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UNDERSTANDING THE THERMAL COAL MOVEMENTS FROM COLOMBIA TO CHILE THROUGH THE PANAMA CANAL USING LOGIT MODELS- LOOKING AHEAD

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ABSTRACT
This study attempted to specify logit models for bulkers transporting mostly thermal coal from the East Coast of Colombia to Chile through the Panama Canal compared to the alternative route. The preliminary proposed predictors for the logit models included voyage cost variables and Canal's attributes. For the route choice of coal from the East Coast of Colombia to Chile, voyage cost factors such as Panama Canal cost, distance difference between Panama versus alternative route, post arrival of vessel to the next port and the maximum transit draft were important factors in this choice, as well as Panama Canal attributes such as vessel arrivals at the Panama Canal and the Panamax Plus requirement to transit the neopanamax locks. The route choice involved the Panama Canal and Cape Horn/Magellan Strait in the Southern tip of South America. This study analyzed coal traffic between October 1, 2016, and September 30, 2020, and briefly discussed the future of coal movements through Panama, given Chile's long term plans to generate electricity using renewanable energy sources and hydrogen. This paper is a contribution to the discrete choice literature and attempted to provide insights into route choice factors involving the Panama Canal, proposing new preliminary explanatory variables to better understand route choices that may apply in future Panama Canal studies. The study will be a contribution to the universal maritime coal transportation literature, and it is a continuation on research related to the Panama canal, particularly on route choices using AIS information.

Keywords: Panama Canal, Cape Horn, Magellan Strait, Logit Model, Thermal Coal, Panamax Plus

Introduction

The coal and coke category, not including petroleum coke, was the fifth most important commodity group through the Panama Canal in the fiscal year 2020[1] after petroleum and products, containerized cargo, grains, and the chemical and petrochemicals categories. In terms of commodity group in dry bulkers, coal and coke are the second most important group after grains in cargo and toll amount (Table 1). The coal and coke group includes thermal or steam coal for electricity generation, metallurgical coal for iron and steel production (coking coal, pulverized coal injection coal (PCI) and metallurgical coke itself) and any other coal for industrial use not classified as petroleum coke. Petroleum coke is part of the petroleum and products commodity group.

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[1] FY: fiscal year. Fiscal years runs from October 1 to September 30. Data: Panama Canal Authority.

Table 1: Main Commodities in Dry Bulkers- Panama Canal (Millions of Long Tons and Millions of U.S. dollars*)

Commodity	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020
Grains	40.1 ($123.7)	35.7 ($114.1)	27.4 ($86.9)	26.5 ($84.2)	29.9 ($96.3)
Coal and Coke (excluding Petcoke)	8.1 ($24.1)	17.3 ($47.0)	18.2 ($49.0)	17.7 ($49.5)	11.9 ($35.2)
Nitrates, Phosphates and Potash	6.7 ($21.8)	7.4 ($24.5)	10.1 ($33.0)	8.7 ($28.2)	8.7 ($28.6)
Ores and Metals	9.5 ($40.9)	9.8 ($40.3)	9.7 ($40.3)	9.2 ($40.2)	7.7 ($32.4)
Minerals Miscellaneous	6.6 ($19.9)	5.5 ($17.5)	7.6 ($23.6)	8.3 ($26.4)	6.3 ($19.7)
Manufactures of Iron and Steel	4.4 ($21.1)	5.8 ($25.9)	5.3 ($23.9)	5.0 ($23.6)	4.5 ($23.3)
Petroleum and Products	3.4 ($10.7)	4.7 ($13.7)	4.6 ($13.3)	4.0 ($11.6)	4.3 ($13.1)
Lumber and Products	1.8 ($5.9)	1.6 ($5.4)	1.8 ($6.0)	1.8 ($5.9)	2.2 ($7.3)
Others	9.0 ($31.5)	8.5 ($36.9)	8.1 ($33.1)	8.9 ($36.0)	8.4 ($32.3)
Total	89.6 ($299.6)	96.3 ($325.3)	92.8 ($309.1)	90.1 (305.6)	83.9 ($288.2)

*Toll income only (in parentheses), not including reservation income or any other non-toll income (Source: Panama Canal Authority)

From Panama Canal data, the coal and coke group had registered an upward but volatile trend between fiscal years (FY) 1997 - 2020, coinciding with the change in the importance of particular coal routes through the Panama Canal. Although the coal and coke category benefited from an expanded waterway, posting more than 17.0 million long tons between FY 2017 - 2019 compared to a previous maximum of 16.2 million long tons in the fiscal year 2013, and reversing a declining trend between FY 2014 - 2016, it recorded a significant decline in FY 2020 (Figure 1).

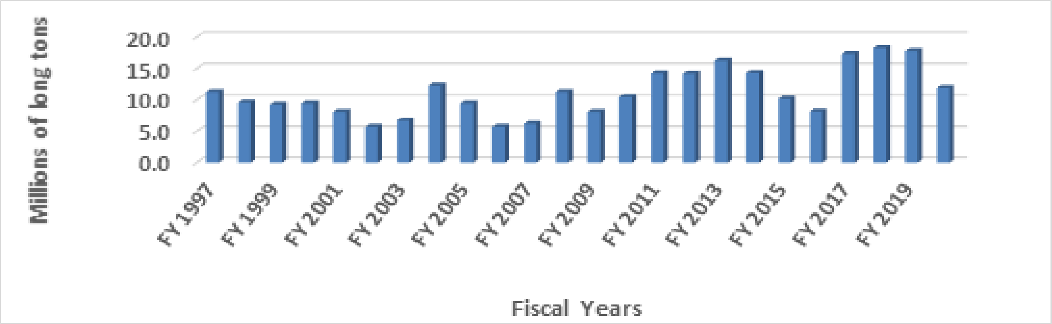

Figure 1: Coal and coke flows through the Panama Canal (not including petroleum coke)
(Source: Panama Canal Authority)

According to Panama Canal data, the East Coast to the West Coast of South America coal route averaged close to 4.1 million long tons between FY 2016-2020. Colombian exports of thermal coal to Chile have been significant for the dry bulk category of the Panama Canal. As the closest main thermal coal supplier to Chile, Colombia exports mostly from dedicated coal terminals such as Puerto Bolivar, Puerto Drummond, Puerto Nuevo, Santa Marta, Puerto Brisa and Cartagena (Figure 2)[2]. Tewalt *et al*. (2006) study the history of coal production in Colombia and the main thermal coal-producing regions are located in the department of La Guajira and Cesar on the Caribbean Coast[3]. This coal is delivered for electricity generation in the north, center, and southern regions of Chile, and it is consumed by the mining, industrial, commercial, and residential sectors. Since Chile has a high electricity demand, imports coal from Colombia, and savings in the distance by using the Panama Canal route, why isn't all thermal coal transported from Colombia to Chile through the Canal, considering that it is the shortest route? The Panama Canal route from the East Coast of Colombia to Chile saves between 3,178 - 5,850 nautical miles[4], depending on the destination port in Chile, given its large north-south coastline. What are the main factors that determine the coal route from Colombia to Chile? Even with the expanded Panama Canal allowing larger dry bulkers through the waterway, what are the possible explanations for some thermal coal transits from Colombia to Chile deviating into alternative routes? Are alternative routes to the Panama Canal significant for thermal coal from Colombia to Chile?

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[2] In 2020, Colombia was the 5th largest seaborne thermal coal exporter in the world (Source: Dry Bulk Trade Outlook, Clarksons Research August 2021).

[3] Also verified in World Coal. https://www.worldcoal.com/coal/10022011/coal_in_colombia/.

[4] Based upon distance information from IHS Markit (MINT), an Automated Information System (AIS) application.

Figure 2: Approximate port locations- Colombia and Chile
Drawing by authors using Google Maps.

This study applied the discrete choice model theory to answer these questions to explain the route choice decision for thermal coal from Colombia to Chile. The discrete binomial choices for this research on route choice were the Panama Canal and Cape Horn/Magellan Strait routes[5]. To model this binomial choice, this research attempted to fit logit models for dry bulkers that transport mainly thermal coal from the East Coast of Colombia to Chile through the Panama Canal compared to the alternative route by hypothesizing and relating the route choice to voyage cost factors and Panama Canal attributes. The logit formulation is widely used in transportation to choose alternatives, including route choices. The study began with an explanation of the Chilean demand for thermal coal in terms of alternative sources of thermal coal and alternative energy sources and discussed the importance of coal within the dry bulk segment. Coal consumption is derived from the electricity demand and thermal coal imports from Colombia to Chile requiring maritime transportation. However, in terms of route decision and focusing on the purpose of this study, it is important to understand the impact of the preliminary potential explanatory variables on the route choice of thermal coal movements from Colombia to Chile, especially since the inauguration of the expanded Panama Canal in June 2016. Therefore, the proposed initial potential explanatory variables for the logit models considered predictors related to voyage cost calculations from a vessel operator point of view --including Panama Canal costs-- and specific Canal attributes that may play a role in the route choice, especially after the Panama Canal expansion.

