentioned in Chapter 3, filled in the 2010-2012 gap. Forecasting price has always been difficult, and the safest method would be to follow the historical trend. Prices from 2017 to 2020 had a decline rate of -3%, which we assigned as the status quo assumption. The exceptional growth assumption had an even higher decrease of -7% based on the actual numbers from 2017-2023. Lastly, in the pessimistic scenario, we assumed that the price would stay similar as the average price from 2017-2023, which was 750 R$/tkm.

Figure 27 Historical cabotage freight rate

cabotage freight rate R$/tkm
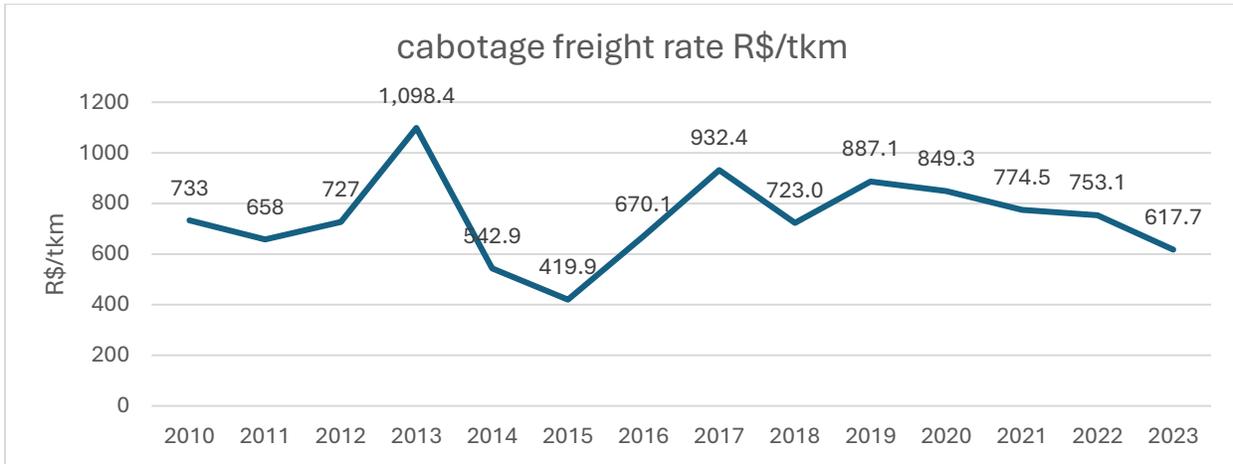
Source: Author and (Infra S.A., 2022)

Figure 28 Cabotage freight rate forecast assumption


Cabotage freight rate assumption (R$/tkm)
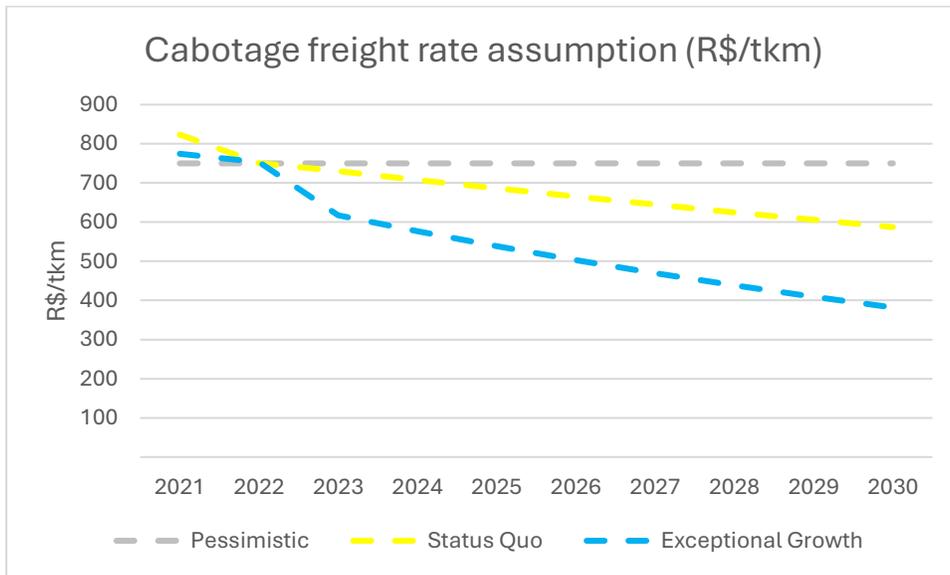
Source: Author

The choice of port market share in this scenario was much more limited compared to PoR's Brazil Model, which had to compare port competition between all ports in Brazil. There are only two container ports in Ceará: Port of Pecém, which is the subject of this forecast operated by a private company, and Fortaleza Port, which is operated by the public port authority. Historical share grew in favor of Pecém at close to 100% in the past

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5 years. Based on the author's discussion with Port of Pecém colleagues, this was due to Port of Rotterdam and APM's investment in Pecém and the limited draft of Fortaleza Port. Therefore, we assumed that the forecasted cabotage throughput will all go to Pecém.

Figure 29 Container port market share in Ceará
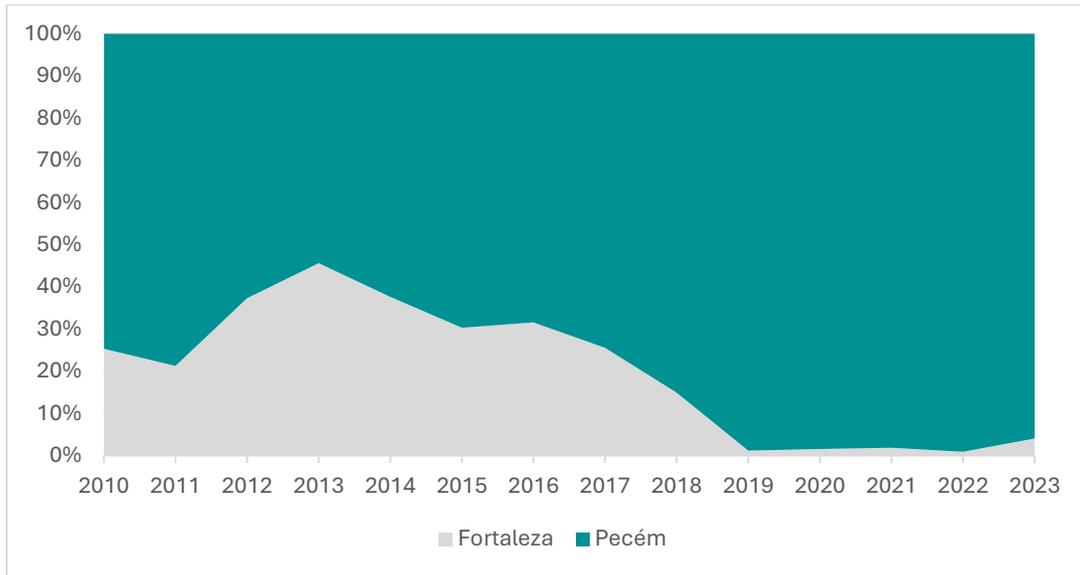
Source: (ANTAQ, 2024)

Ultimately, we came up with three different scenarios:

Table 9 Cabotage container forecast scenarios and drivers

| Scenarios	Drivers			
	GDP	Population	Fleet Capacity	Freight Rate
Exceptional Growth	High growth North, North-East, & Central-West same growth South & South-East	0,8% growth rate	40% increase by 2030	-7% price decrease per year
Status Quo	Same growth for all regions	0,52% growth rate	20% increase by 2030	-3% price decrease per year
Pessimistic	Slow growth for all regions	0,28% growth rate	No new ships	Constant at 750 R$/tkm

4.2.3 Forecast Results

Based on the drafted scenarios in Table 9 above, we used the intranational gravity model and came up with the cabotage container forecast up to 2030, as shown in figures 29, 30, and 31 below. We only used forecasts of non-landlocked states. The inflow forecast is less accurate than the outflow forecast when compared with the actual volume from 2021 to 2023. However, in total, the forecast was unable to go near the actual values in the past couple of years. Even in the exceptional growth scenario, the total throughput was 113.000 TEUs less than the actual numbers.