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[5] We are assuming Magellan Strait and Cape Horn as one single alternative to the Panama Canal.

For this study, we analyzed coal traffic from Colombia to Chile between FY 2017-2020, a post-Panama Canal expansion timeframe. From the questions about the decision to transit or not the Panama Canal, we want to analyze and propose the most likely explanatory variables that may explain this route choice decision. Data used for the study came from Panama Canal transit information, Panama Canal's daily operations report, Clarksons, and actual transit verifications using IHS Markit's MINT to confirm actual Panama Canal and alternative route transits, departure, and arrival dates. We also received cargo amounts for particular vessels from Coal Marketing Company (Cerrejon), Drummond and Sociedad Portuaria Regional de Santa Marta[6]. Firstly, this paper reviewed the more relevant literature on the Panama Canal and discrete choice models. Although there are previous studies related to the Panama Canal and very limited literature applying discrete choice models to the Panama Canal, this research focused specifically on coal from Colombia to Chile and attempted to address the current gap in the literature, including post-Panama Canal expansion studies. Secondly, we presented the possible logit models based on voyage costs and Canal's attributes to provide insights into the factors impacting this routing decision. Subsequently, the lessons from this exploratory research may extrapolate into future studies applied to commodities using the interoceanic waterway, including grains. Finally, besides a better understanding of the route decision of thermal coal transits from Colombia to Chile, the discussion on coal flows from Colombia to Chile will involve Panama Canal cost and transit issues. At the same time, the future of electricity based on coal generation in Chile may have important managerial and policy implications for the Panama Canal in terms of the future traffic composition, especially with the decarbonization of the electricity matrix in Chile.

Literature Review

The following is the literature assessment providing the foundation for our study regarding the theory and methodology to model thermal coal flows from the East Coast of Colombia to Chile through the Panama Canal, specifically the groundwork for the logit estimation to explain and understand the route choice for this flow. Coal movements from Colombia to Chile are derived from the electricity demand in Chile. According to data from the National Electric Coordinator of Chile (Coordinador Electrico Nacional), in 2020, coal was the main electricity source in Chile, generating 27.0 million GWh/year and representing 34.7 per cent of total electricity generation[7] (Figure 3). According to the same source, coal became the number one energy source in Chile since 2011 surpassing hydro, although showing a clear downward trend since 2016 and representing only 18.7 per cent of total generating capacity (MW) in 2020. According to statistics from the same source, solar and wind power capacity has increased since 2014. Likewise, according to Comision Chilena del Cobre (Cochilco) --up to 2019-- copper mining represented 14 per cent of total energy consumption, divided almost equally between fuel and electricity consumption[8]. Undoubtedly, mining is an important activity that explains the growing electricity consumption in Chile, including thermal coal as part of the energy matrix.

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[6] Jackie Cantillo, formerly of IHS Markit, provided data for some cargo flows.

[7] From Coordinador Eléctrico Nacional of Chile. https://www.coordinador.cl/reportes-y-estadisticas/#Estadisticas. Accessed April 21, 2021.

[8] Comisión Chilena del Cobre de Chile (Cochilco). Informe de actualización del consumo energético de la minería del cobre al año 2019. https://www.cochilco.cl/Mercado%20de%20Metales/Informe%20de%20Consumo%20de%20Energ%C3%ADa%202019.pdf

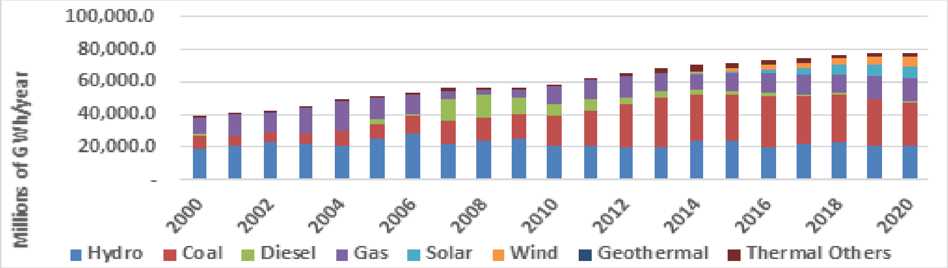

Figure 3: Sources of power generation in Chile

(Source: Coordinador Eléctrico Nacional de Chile)

About the data to verify route choice, vessel movement data from AIS (Automated Identification System), such as IHS Markit's MINT used in this research, is an important tool in the navigational and operational processing of vessels. AIS facilitates voyages and allows ships to be identified by others for security and safety planning, as in Serry (2017), Wright *et al*. (2019) and Lee *et al*. (2019). Alternatively, AIS data is available online in applications such as Marine Traffic, VesselFinder and MINT. AIS data includes ship name, speed, direction, and geographical position. This information is accessible and can be displayed on a computer.

The most important characteristic of AIS data is that it can be stored and retrieved. Tu *et al*. (2017) and Mao *et al*. (2018) list free data sources and commercial data providers. Studies applying AIS inputs for understanding and visualizing trade patterns include Fiorini *et al*. (2016), Wu *et al*. (2017) and Svanberg *et al*. (2019). Although very technical about data collection, these works explain a procedure for displaying AIS data to obtain traffic density information and achieving route optimization through route planning. Other applications of AIS data include maritime spatial planning such as marine traffic density, navigational flows, fishing zones and hierarchical network of sea routes as per Tixerant *et al*. (2018). Fiorini *et al*. (2016) explain that every 6 minutes, the AIS transmitter sends information such as vessel name, IMO number, vessel type, draft, and destination. This information is important because vessel departure data from Colombia's coal terminals and vessel arrival information to the main Chilean coal importing ports can be retrieved and cross-checked with Panama Canal's coal transit data from Colombia to Chile and visualized and verified using MINT.

The theory and estimation of discrete choice models, including logit models, are widely used in transportation modes and route choices, as in our research. Various studies have examined the choices between two alternatives, that is, Reggiani *et al*. (1997), Guoqiang (2012), Manssour *et al*. (2013), Surbakti and Bombongan (2017) and Wojcik (2017). These works were related to the binary choice of ground transportation such as rail/truck, car/bus, bus/train or public/private transportation. Regarding models with more than two choices (multinomial), we included the papers by Chang *et al*. (2013), Manssour *et al*. (2013) and Hussain *et al*. (2017). Most of these studies used survey data and publicly available transportation data to understand transportation patterns, improve mobility, and project future demand for the different transportation modes. In port choices, Itoh, H *et al*. (2002) developed a model for container cargo originating in the Kita Kanto region of Japan. The flow of cargo to and from the ports depends on the location of shippers, availability of shipping line services and the facilities offered by the ports. In this study, the authors developed a nested multinomial logit model, which included, as port decision factors, both port and shippers' characteristics. Within the shippers' characteristics, the authors included factors such as distance of shippers to ports, time of travel to the port, type of trade (export/import), municipality output and shipper's facilities variables such as vanning/devanning of container cargo. The time of travel to the port is a very important factor in the port choice by shippers. Kanamoto *et al*. (2021) estimated multinomial logit models to obtain the optimal dry bulk vessel type for different dry bulk commodities such as iron ore, coal, grains, and fertilizers. Explanatory variables for this study were trade volume (in thousand tons), voyage distance (km), maximum loading draft (m), discharging maximum draft (m), and the Panama Canal and the Suez Canal's market share. The study concluded that, in most cases, larger trade volumes, maximum draft in ports and voyage distance increase the probability of using a larger ship. Wen and Huang (2007) estimated a multinomial logit model for the choice of ocean carrier based on mail surveys to freight forwarders in Taiwan. Besides the examined ocean carriers, the main explanatory variables in evaluating carriers included transit time, frequency of services, cargo delays, freight rates, and service factors such as speed, reliability, and convenience.

Additionally, Sytsmas and Wilson (2021) developed a logit model for the preferences of U.S. Upper Mississippi River Valley corn shippers for barges instead of railroad transportation, depending on the shipper location relative to the Mississippi River. They incorporated nine shipment destination regions represented in eight dummy variables and concluded that the closer the shipper to the Mississippi River is, the greater the preference for the barge mode of transportation. This concept of the preference for the shorter distance represented by the barge system on the Mississippi River can be incorporated into our model estimation.

For the case of route decision, earlier studies related to route choices in maritime transportation are summarized by Schøyen *et al*. (2011), Breen *et al*. (2015), Shibasaki *et al*. (2016), Shibasaki *et al*. (2017), Shibasaki *et al*. (2019), Bai *et al*. (2019) and Wu and Xu (2021). Schøyen *et al*. (2011) highlight the navigational shorter distance of the Northern Sea Route (NSR) compared to the Suez Route in Northwest Europe- Far East route for containers and dry bulkers. However, the NSR is seasonal and uncertain in terms of schedule reliability. Breen *et al*. (2015) developed three multinomial logit models to analyze transport and route choice for Irish exporters to continental Europe, namely the United Kingdom land bridge and the direct connection to continental Europe. The factors considered in the formulations were the cost of transportation from origin to destination (in Euros per shipment), transit time (in hours), probabilities of delays (percentages), duration of delays (hours) and service frequency in terms of waiting hours concerning the preferred departure hour.