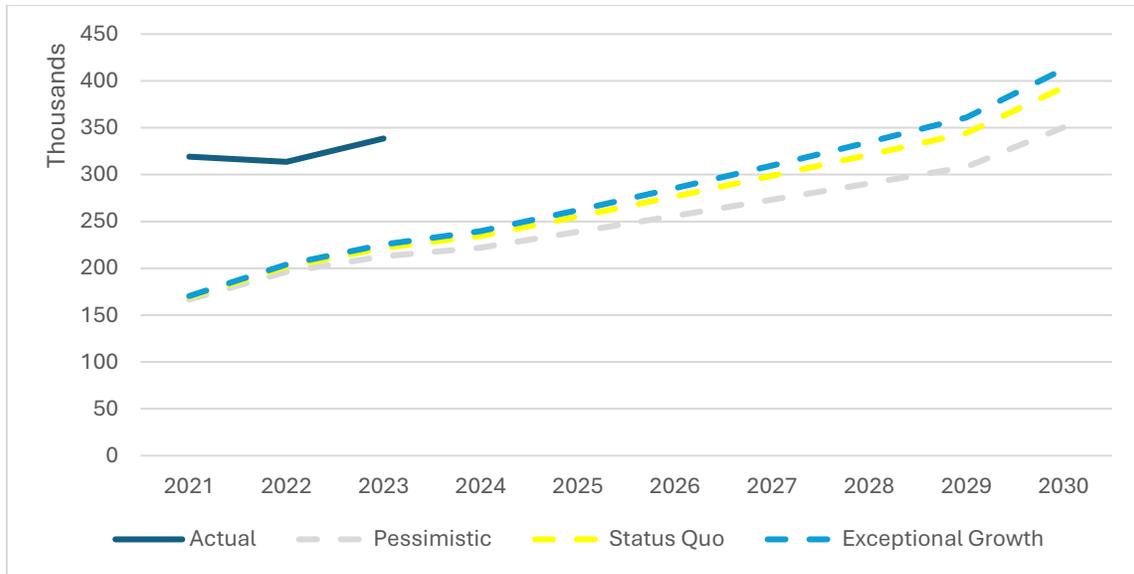*Figure 30 Ceará annual cabotage in containers forecast*
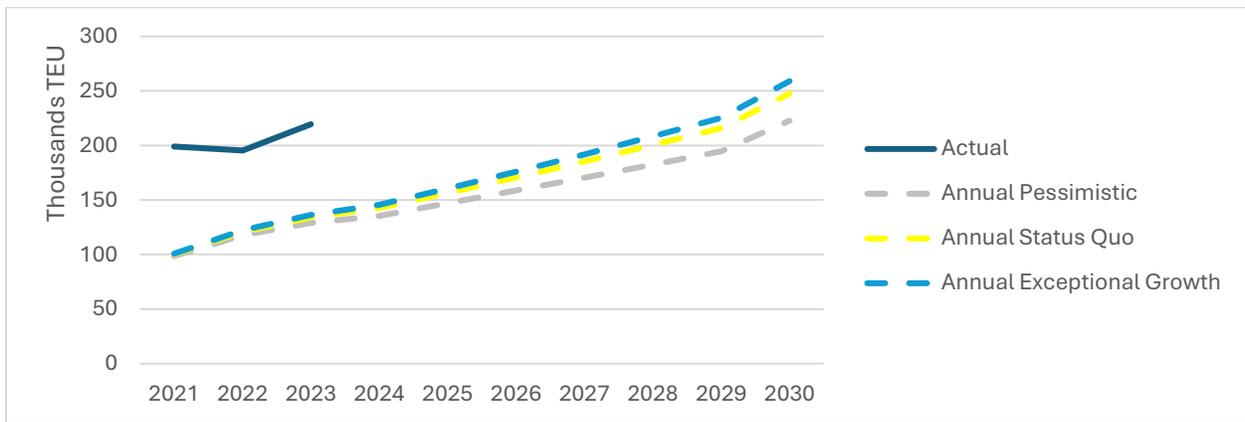
Source: Author and (ANTAQ, 2024)

Figure 31 Ceará annual cabotage out containers forecast
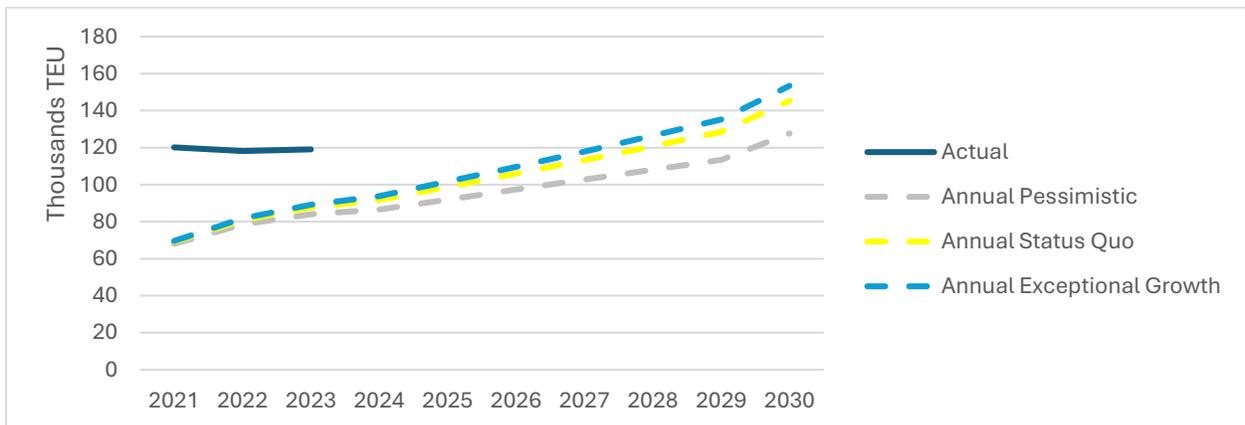
Source: Author and (ANTAQ, 2024)