Furthermore, Shibasaki *et al*. (2016) developed a case study of the Suez Canal and route choice for containerships, first reporting on the market share of the Suez Canal for several origin-destination regions, checking the competition with other routes, including the Panama Canal and the Cape of Good Hope-, and then estimating an aggregate logit model to help describe the share of each route. The route factors under consideration for this research were shipping cost per unit of capacity (US$/TEU-including fuel, capital cost and operating costs) and shipping time. Similarly, Shibasaki *et al*. (2017) estimated an aggregated logit model to predict the market shares of several origins-destinations routes, comparing the Suez Canal and alternative routes. The aggregated logit model is utilized in sensitivity analysis to simulate declines in bunker prices, the impact of the Panama Canal expansion and the elimination of piracy around the Somalian coast. Furthermore, Shibasaki *et al*. (2019) asked about competition among shipping routes for LNG transits (laden and ballast), focusing on the alternative routes for the Suez Canal and the Panama Canal. The authors explained that the dynamic of maritime routes for LNG is a function of new LNG export terminals (new trade patterns) and the cost of a bunker, the latter making the longer alternative routes more attractive when the cost of a bunker is low.

According to the same authors, another competitor route for the Suez Canal is the Northern Sea Route, the shorter distance between Northern Europe and East Asia and being attractive when fuel price is high. Bai *et al*. (2019) studied a destination choice model for large gas carriers (VLGC) departing from the U.S. Gulf. It applied a logit model and analyzed the effects of the Panama Canal expansion on destination routes. Bai *et al*. (2019) assumed a charterer's perspective and included as regressors freight rates, propane price spreads, bunker costs and the number of vessels located in the destination areas. Finally, Wu and Xu (2021), on research about alternative routes to the Suez Canal for containerships, explained that waiting costs, including toll rate and ship charter, called "ship rent" by the authors, are important factors in the decision of whether to deviate or not from the Suez route. According to the authors, when the cost of deviation from Suez is high, the ship will prefer the Suez route. In a nutshell, transportation/shipping costs, distance, delays/waiting time, transit time and fuel cost are common factors in a route choice, including logit formulations.

There are few studies on the Panama Canal's shipping demand itself, the majority either focusing mainly on the container market share or the competitiveness of the Panama Canal compared to alternatives. Some of these studies include Fan *et al.* (2012), Ungo and Sabonge (2012), Martinez *et al*. (2016) and Pham *et al.* (2018). Furthermore, we are not aware of any academic studies involving coal movements through the Panama Canal, except perhaps general Panama Canal traffic studies such as Mason and Rowlands (1938) or Nathan Associates (2012), the latter a long-term dry bulk demand study-including coal and coke-contracted by the Panama Canal Authority. Other studies include Wilson and Ho (2018), Ho and Bernal (2018b) and Ho and Bernal (2019). Wilson and Ho (2018) described commodity traffic through the Panama Canal and provided examples of voyage calculations for several market segments comparing the Panama Canal with the Cape of Good Hope route. For example, for the case of grains from the U.S. Gulf to Asia explanatory variables under consideration were voyage factors such as Panama Canal tolls, freight rates and fuel prices in the inter-route competition between the Panama Canal compared to the Cape of Good Hope route.

On the other hand, Ho and Bernal (2018b) attempted to estimate an aggregated demand function for dry bulkers at the Panama Canal using the OLS method and to incorporate regressors such as Panama Canal effective toll rate, GDP per capita of the world, the Baltic Dry Index (BDI), and Pacific Northwest (PNW) and U.S. Gulf freight rates. Of the five proposed regressors in the research, the first three were the only significant variables with the correct sign. However, this research was based on consumption theory. Likewise, Ho and Bernal (2019) estimated a logit model for grains transits attempting to explain the route decision between the Panama Canal compared to alternatives, mainly the Cape of Good Hope route. This study utilized voyage cost attributes assuming the point of view of a carrier/vessel operator and, as such, included route choice factors such as transit costs (pure tolls and other maritime services charge), transit draft, bunker prices, and Canal Water Time (CWT). However, the study only covered fourteen months of data- from July 1, 2017, to September 30, 2018, a post-Panama Canal expansion period- and the only significant factor was transit draft as a proxy for cargo amount. In particular, Ho and Bernal (2019) attempted to include explanatory variables directly related to the Panama Canal route, such as Canal Water Time and transit draft. The authors also mentioned the importance of compliance with the requirements to transit the expanded Canal for Panamax vessels (Panamax plus) and the risk of overdraft. They suggested using other variables to explain route choice, such as vessel arrivals or vessel backlogs, to be applied as proxies for delays as an important factor stated in the literature.

In summary, the literature review identified the broad use of discrete choice models -and logit formulations-in maritime transportation, especially route choices, attempting to model the route decision of thermal coal from Colombia to Chile. It highlighted the ever-increasing importance of AIS-generated information and tools for route choice models and emphasized the usefulness of this type of study for the Panama Canal. Therefore, based on previous studies suggesting the importance of attributes such as short distances, time-saving, possibilities of delays, bunker prices, draft, and Canal cost, and drawing on the previous experiences, this current study is proposing particular Panama Canal factors to understand better the mostly thermal coal flows from Colombia to Chile, applying a time framework comprising FY 2017 - 2020. Consequently, using the theoretical and methodological foundations provided by past writings, our paper attempted to fit logit models for dry bulkers transporting thermal coal from the East Coast of Colombia to Chile through the Panama Canal versus an alternative route. As a result, this paper may complement the route choice literature but focus specifically on the East Coast of Colombia to Chile thermal coal route. Also, this paper will contribute to the universal maritime coal transportation literature and represents a continuation of studies related to the Panama Canal, particularly on route choices using AIS information.

Research Model, Data and Methodology

Hypothesis and Research Model- The Logit Formulation Proposed

Thermal coal, also called steam coal, is a widely used fossil fuel for electricity generation transmitted on national grids or as energy in the manufacturing, chemical, or cement industries. It is different from metallurgical coal, such as coking coal, pulverized coal injection (PCI), and coke, which is utilized in the iron and steel industry to process ironore[9].

According to Clarksons Research, 915.0 million metric tons was the volume of steam coal for 2020 compared to 250 million metric tons for coking coal, the largest component of metallurgical coal[10]. According to the same source, steam coal is the second largest component of major bulks after iron ore and represented close to 29.0 per cent of seaborne major bulks in 2020[11]. Thermal coal is priced and demanded according to its calorific value and graded in terms of sulfur, ash, volatile and moisture content.

According to Coordinador Electrico Nacional of Chile, coal was the main source of electricity in 2020, representing about a third of total electricity generation. More than 60 per cent of total coal imports by Chile since 2017 originated in Colombia

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[9] Iron ore can also be processed using natural gas to produce direct reduced iron (DRI).

[10] Dry Bulk Trade Outlook, Clarksons Research. Volume 27, No. 3. March 2021.

[11] Major bulks include iron ore, steam and coking coal, grains (wheat, coarse) and soybeans.

compared to other countries[12] (Table 2). At the same time, Colombian movements of coal and coke to Chile through Panama averaged close to 37 per cent of total coal imports between 2015 - 2019[13].

Table 2: Coal Imports by Chile- Origin Countries (millions of metric tons)

Exporter	2015	2016	2017	2018	2019
Colombia	4.1	4.8	7.0	7.9	8.2
United States	3.1	2.6	1.5	2.0	1.0
Australia	2.0	3.5	2.3	1.0	0.9
Canada	0.3	0.7	0.2	0.2	0.2
Others	0.2	0.1	0.1	0.0	0.1
Total Imports	**9.7**	**11.7**	**11.1**	**11.1**	**10.4**

(Source: United Nations Conference on Trade and Development (UNCTAD)

In a strict microeconomics sense, a firm's demand for electricity is a derived demand to produce outputs a firm offers to the market, as stated by Berndt and Wood (1975). Likewise, the production of energy in a country is a summation of the derived demand for electricity from residential, commercial, and industrial users. As a significant energy input to produce electricity in Chile, thermal coal consumption and imports are also derived demands, impacting the coal flows from Colombia to Chile through the Panama Canal. Nonetheless, although coal movements from Colombia to Chile through the waterway are a derived demand of the electricity market in Chile, this paper, however, is attempting to understand the thermal coal movements of this trade not in terms of the variables involved in the electricity demand, but more in connection with the route options, that is, the choice of the Panama Canal route versus alternative, namely Cape Horn/Magellan Strait applying discrete choice theory. In other words, given the derived demand for coal inputs in Chile for electricity generation and Colombia being an important and the closest source of thermal coal to Chile, we hypothesize and model dry bulkers hauling mostly thermal coal from the Caribbean coast of Colombia to Chile through the Panama Canal compared to alternative route applying logit models.