Figure 32 Ceará total annual container throughput forecast

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Figure 33 below shows which regions will become important for Ceará and Pecém's cabotage container trade. The top 10 states represent between 86% of total cabotage throughput in the Exceptional Growth scenario and 87% in the Pessimistic scenario.

One considerable change between 2020 and 2030 is the position of Amazonas, which fell to the 9th position despite being one of the top 3 in 2020. The forecast replaced Amazonas by Rio Grande do Sul. The reason for this would probably be the author's model's heavy reliance on GDP that is based on its linear base. This also affected the same container throughput on the top 5 trading states that were part of both the South and South-east regions, because they had the same GDP growth assumption. Therefore, the model was unable to accurately forecast future cabotage container volumes.

Figure 33 Top 10 forecasted trading state based on cabotage container throughput in 2030
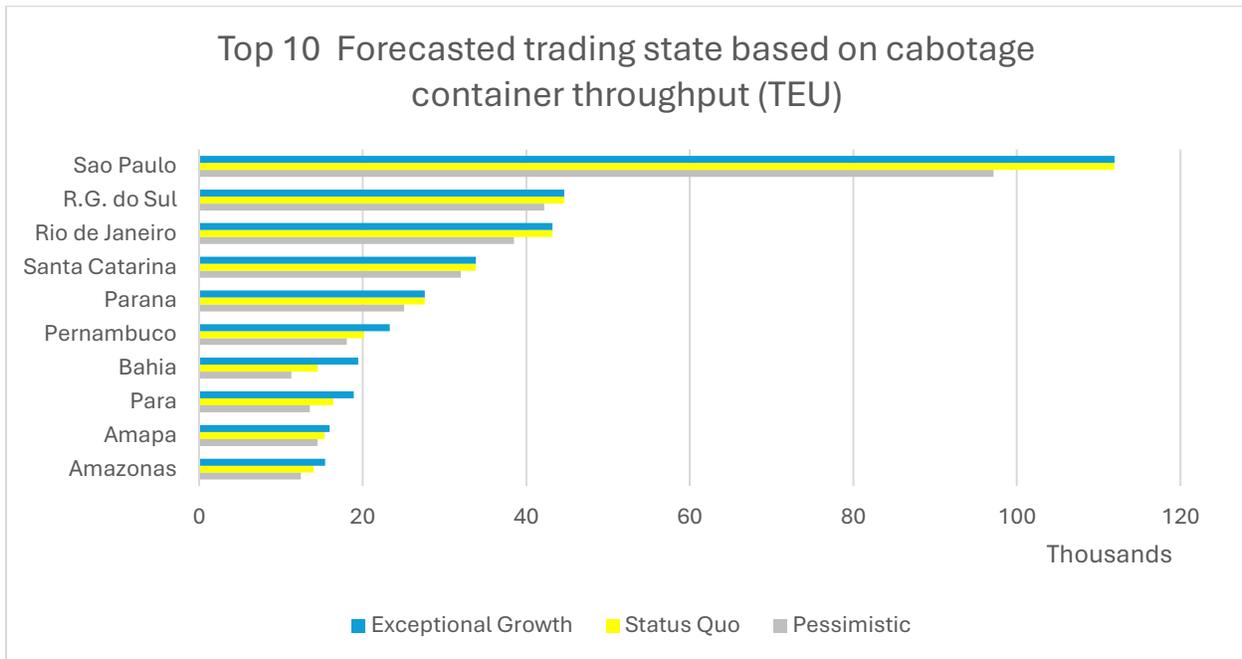
Source: Author

5. Conclusion

5.1 Discussion

PoR's Brazil Model performed relatively well in forecasting Brazil's national volume for all flows, import, export, and cabotage. However, the issue was the market share calculation which led to pessimistic container volumes for Pecém. There was also a high growth of cabotage containers in Brazil in the past 15 years. The author then decided to forecast the cabotage container trade flows to and from Ceará until 2030 based on the available data from 2010 to date using the well-founded gravity equation regression.