From the discrete choice modelling framework, and as part of the proposed logit formulations, we also hypothesize the importance of voyage cost and Panama Canal factors as significant contributors to route choice, based on variables drawn from the past literature but adapted to this Panama Canal study, from a voyage planning perspective of a dry bulk operator. The route choice decision is a function of voyage costs and Canal attributes. Assuming a voyage planning perspective, a vessel operator n at time t faces j mutually exclusive routes. Then the vessel operator chooses the route with the highest utility, the option with the maximum attractiveness. The utility level from a route choice j at time t for vessel operator n can be estimated by the following utility function:

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[12] Data from UNCOMTRADE for harmonized code 2701. Accessed April 28, 2021. https://comtrade.un.org/data

[13] Flows from Colombia to Chile between 2015-19 from UNCOMTRADE and Panama Canal movements for calendar years 2015- 2019.

$$U_{tjn} = V_{tjn} + \varepsilon_{tjn} \tag{1}$$

where V_{tjn} is deterministic, known to the researcher from both observed attributes of the route X_{tjn} and observed attributes of the decision maker S_{tjn} (see examples in Chang *et al*., 2013, Bai *et al*., 2019 and Sytsmas and Wilson, W., 2021). V_{tjn} is called the representative utility and is denoted by $V_{tjn} = f\,(X_{tjn}\,,\, S_{tjn}\,)$. On the other hand, ε_{tjn} is not observable and is unique to each vessel operator. Therefore the vessel operator route choice cannot be predicted with certainty, and it is a random component of a vessel operator's utility function for route choice j at time t. According to Chang *et al*. (2013), representative utility is assumed in a linear and additive function such the

$$U_{tjn} = \textstyle\sum_{k}^{N} \beta_k X_{tjnk} + \varepsilon_{tjnk} \tag{2}$$

where X_{tjnk} is the k^th^ observed attribute of destination *j* at time *t* for vessel operator n. The term β_k represents the coefficient of the k^th^ observed attribute X_{tjnk}. The odd that a vessel operator n at time t chooses destination j given k attributes is

$$P_{tjn} = \frac{e^{V_{tjn}}}{\sum_{n=1}^{n} e^{V_{tjn}}} \tag{3}$$

where V_{tjn} is the measurable component of the vessel operator utility. For our study, the endogenous variable we want to explain is qualitative or discrete, mainly the choice of the Panama Canal route or alternative.

For our study, given that *i* represents an individual transit, our logit model will take the following general form:

$$\mathrm{Ln}\,\frac{Pi}{1-Pi} = V_i = \alpha + \beta X_i \;\; \mathrm{Ln}\,\frac{Pi\;(Canal\;thermal\;coal\;transit\;Colombia-Chile)}{1-Pi\;(Canal\;thermal\;coal\;transit\;Colombia-Chile)} = \beta_1 + \beta_2 Z_2 + \ldots + \beta_k Z_k \tag{4}$$

or we specify the deterministic component (V) as a function of the following variables:

$$\begin{gathered}\mathrm{Ln}\,\frac{Pi\;(Canal\;thermal\;coal\;transit\;Colombia-Chile)}{1-Pi\;(Canal\;thermal\;coal\;transit\;Colombia-Chile)} = Intercept + Total\;Panama\;Canal\;Cost\;+ \\ Houston\;Bunker\;Price + Panamax\;Plus\;Requirement\;+ \\ Diferential\;Distance\,\frac{Panama}{Alternative} + Arrivals + maximum\;draft + \\ Days\;between\;assignments + Outages\end{gathered} \tag{5}$$

where

$Pi\;(Canal\;thermal\;coal\;transit\;Colombia - Chile)$= probability of Panama Canal thermal coal transit from Colombia to Chile

$1 - Pi\;(Canal\;thermal\;coal\;transit\;Colombia - Chile)$= probability of no Panama Canal coal transit (alternative route)

From the vessel operator point of view of planning a possible transit through the Panama Canal, the particular Panama Canal factors directly or indirectly derived from the literature review include vessel arrivals, the periods of maintenance/outages and compliance with the requirements to transit the neo-Panamax locks. On the other hand, the greater the number of ships that arrive, the greater the possibility of congestion, delays, and transit uncertainty at the Panama Canal. Therefore, we included this regressor with an expected negative sign. Also, we added two dummy variables related to the use of the Panama Canal route: maintenance/outage and Panamax plus requirements. Maintenance/outage intends to capture the days of outages at the waterway, impacting capacity and reducing daily transits, increasing the probability of ships using alternative routes. Thus, we expect a negative sign for the maintenance/outage dummy variable. As for the Panamax plus requirements, this dummy variable represents all Panamax or below vessel sizes that comply with all the requirements to transit the neo-Panamax locks[14]. These requirements are sine qua non-conditions to transit the neo-Panamax locks for any vessel, and we expect a positive sign for this variable[15].

Regarding voyage cost factors that may impact the probabilities of thermal coal traffic through Panama, we added Panama Canal costs[16], Houston fuel oil price (IFO 380cst), the distance difference between the Panama Canal route versus the alternative, the days between the vessel arrived at the destination port in Chile and the next assignment (next port call), and the maximum transit draft of a vessel. The total Panama Canal fee, which includes tolls and other charges to transit the Panama Canal, is one of the most important factors that we hypothesized to be important to our logit models, and it is expected to post a negative sign representing the total cost for using the Panama route. Houston fuel oil price is a proxy for the fuel cost involved in a voyage. The higher the price of fuel, the greater the fuel expenditure of a vessel and, consequently, we expect a positive sign for this variable because the Panama Canal is the shortest route and, as a result, saves fuel based upon voyage cost calculation[17]. As far as the distance difference between the Panama Canal route versus the alternative is concerned, this variable is included to take into account the distance saving represented by the Panama Canal route instead of a longer option; hence we expect a positive sign to account for the higher probability of using the shorter route.\

Another key explanatory variable in our study is represented by the days between the vessel's arrival at the destination port in Chile and the next port call arrival, expected to post a positive sign to account for the greater probability of using the Panama Canal if more days are necessary to reposition at the next port of call. Finally, the maximum transit draft variable is incorporated to consider the impact of cargo intake in the route decision. In our case, we expect this maximum transit draft factor of a vessel to be negative as it represents the amount of cargo favouring the longer route trying to achieve economies of scale with a

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[14] Panamax Plus vessels: All Panamax vessels approved for transit through the new locks. Source: NT Notice to Shipping N-1-2019, pg. 10.

[15] To transit the Expanded Canal, vessels must have adequate chocks and bits for towing and mooring. NT Notice to Shipping N-1-2019, pp. 38- 46.

[16] Canal fees are part of voyage cost calculations.

[17] Fuel expenditure on a voyage also depends on the average and efficient speed of a ship.

larger vessel and cargo intake. Even with the expanded Panama Canal, the maximum seasonal draft of 15.02 meters does not allow higher utilization of capsizes drafting on average 18.1 meters[18].

Data, Variables and Sample

For the estimation of the logit models for dry bulkers transporting mostly steam coal from the Caribbean Coast of Colombia to Chile through the Panama Canal compared to the alternative route, we created a database of dry bulkers departing from the main coal terminals in Colombia using IHS Mint, by performing a query from October 1, 2016, to September 30, 2020, a post-Panama Canal expansion timeframe. Next, we created a database of dry bulkers arriving at the main coal import terminals in Chile by executing a query using IHS Mint and the same period as the departure from Colombia. The origin ports in Colombia and destination ports in Chile, along with information on transits and the average size of vessels (in DWT), are listed in Table 3.

Table 3: Origin Ports Colombia, Destination Ports Chile, Transits and Average Size

Origin Port Colombia	Transits	Avg. DWT	Destination Port Chile	Transits	Avg. DWT
Puerto Bolivar	206	76,738	Mejillones	158	76,877
Puerto Drummond	129	69,226	Coronel	92	67,819
Santa Marta	63	66,240	Ventanas	87	71,419
Puerto Nuevo	47	67,227	Huasco	63	68,551
Puerto Brisa	6	31,861	Tocopilla	38	69,677
Barranquilla	3	31,961	Patache	8	59,917
Cartagena	1	63,200	Penco	6	33,931
			Others	3	55,485
Total= 455 transits					

(Sources: IHS Mint and Panama Canal Authority)

The vessel departures and arrivals from the databases created were cross-checked and matched, ensuring a vessel departure from Colombia corresponded to a vessel arrival in Chile. Once we obtained origin-destination trips by ship name, we visually verified each vessel and voyage with the IHS Markit tool and cross-checked with the Panama Canal transits database to confirm transits through the Panama Canal route[19]. Thus, we verified the route, coal as the commodity transported, and the specific origin-destination terminals[20]. With these databases and route and commodity verifications, we could generate the sample of 455 total transits for the logit models between fiscal years 2017 - 2020: 329 transits through Panama and 126 transits using the alternative route. As part of the 455 total transits, we identified a subset of

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[18] Dry Bulk Trade Outlook, Clarksons Research. Ibid. Also, capesizes with coal had transited the Expanded Canal with the maximum draft of 15.02 meters.

[19] With the IHS Markit tool, we were able to verify actual export and import terminals.

[20] Coal in Colombia is exported from dedicated terminals. Also, Panama Canal data allowed the identification of the commodity transported by ships using the Panama Canal route.

only 432 transits that did or did not comply with the Panamax Plus requirements to transit the neo-Panamax locks, specifically 324 transits through the waterway and 108 transits on the alternative route. This subset includes vessels the Panama Canal had information on because of either previous transit or ships that previously sent mooring arrangement plans and ship drawings for Panamax Plus assessment[21]. The 455 total sample and the 432 subsets may be the same vessel transiting the Panama Canal and/or alternative but on different dates.

Once we obtained the 455 total transits sample and the 432 total Panamax Plus subsample, we proceeded to map and calculate the total Panama Canal transit cost (toll fees and other charges), Panama Canal total arrivals numbers, and the price of Houston fuel oil. We assigned a value of 1 for days of outages, 0 otherwise for each transit according to its departure date; 1 for Panamax Plus ships complying with the requirements to transit the neo-Panamax locks, 0 otherwise for each transit listed, no matter how many times a ship transited the waterway or alternative but using the departure date from Colombia as the reference[22]. For the total Panama Canal cost, we added actual toll fees and other marine charges from the Panama Canal transit database for each vessel that transited the waterway. For the cases in which a ship by passed the Panama Canal, we calculated a theoretical total Panama Canal cost by calculating tolls and other marine charges based on the vessel DWT and cargo amount per a proforma bill[23]. For the voyage fuel cost, we used the weekly price of Houston IFO 380 cst fuel oil from Clarksons as a proxy for this cost and assigned it according to the departure date of the vessel corresponding to that week. For example, if a vessel departed Colombia on July 17, 2019, the corresponding fuel oil price was between July 13 - 19, 2019. In terms of total arrivals at the Panama Canal, its value was also based on the departure date of the vessel. If a ship departed from Colombia on July 17, 2019, we assigned the total number of arrivals at the Panama Canal on July 17, 2019, to this transit as a proxy for the possibility of congestion at the Panama Canal.

The initial database using IHS Mint of dry bulkers departing Colombia or arriving in Chile included a field with the maximum transit draft of each vessel, which we assigned to each transit as an approximation of the impact of maximum cargo intake and vessel size in the route decision. On the other hand, the arrival database from IHS Mint included the arrival date of a ship to the coal importing terminal. We followed the ship to the next port assignment using IHS Mint and wrote down the new next port arrival date. Thus, we subtracted the new port arrival date from the previous arrival date at the coal terminal in Chile to obtain the days between assignments. The greater the number of days to the next repositioning, the higher the probability of using the shorter Panama route. Finally, for each transit from port A to B, we included the distance difference between taking the Panama Canal route and the longer alternative route from Colombia to Chile.

For example, if a vessel transited the Panama Canal from port A in Colombia to port B in Chile, we assumed the Magellan distance as the next best alternative from Port A to B. Likewise, if a ship transited

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[21] There is no information of Panamax Plus requirements for vessels with no previous Panama Canal transits. Panamax Plus does not include capesizes or any vessel size above the kamsarmax range (80,000- 89,999 DWT from Clarksons).

[22] The assignment of values for the predictors of the logit is based upon the departure date from Colombia as an assumption, given the fact that Colombian ports are only a 1- day away from Panama.

[23] This is like when a customer requests a rough estimate of total Canal transit cost before deciding to use or not the waterway. Assuming no reservation fee.

either the Magellan Strait or Cape Horn from ports A to B, the Panama Canal route is the alternative. Consequently, this explanatory variable was created and incorporated into our data sample to consider the distance saving afforded by the Panama Canal as a key factor in a voyage calculation. The complete list of voyage cost factors and Panama Canal attributes in detail are included in Table 4.

Table 4: Explanation of Voyage Cost Factors and Panama Canal Attributes

Data	Type	Metric	Source	Explanation	Observations
Total Panama Canal Cost	Voyage cost factor	U.S. dollar	Panama Canal	Toll fees + other Canal charges.	Panama Canal bypasses “assessed” only basic tolls and charges (theoretical)
Distance difference Panama/ Alternative Route	Voyage cost factor	Nautical miles	IHS Mint	Distance difference comparing a voyage through Panama vs alternatives	Same origin-destination Panama route versus next best alternative.
Arrivals	Panama Canal Attribute	Number of ships	Panama Canal	Total arrivals	Daily vessel arrivals
Post Arrival Next Port	Voyage cost factor	Days	IHS Mint	Difference in days	Next port arrival date minus previous port arrival date
Maximum Transit Draft	Voyage cost factor	Meters	IHS Mint	Maximum draft	Maximum transit draft of a ship
Houston IFO 380 cst	Voyage cost factor	$/ton.	Clarksons	Weekly fuel price	Weekly price assigned to a transit based on its departure date

Outages	Panama Canal Attribute	1 when there is outage, 0 otherwise	Panama Canal	Dummy Variable	Value assigned to the dates with outages
Panamax Plus	Panama Canal Attribute	1 when ship complies with requirements, 0 otherwise	Panama Canal	Dummy Variable	Value assigned if ship complies with requirements for transiting neo-Panamax locks

(Sources: IHS Mint, Panama Canal Authority and Clarksons)

Methodology- Model Specification

Our logit models for mainly thermal coal movements from the East Coast of Colombia to Chile assume coal as part of the energy mix in Chile. Furthermore, it considered voyage cost variables and Panama Canal attributes and assumed a vessel operator point of view. These models were expressed as follows, including the expected sign of the potential explanatory variables:

$$\text{Route} = \text{F}(\text{C}, \mathit{Total\ Panama\ Canal\ cost}^{(-)},\ \mathit{Distance\ Difference\ Panama/Alternative}^{(+)}, \mathit{Arrivals}^{(-)}, \mathit{Post\ Arrival\ Next\ Port}^{(+)}, \mathit{Maximum\ Draft}^{(-)}, \mathit{Houston\ IFO\ 380\ cst}^{(+)}, \mathit{Outages}^{(-)}, \mathit{Panamax\ Plus}^{(+)})$$

where

Route= the route choice, with the value of 1 if the Panama Canal route and 0 for the alternative route (Magellan strait/Cape Horn).

C= Constant

Total Panama Canal Cost (in U.S. dollars): explanatory variable for the cost of transiting the Panama Canal. The total Panama Canal cost included the real value for Panama transits and the theoretical Canal cost for bypasses.

Distance difference between Panama versus alternative: variable to consider the shorter Panama Canal distance compared to the alternative. It was measured in nautical miles.

Arrivals: daily vessel arrivals. A proxy for the probability of congestion/delays/transit uncertainty at the Panama Canal. It was the total daily ship arrivals at the Panama Canal.

Post arrival next port: the difference in days between the next port arrival date and the previous port arrival date in Chile. It was a probable indicator of a route choice depending on how quickly the vessel was needed for its next assignment.

Maximum transit draft: It was the transit draft. It was a variable that considered the cargo amount and size of a ship.

Houston IFO 380 cst: a proxy for fuel price. It was a variable that represented fuel cost in a voyage calculation.

Outages: dummy variable with a value of 1 for days of outages, 0 otherwise. Outages decrease Canal capacity; therefore, the higher the probability of congestion/delay.

Panamax Plus: dummy variable with a value of 1 for ships that complied with the requirements to transit the neo-Panamax locks, 0 otherwise.

The logit models included estimations in levels. We also performed logit estimations with the subset of ships for which the Panama Canal had compliance information or not with the requirements to transit the neo-Panamax locks. Tables 5 and 6 provide the statistical descriptions of the continuous predictors involved in this study and the dummy variables utilized.

Table 5: Statistical Description of Continuous Explanatory Variables

Variable	Mean/ Standard Deviation	Highest/ Lowest Value	Unit
Total Panama Canal Cost	$204,806.41/ $1,904.07	$279,194/$78,980	U.S. $
Distance Difference Panama/Alternative Route	4,881.03/34.34	5,850/3,178	Nautical miles
Arrivals	33.69/0.27	56/20	Vessels per day

Table 6: Dummy Variables- Number of Observations

Variable	No. of Observations	Value of 1	Value of 0
Route (dummy dependent variable)	455	329	126
Outages (dummy independent variable)	455	23	432
Panamax Plus (dummy independent variable)	432	134	298

(Sources: IHS Mint and Panama Canal Authority)

Analysis and Results

The following is the sequence of logit models for estimating the steam coal traffic from the East Coast of Colombia to Chile through the Panama Canal or alternative, namely Magellan Strait or Cape Horn, based on the databases created and revised with visual observations using IHS Mint. Models 1-3 are logit formulation in levels (Table 7). The standard errors of the regressors are in parenthesis. The coefficients on the table are the parameters of the deterministic, measurable component of the vessel operator utility. The significance levels of predictors are based on p-values.