What is the forecasting methodology used by the Port of Rotterdam?

PoR's Brazil Model used the gravity equation for international trade and a simple regression of GDP and population for the national Brazil cabotage throughput. They limit it to Pecém through market share assumption. The forecast was also combined with three scenarios to adjust the variables based on the geopolitics and economic growth.

What are the strengths and weaknesses of the current model?

The current model performed well in forecasting the national throughput but fell short in the market share assumption, which was assumed the same for both international and intranational container trade. They were lacking the national context needed to narrow down the throughput for the Port of Pecém.

Was there a model failure or an outstanding market circumstance?

Statistically speaking, there was no model failure. We assumed that there was an outstanding market circumstance concerning the cabotage container trade. Therefore, we used the gravity equation to find out what are the drivers of cabotage container throughput.

What are the drivers for cabotage volume?

Based on our OLS analysis, the drivers were the classical gravity equation variables, such as GDP and population of the trade partner, distance between trading states, access to coastline, and how remote is the trading state from the national economic center. For our forecast assumption, we added also cabotage fleet capacity and freight rate to show how cabotage can be an interesting mode of freight transport.

How should the cabotage volume be modeled?

The Updated 2.1 Model that the author made performed the best based on the adjusted r-squared and mean squared error of the backcasting for both inflow and outflow.

What is the result of the back-casting of the updated model?

The Updated 2.1 Model was able to follow the ups and downs of the actual numbers from 2010-2020. They also produced less mean-squared error.

What is the market share of Pecém Port in the updated forecast?

We assumed an almost 100% share of the cabotage trade in Ceará for the Port of Pecém, due to the draft limitations of their competitor, the Port of Fortaleza.

What is the 10-year forecast for Ceará and the Port of Pecém?

After multiple trials of regression analysis, backcasting, and benchmarking, we decided on a model based on GDP, population, distance between state capitals, access to coastline, cabotage fleet capacity, and freight rate. Three scenario assumptions were used, and we came up with the total cabotage container throughput for Pecém of 350.000 TEUs in the pessimistic scenario, 392.000 TEU in the status quo scenario, and 412.000 TEU in the exceptional growth scenario. However, the model did not perform well compared with the actual throughput for 2021-2023. This meant that the historical

numbers could grow because of factors the author did not include. The implication for Pecém is that the forecasted volume added, with the relatively constant average international container flow of 75.000 TEUs (see Figure 5 above), might just touch their current capacity of 500.000 TEU by the year 2030.

How can the Port of Rotterdam's container trade flow forecast model for Brazil be improved?

There needs to be a more specific look into the cabotage container flows within Brazil. However, the gravity equation is not the ideal method to capture the reason behind the cabotage throughput growth and flows for Pecém in these past couple of years. The recent numbers were higher compared to the mainly GDP-based forecast.

5.2 Recommendation

For future academic research, we would recommend that others investigate the same matter but from a non-linear perspective to better identify the cabotage drivers. One variable that the author could not apply, but might be very relevant, was linear connections. To use this variable, it may be better to slice the trade data into monthly or even weekly to match it with the changing cabotage liner services available, and this data is mostly available inside the cabotage container services providers, such as Log-In, Aliança, Mercosur Line, and Norcoast.

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Appendix

Table 10 Interview list

Date	Name	Position	What are the drivers for cabotage?
3rd April 2024	Fabio Grandchamp	Executive Vice President (COO) at Port of Pecém	ship capacity, truck competition, and hinterland consumption
30th April 2024	Corne Hulst	International Commercial Manager at Port of Rotterdam *Former COO at Port of Pecém*	Economic growth, truck competition, liner services, port infrastructure
30th April 2024	Duna Uribe	International Project Manager of Port of Rotterdam *Former Executive Commercial Director at Port of Pecém*	Gas price hike, trucking cost increase, Covid-19, BR do Mar (ship capacity), liner services
7th May 2024	Frank van der Laan	Business Intelligence Advisor at Port of Rotterdam	Economic growth, liner services, port infrastructure, containerization rate
24th July 2024	Raul Viana Neris	Port Business Manager at Port of Pecém	Security, load capacity, gasoline and diesel price, environment, time, and safety

Source: Author