Table 7: Logit Estimations of Thermal Coal from Colombia to Chile

Regressor	Model 1	Model 2	Model 3
Constant	44.38403***	40.00000***	36.73519***
	(6.378297)	(5.675206)	(6.203795)
Total Panama Canal Cost	-6.86E-05***	-6.40E-05***	-8.81E-05***
	(1.11E-05)	(9.87E-06)	(1.23E-05)
Distance Difference Panama/Alternative	0.000891***	0.000822***	0.000598*
	(0.000245)	(0.000229)	(0.000256)
Arrivals	-0.043180	-0.076401*	-0.086614*
	(0.034774)	(0.031938)	(0.036007)
Post Arrival Next Port	0.029690#	0.049904**	0.051588*
	(0.018018)	(0.018134)	(0.021610)
Maximum Transit Draft	-1.973557***	-1.950572***	-1.273021**
	(0.447862)	(0.400697)	(0.452511)
Houston IFO 380 cst	-0.011629***	-	-
	(0.002442)	-	-
Outages	-1.458753	-1.621506#	-1.533011#
	(0.909924)	(0.840494)	(0.894649)
Panamax Plus	-	-	2.048002***
	-	-	(0.407467)
McFadden R- squared	0.591847	0.544057	0.590026
Akaike Info. Criterion	0.516805	0.568803	0.498123
Schwarz Criterion	0.589250	0.632193	0.573464
Log Likelihood	-109.5731	-122.4028	-99.59456
Number of observations	455	455	432

Std. errors are in parentheses. P-value ranges: *** (0, 0.001), **(0.001, 0.01), *(0.01, 0.05), #(0.05, 0.1)

Model 1 was the starting model with Panama Canal attributes such as Arrivals at the Panama Canal and Maintenance/Outages; and voyage costs attributes such as Total Panama Canal cost, Distance Difference Panama/Alternative, Post Arrival Next Port, Maximum Transit Draft of a vessel, and Houston IFO 380 cst.

Model 1 included all 455 observations. Regarding the expected signs in Model 1, every predictor posted the correct sign except Houston IFO 380 cst. On the other hand, all regressors were statistically significant (p-value= 0.000) except Post Arrival Next Port (p-value= 0.088), Arrivals and Outages. In Model 2, we eliminated Houston IFO 380 cst because of the unanticipated negative sign contradicting voyage cost expectation of favouring the shorter route, that is, Panama, when fuel prices are high based on the literature and voyage cost expectation[24].

Further exploring the possible reason for the unexpected sign for fuel price, we found no strong correlation of Houston IFO 380 price with the rest of the proposed regressors. However, performing an individual logit estimation with Houston fuel price as the only variable resulted in an unexpected negative sign, confirming the decision not to include this particular factor in our estimation. Nonetheless, we attempted new estimations with the rest of the regressors with the expected sign regardless of significance. Model 2 also included all 455 observations, and almost every explanatory variable, especially the Panama Canal attributes, was significant (p-value ≤ 0.017) and registered the correct sign, except Outages (p-value= 0.055). On the other hand, for Model 3, we used the 432 transits subset to include every transit in which the Panama Canal had information on vessel compliance to transit the neo-Panamax locks, that is, we did not include ship transits in which the Panama Canal did not have information on whether the vessel complied or not with the requirements to transit the neo-Panamax locks. Therefore, Model 3 is similar to Model 2 except that it

Again, as in Model 2, almost every predictor in Model 3, voyage cost factors and Panama Canal attributes, except Outages (p-value= 0.088), was statistically significant and posted the expected sign, indicating that the Panamax Plus attribute was a very significant explanatory variable in Model 3 (p-value= 0.000). Model 3 represented the preferred specification based on likelihood values, the Akaike and Schwarz criterion and the expected signs; however, Model 2 provided a useful specification for global transits, regardless of the compliance information or not with the neo-Panamax requirements.

Because of economies of scale, coal shippers from Colombia to Chile would use larger ships on average in the alternative route instead of the Panama Canal (Table 8). Smaller lot sizes favoured the Panama Canal route. At the same time, vessels larger than 70,000+ DWT preferred the alternative routes using larger drafts than the Panama route, a fact well captured by the maximum transit draft variable in the logit specifications according to the expected negative sign and its statistical significance (p-value= 0.000). In contrast, according to Panama Canal data, it is worth noting that, different from other coal routes that have utilized capsizes (170,000+DWT) to transport coal through the Panama Canal, coal shipments in capsizes from Colombia to Chile have preferred the alternative routes because of the limited seasonal maximum draft of 15.02 meters in the neo-Panamax locks and other Panama Canal attributes, such as congestion, that may hinder larger dry bulkers through the waterway. included the Panamax Plus dummy variable that considered compliance or not with the neo-Panamax transit requirements.

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[24] The expected positive sign for the shorter route is also confirmed in the news. See "Record Number of Boxships Take Longer Cape Route as Bunker Prices Slide", Ship & Bunker News, May 6, 2020. https://shipandbunker.com/news/world/514784-record-number-of-boxships-take-longer-cape-route-as-bunker-prices-slide and "Cheap oil is taking shipping routes back to the 1800s", BBC, March 4, 2016. https://www.bbc.com/future/article/20160303-cheap-oil-is-taking-shipping-routes-back-to-the-1800s

Table 8: Table of Comparisons: Panama Canal Route vs Alternative

Route	Transits	Cargo (mt)	Avg. Size (DWT)	Avg. Transit Draft (m)	Avg. Cargo (mt)	Panamax Plus Compliance (Subset)
Panama Canal	329	17,865,798	64,660	12.2	54,460	107/ 217
Alternative	126	10,333,626	88,477	14.3	82,013	27/ 81
Total	**455**	**28,199,424**				**432**

(Sources: IHS Mint and Panama Canal Authority)

For the case of vessels between 70,000- 89,999 DWT, namely Panamax and kamsarmax ships, the compliance with the requirements to transit the neo-Panamax locks and the low chances of obtaining a reservation to utilize these locks were factors in favour of the alternative route[25]. This interplay in the case of Panamax and kamsarmax ships was well captured in the Panamax Plus dummy variable, posting the correct sign and significance level (p-value= 0.000). Perhaps the factors that limit the greater participation of dry bulkers between 70,000- 89,999 DWT in the neo-Panamax locks, plus the economies of scale, were driving forces in the decision of larger ships to use alternatives and may explain the larger average vessel size, transit draft and average cargo in the alternative route.

Discussion

From the combined data for vessel departures and arrivals and the mapping of voyage costs values and Panama Canal attributes-except Houston fuel cost- we were able to estimate preliminary variables that helped us understand the route decision of thermal coal from Colombia to Chile, from the vessel operator point of view of maximizing utility. In the research, we incorporated Houston fuel price as an explanatory variable. Although Houston fuel price was significant in the initial model 1, this voyage cost variable was disregarded because of the unexpected negative sign, as explained in the analysis and results section. Perhaps it was impossible to include a proxy predictor accounting for the fuel cost expenditure of a voyage into our logit formulations because of the varieties of bunker types (HSFO, VLSFO, MGO), fueling alternatives and price hedging strategies. It is possible that the fuel cost impact on route choice decision may not follow maritime economic theory or expectations, as in the case of the optimization of voyage speed in Adland and Jia (2018), and therefore it is more related to charter party contracts defining route choice and average vessel speed. Charter party factors are beyond the reach of our estimations. On the other hand, the total Panama Canal cost was significant (p-value= 0.000) and resulted in the expected negative sign in models 1-3. Furthermore, models 2 and 3 are the most relevant regarding statistically significant predictors and expected signs.

Model 2 was the logit formulation for general transits, which do not consider the requirements for neo-Panamax locks transits and totalled 455 observations. In other words, model 2 provided the probability of using the Panama route with regards to factors such as Panama Canal cost, distance differences, transit draft of a vessel, total arrivals

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[25] Containerships, LNG and LPG compete against dry bulkers for the limited reservation slots and pay higher toll rates than dry bulkers.

at the Panama Canal, next port arrival, and, to a lesser extent, periods of outages as a proxy for the probability of delays. This lower level of statistical significance (p-values ≤ 0.094) suggested that the period of outages was only somewhat important in the route choice calculation and was perhaps a consequence of the reduced maintenance window at the Panama Canal. Maintenance is normally scheduled during low-traffic months. Our research only impacted 23 of the total 455 transits. The importance of Panama Canal costs, distance differences, maximum transit draft and next port assignments were most significant in the utility maximization decision of a vessel operator when choosing a route. Total vessel arrivals were also significant (p-value ≤ 0.017), which attested to the importance of congestion and possible transit delays at the Panama Canal when vessel arrivals were high. These variables were important in a voyage plan, perhaps not only for coal from Colombia to Chile but also in any oceangoing trip.

Model 3 utilized information the Panama Canal had on vessels that either complied with or did not comply with the requirements to transit the neo-Panamax locks, specifically ships belonging to the kamsarmax category or below. This subset consisted of 432 observations. This model provided the probability of using the Panama route concerning factors such as Panama Canal cost, distance differences, maximum draft of a vessel, total arrivals at the Panama Canal, next port arrival, and, to a lesser extent, periods of outages, as in model 2 already discussed. For model 3, however, we incorporated the dummy variable Panamax Plus to account for the compliance or not with the requirements to transit the neo-Panamax locks. This Panama Canal attribute was very significant (p-value= 0.000), highlighting the importance of vessels complying with the neo-Panamax transit requirement to increase the probability of transits through the waterway. Likewise, the total vessel arrivals variable, as in the case of model 2, emphasized the importance of the congestion factor at the Panama Canal in the route decision-making process.

Given the high statistical significance of total Canal costs, the logit models could be applied in toll sensitivity analysis to help formulate future toll policies for the Panama Canal, especially in the neo-Panamax locks. This statistical significance confirms the importance of Panama Canal costs in the voyage cost calculation, and it is part of the route decision. However, other Canal attributes related to congestion/delays, such as arrivals and outages, are also important from the managerial point of view and highlight the importance of the optimal management of traffic throughput by the Panama Canal Authority. Normally the Panama Canal Authority schedules maintenance during non-peak months, roughly between May-September. However, not a Canal attribute per se, the statistical significance of the maximum transit draft predictor highlights the importance of water management and regular dredging at the Panama Canal to maintain maximum seasonal draft and to attract larger vessels.

Conclusion and Contributions

Building from previous literature related to discrete choice models-such as the logit formulation applied in transportation-and the use of AIS-generated data, this paper attempted to provide a better understanding of the mostly thermal coal movements from Colombia to Chile, deciding either the Panama Canal route or alternative, with the route choice explained as a utility-maximizing decision from a vessel operator perspective as suggested in the literature. The paper also explained the electricity demand in Chile and the importance of coal in the energy matrix of Chile. As stated in the literature review, this paper drew on previous contributions of factors such as shipping costs, transit time, distance, and delays and proposed preliminary new explanatory variables to explain the route choice between Colombia and Chile based on the review of previous studies and taking into consideration the particularities of the Panama Canal route not mentioned in other route choice models. Although other explanatory variables such as reliability and shipper/importer preference may play a role in the route choice, this paper is based more on voyage cost, so the logit specifications proposed in this research confirmed the importance of most of the hypothesized voyage cost factors and the attributes of the Panama Canal in the route choice for coal from Colombia to Chile. One exception was fuel price due to its unexpected negative sign, contrary to voyage calculation intuition in which the shorter route, the Panama Canal, is supposed to be favoured when fuel prices go up. Perhaps other fuel price references or a combination of different fuel prices may be attempted in future studies to incorporate fuel cost as part of the voyage cost parameters.

Voyage cost variables such as Panama Canal costs, the voyage distance using the Panama Canal route compared to the alternative, the next voyage arrivals and the maximum transit draft were significant factors in the route choice decision. The total Panama Canal cost in this research was significant, intuitively making sense from a voyage planning perspective. Also, the distance between alternatives and planning for the next voyage was the logical factor that vessel operators seemed to consider in the voyage planning process, the latter obtained from the capabilities of AIS tools such as IHS Mint that allowed us to follow voyages after reaching coal terminals in Chile. The maximum transit draft as a proxy for the cargo amount was also an important factor in the route decision, explaining the higher probability of utilizing the alternative route for the vessel with a larger cargo capacity but limited by the maximum draft in the neo-Panamax locks. About Panama Canal attributes, the possibility of congestion at the Panama Canal, especially with the arrivals and, to a lesser extent, outages, was an important consideration in a voyage plan. On the other hand. For the subset of vessels between 50,000-89,999 DWT and below, the Panamax Plus requirement was a very important factor in the route choice decision.

In the end, this paper contributes to the discrete choice literature and attempts to provide insights into route choice involving the Panama Canal. Particularly, this research proposed new preliminary explanatory variables to understand better route choices that may apply to future Panama Canal studies. For example, these variables may be applied to future logit formulations in other market segments of the Panama Canal, including route choice for grains and liquid bulks. On the other hand, as per the future of coal movements, particularly the flows from Colombia to Chile, the steps were taken by Chile to decarbonize its energy matrix will negatively impact coal traffic through the Panama Canal in the near future, meaning likely changes in the vessel traffic mix of the Panama Canal. Conceivably there is the possibility of other vessel types replacing this traffic. Likewise, the specific decarbonization stages by Chile include plans to close 50 per cent of steam coal capacity by 2025, including a commitment by Engie to close 1,500 MW of thermal coal generation by 2025 and the closing of 800 MW of the oldest steam coal plants by 2024[26], all of this in the short term.

[26] Ministerio de Energía de Chile web page, April 28 2021. https://energia.gob.cl/noticias/nacional/ministro-de-energia-anuncia-que-para-el-2025-habremos-retirado-el-50-de-las-centrales-carbon. Accessed May 13, 2021

On the other hand, Chile has a growing renewable energy capacity and is committed to becoming an important player in the production of green hydrogen. This country is planning on producing and exporting green hydrogen, given its comparative advantages regarding wind power in the Magallanes region in the South and solar radiation in the Atacama Desert in the North, to produce it using sea water, as stated in the National Strategy on Green Hydrogen[27]. According to the long-term planning of the Ministry of Energy of Chile, there are five scenarios (A, B, C, D, and E) in which solar and wind power are important investments in terms of annual yearly generation and installed capacity. In the case of green hydrogen, there is a cooperation agreement between the European Union and Chile for a competition related to green hydrogen studies and a Memorandum of Understanding (MOU) between Chile and the Port of Rotterdam for the export of green hydrogen from Chile to Europe[28]. Other European ports, such as Wilhelmshaven in Germany, are preparing to become green hydrogen terminals[29]. As a policy recommendation, perhaps the Panama Canal could pursue an incentive policy to attract traffic from Chile to Europe.

On the other hand, the World Coal Association is investing in clean coal technologies, although expensive, such as carbon capture, use and storage (CCUS) of coal to remain relevant[30]. However, future coal mining financing is in peril. Nonetheless, Chile, the European Union, Japan, and South Korea are examples of countries and regions pushing hard to reduce emissions and venturing into hydrogen, even though further steps are necessary-and significant challenges remain-for hydrogen to become the main energy of the future. Nonetheless, hydrogen production and imports are part of European's strategy to diversify its energy matrix and move toward renewable energy production[31].

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[27] Estrategia Nacional de Hidrogeno Verde. https://energia.gob.cl/sites/default/files/estrategia_nacional_de_hidrogeno_verde_-_chile.pdf

[28] https://energia.gob.cl/noticias/nacional/chile-firma-memorandum-de-entendimiento-con-el-puerto-mas-grande-de-europa-para-exportar-hidrogeno-verde. Accessed May 17, 2021.

[29] "TES pushes Wilhelmshaven green energy hub development". March 3, 2022. https://www.offshore-energy.biz/tes-pushes-wilhelmshaven-green-energy-hub-development/. However, the war in Ukraine may impact this transition.

[30] World Coal Organization. https://www.worldcoal.org/clean-coal-technologies/

[31] REPowerEU of the European Commission. https://ec.europa.eu/commission/presscorner/detail/en/SPEECH_22_1632*

REFERENCES

Adland, R., & Jia, H. (2018). Dynamic speed choice in bulk shipping. *Maritime Economics & Logistics*, *20*(2), 253-266. https://doi.org/10.1057/s41278-016-0002-3

Bai, X., & Siu J. (2019). A destination choice model for very large gas carriers (VLGC) loading from US gulf. *Energy, 174*, 1267- 1275. https://doi.org/10.1016/j.energy.2019.02.148

Berndt, E., & Wood, D. (1975). Technology, prices and the derived demand for energy. *The Review of Economics and Statistics*, *57*(3), 259- 268. https://doi.org/10.2307/1923910

Brantes, R., & Cantallopts, J. (2020). Informe de actualización del consumo energético de la minería del cobre al año 2019. Comisión Chilena del Cobre (Cochilco*)*. Registro Propiedad Intelectual © N° 2020-A-9342. DEPP 16/2020. October 2020. https://www.cochilco.cl/Mercadoper cent20deper cent20Metales/Informeper cent20deper cent20Consumoper cent20deper cent20Energper centC3per centADapercent202019.pdf

Breen, B.,Vega, A., & Feo-Valero, M. (2015). *An empirical analysis of mode and route choice for International Freight Transport in Ireland*. Working Paper 262587, Galway: National University of Ireland, Socio-Economic Marine Research Unit. DOI: 0.22004/ag.econ.262587

Chang, M., & Lu, P. (2013). A Multinomial Logit Model of mode and arrival time choices for planned special events. *Journal of the Eastern Asia Society for Transportation Studies*, *10*, 710-727. https://doi.org/10.11175/easts.10.710

Coordinador Eléctrico Nacional of Chile (n.d.), *Reports, statistics and frequently used platforms*. Accessed on April 21, 2021, from https://www.coordinador.cl/reportes-y-estadisticas/#Estadisticas.

Fan, L., Wilson, W., & Dahl, B. (2012). Impacts of new routes and ports on spatial competition for containerized imports into the United States. *Maritime Policy & Management*, *39*(5), 1-23. https://doi.org/10.1080/03088839.2012.705027

Fiorini, M., Capata, A., & Bloisi, D. (2016). AIS Data Visualization for Maritime Spatial Planning (MSP). *International Journal of e-Navigation and Maritime Economy*, *5*, 45-60. https://doi.org/10.1016/j.enavi.2016.12.004

Guoqiang, S., & Jiahui, W. (2012). A Freight Mode Choice Analysis using a Binary Logit Model and GIS: The case of cereal grains transportation in the United States*. Journal of Transportation Technologies*, *2*, 175-188. http://dx.doi.org/10.4236/jtts.2012.22019

Ho, J. & Bernal, P. (2018b). *Elastic or not elastic? Attempting to estimate an aggregate demand function for the dry bulkers at the Panama Canal. Presented at the International Association of Maritime Economist Conference (IAME) in Mombasa, Kenya*. September 2018.

Ho, J. & Bernal, P. (2019). Panama Canal vs alternative routes: Estimating a logit model for grains. *Maritime Business Review*, *5*(1), 99-120. http://dx.doi.org/10.1108/mabr-07-2019-0025

Hussain, D., Mohammed, A., Salman, A., Rahmat, R., & Borhan, M. (2017). Analysis of transportation mode choice using a comparison of artificial neural network and multinomial logit model. *ARPN Journal of Engineering and Applied Sciences*, *12*(5), 1483-1493.

Itoh, H., Tiwari, P., & Doh, M. (2002). An Analysis of cargo transportation behavior in Kita Kanto (Japan). *International Journal of Transport Economics*, *29*(3), 319- 335. http://worldcat.org/issn/03918440

Kanamoto, K., Murong, L., Nakashima, N., & Shibasaki, R. (2021). Can maritime big data be applied to shipping industry analysis? Focussing on commodities and vessel sizes of dry bulk carrier. *Maritime Economics & Logistics*, *23*, 211- 236. https://doi.org/10.1057/s41278-020-00171-6

Lee, E., Mokashi, A., Moon, S., & Kim, G. (2019). The maturity of Automatic Identification Systems (AIS) and its implications for innovation. *Journal of Marine Science and Engineering*, *7*(9), 287. https://doi.org/10.3390/jmse7090287

Manssour, A., Alhodairi, A. M., & Rahmat, R. (2013). Modeling a Multinomial Logit Model of intercity travel mode choice behavior for all trips in Lybia. *International Journal of Civil and Environmental Engineering*, *7*(9), 636-645. doi.org/10.5281/zenodo.1087592

Manssour, A., Alhodairi, A. M., & Rahmat, R. (2013). Modeling of intercity transport mode choice behavior in Lybia: A binary logit model for business trips by private car and intercity bus. *Australian Journal of Basic and Applied Sciences*, *7*(1), 302-311.

Mao, S., Tu, E., Zhang, G., Rachmawati, L., Rajabally & E., Huang, G. (2018). An Automatic Identification System (AIS) Database for Maritime Trajectory Prediction and Data Mining. In: Cao J., Cambria E., Lendasse A., Miche Y., Vong C. (Eds.), *Proceedings of ELM-2016. Proceedings in Adaptation, Learning and Optimization*, *9*. Cham: Springer, https://doi.org/10.1007/978-3-319-57421-9_2

Martinez, C., Adams, S., & Dresner, M. (2016). East Coast vs. West Coast: The impact of the Panama Canal's expansion on the routing of Asian imports into the United States. *Transportation Research Part E: Logistic and Transportation Review, 91*(C), 274-289. https://doi.org/10.1016/j.tre.2016.04.012

Mason, C., & Rowlands, A. (1938). Panama Canal traffic. *Economic Geography*, *14*(4), 325-337. https://doi.org/10.2307/141526

Nathan Associates (2012). Update and development of the dry bulk market segment study. Arlington, Virginia. Nathan Associates. Study for the Panama Canal Authority.

Pham, T., Kim, K., & Yeo, G. (2018). The Panama Canal expansion and its impact on East–West liner shipping route selection. *Sustainability, 10*(12), 4353. https://doi.org/10.3390/su10124353

Regianni, A., Nijkamp, P., & Tsang, W.F. (1997). *European Freight Transport Analysis using Neural Networks and Logit Models* (No. 97-032/3). Tinbergen Institute discussion paper, 5-9.

Schøyen, H., & Bråthen, S. (2011). The Northern Sea Route versus the Suez Canal: Cases from bulk shipping. *Journal of Transport Geography*, *19*(4), 977-983. https://doi.org/10.1016/j.jtrangeo.2011.03.003

Serry, A. (2017). The Automatic Identification System (AIS): A data source for studying maritime traffic: The case of the Adriatic Sea. *Book of Proceedings, 7th International Maritime Science Conference (IMSC)*, Solin, Croatia, April 20-21, 2017.

Shibasaki, R., Azuma, T., & Yoshida, T. (2016). Route choice of containership on a global scale and model development: Focusing on the Suez Canal. *International Journal of Transport Economics, 43*(3), 263- 288. http://worldcat.org/issn/03918440

Shibasaki, R., Azuma, T., Yoshida, T., Teranishi, H., & Abe, M. (2017). Global route choice and its modelling of dry bulks carriers based on vessel movement database: Focusing on the Suez Canal. *Research in Transportation Business & Management*, *25*, 51-65. https://doi.org/10.1016/j.rtbm.2017.08.003

Shibasaki, R., Kanamoto, K., & Suzuki, T. (2019). Estimating global pattern of LNG supply chain: A port-based approach by vessel movement database. *Maritime Policy & Management, 47*(3), 1-29. DOI:10.1080/03088839.2019.1657974

Surbakti, M., & Bombongan, C. (2017). Characteristics of modal choice preference between bus and train from Medan to Kuala Namu Airport. *IOP Conference Series: Material Science and Engineering*, *180*(1), 012143. DOI:10.1088/1757-899X/180/1/012143

Svanberg, M., Santén, V., Hörteborn, A., & Holm, H. (2019). AIS in maritime research. *Marine Policy*, *106*, 103520. https://doi.org/10.1016/j.marpol.2019.103520.

Sytsmas, T., & Wilson, W. (2021). Estimating the Demand for Railroad and Barge Movements of Corn in the Upper Mississippi River Valley. *Research in Agricultural & Applied Economics*. Cooperative Agreement Number Agreement 18-TMTSD-TN-0012, with the Agricultural Marketing Service (AMS) of the U.S. Department of Agriculture (USDA). https://doi.org/10.22004/ag.econ.308938. https://ageconsearch.umn.edu/record/308938.

Tixerant, M., Guyader, D., Gourmelon, F., & Queffelec, B. (2018). How can Automatic Identification System (AIS) data be used for Maritime Spatial Planning? *Ocean & Coastal Management, 166*, 18-30. DOI:10.1016/j.ocecoaman.2018.05.005

Tu, E., Zhang, G., Rachmawati, L., Rajabally, & E., Huang, G.B. (2017). Exploiting AIS data for intelligent marine navigation: a comprehensive survey from data to methodology. *IEEE Transactions on Intelligent Transportation Systems, 99*, 1-24. 10.1109/TITS.2017.2724551

Ungo, R., & Sabonge, R. (2012). A competitive analysis of Panama Canal routes. *Maritime Policy & Management*, *39*(6), 555- 570. https://doi.org/10.1080/03088839.2012.728727

Tewalt, S., Finkelman, R., Torres, I., & Simoni, F. (2006). World Coal Quality Inventory: Colombia. United States Geological Service (USGS). Chapter 5. Open File Report 2006-1241. https://pubs.usgs.gov/of/2006/1241/Chapterper cent205-Colombia.pdf

Wen, C., & Huang, J. (2007). A Discrete Choice Model of ocean carrier choice. *Journal of the Eastern Asia Society for Transportation Studies, 7*, 795- 807. https://doi.org/10.11175/easts.7.795

Wilson, W., & Ho, J. (2018). Panama Canal. In Blonigen, B., & Wilson, W. (Eds.), *Handbook of International Trade and Transportation* (pp. 628-657). U.K.: Edward Elgar Publishing. 628-657. https://doi.org/10.4337/9781785366154.00032

Wojcik, S. (2017). The determinants of Travel Mode Choice: The case of Lodz. *Bulletin of Geography. Socio-economics Series*, *44*(44), 93-101. doi:10.2478/bog-2019-0018

World Coal. Accessed on March 3, 2022, from https://www.worldcoal.com/coal/10022011/coal_in_colombia/

Wright, D., Janzen, C., Bochenek, R., Austin, J., & Page, E. (2019). Marine observing applications using AIS: Automatic Identification System. *Frontier in Marine Science*, *6*, 1-7. https://doi.org/10.3389/fmars.2019.00537

Wu, L., Xu, Y., Wang, Q., Wang, F., & Xu, Z. (2017). Mapping Global Shipping Density from AIS Data. *The Journal of Navigation*, *70*(1), 67-81. DOI: https://doi.org/10.1017/S0373463316000345

Wu, J., & Xu, D. (2021). *Research on alternative passage of Suez Canal. E3S Web of Conferences, 283, 01017.* Presented in the 2021 3rd International Conference on Civil, Architecture and Urban Engineering (ICCAUE 2021).