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ESTIMATING A PRELIMINARY DEMAND MODEL FOR CORN MOVEMENTS FROM THE U.S. EAST COAST AND GULF TO EAST ASIA, FUTURE CORN TRAFFIC, AND DECARBONIZATION PROCESS

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ABSTRACT

Corn is the second most important component of the grain segment after soybeans, averaging close to 35.7% of total grain traffic through the Panama Canal. The objective of this paper is to attempt to fit a preliminary general demand model for corn traffic through the Panama Canal using Ordinary Least Square (OLS). The corn traffic estimated is the U.S. Gulf and East Coast to East Asia, particularly China, Japan, South Korea, and Taiwan, and the research hypothesized the possible variables that may explain the downward trend in the movements of corn in this route between October 2004 to September 2022. Canal costs, U.S. Gulf freight rates, U.S. Gulf and Pacific Northwest grains inspections and the energy index were the most important explanatory variables in the study. This research also discusses the future of corn traffic through the waterway in terms of alternative sources, routes, and possible demand for corn, and explores the decarbonization process impacting the Panama Canal and the U.S. corn supply chain. For the literature review, the research is leveraging on previous estimation of demand functions for grains and the decarbonization studies related to the maritime industry, and examine papers related to Panama Canal shipping demand, thus closing the gap on the literature about transportation demand through the waterway.

Introduction

Based on data from the data warehouse of the Panama Canal, between fiscal years (FY) 1997–2004, corn was the most important commodity in the grain category of the Panama Canal, averaging 35.7% of total grain traffic through the waterway. However, between FY 2005–2021, it battled for the top spot against soybeans, relinquishing first place in FY 2005, between FY 2009–2017, and FY 2019–2021. Drought, crop yields, the growing purchases of corn, sorghum and soybeans by China, and the supply-demand behaviour of non-United States grain producers may have influenced the volatile behaviour of corn and other grains transported through the Panama Canal. The same influences impacted the U.S. Gulf and East Coast to Asia route, as well as the main grain and corn route of the Panama Canal. Also, as stated by Panama Canal data, there is a clear downward trend in corn movements through the waterway in the U.S. Gulf and East Coast to Asia route and as total corn movements (See figure 1). By far, the most important destinations for U.S. corn from the Gulf and East Coast through the waterway include countries in East Asia, namely China, Japan, and Taiwan, and destinations on the West Coast of Central and South America, such as Colombia, El Salvador and Guatemala (See table 1). Derived from the same Panama Canal proprietary information, between FY 2017- 2021, the compound annual growth rate

(CAGR) of the corn flows from the U.S. Gulf and East Coast was 2.9%; however, during the same period, the CAGR from the same origin to China was an astonishing 158.1%, because of growing imports by China. Since FY 2021, according to Panama Canal data, China has become the main importer of corn through the Panama Canal.

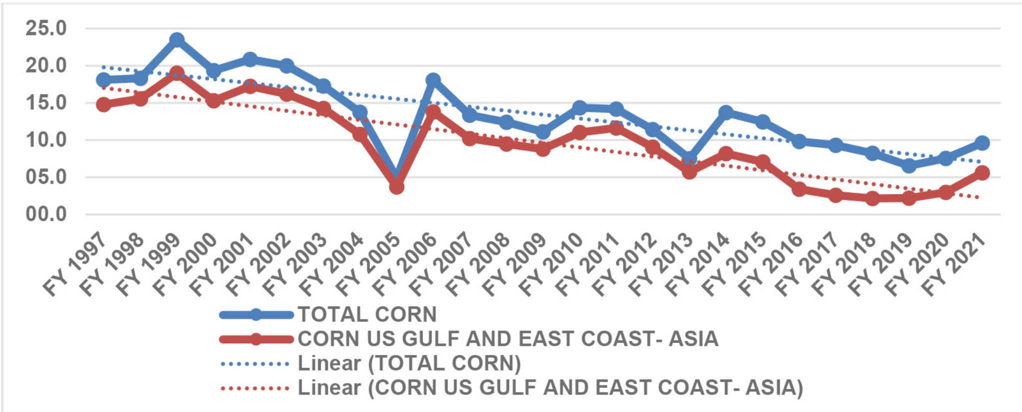

Figure 1: Corn movements through the Panama Canal: total corn movements and U.S. Gulf and East Coast to Asia, in million-long tons
Source: Datawarehouse of the Panama Canal (Proprietary)

Table 1: Top ten main destinations of corn movements from the U.S. Gulf and East Coast, in million-long tons

Destination	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
China	0.1	0.0	0.2	0.4	2.7
Japan	2.2	2.1	1.9	2.3	2.5
El Salvador*	0.7	0.6	0.6	0.6	0.5
Colombia*	1.2	1.2	1.1	0.9	0.5
Guatemala*	0.2	0.4	0.4	0.7	0.5
Peru	1.9	1.9	0.8	0.4	0.5
Costa Rica*	0.4	0.3	0.3	0.3	0.3
Taiwan	0.2	0.0	0.1	0.0	0.2
Nicaragua*	0.1	0.0	0.2	0.2	0.2
Chile	0.5	0.1	0.1	0.2	0.2
Others	0.5	0.2	0.3	0.4	0.8
Total Corn	**7.9**	**6.8**	**5.9**	**6.3**	**8.9**

*On the Pacific Coast
Source: Datawarehouse of the Panama Canal (Proprietary)

Using numbers from United Nations Comtrade, between calendar years 2012- 2021 the United States was the largest exporter of corn to China, Japan and South Korea, posting an annual compound rate of 6.7% during the period, followed by Ukraine, Brazil, Argentina and others (See figure 2). There is a general upward trend in exports to these three Asian destinations, with global exports growing at an annual compound rate of 7.7%. This behaviour of exports-imports of corn by countries is opposite to the downward trend of corn movements from the U.S. Coast and East Coast to East Asia through the Panama Canal between FY 1997–2021, and between FY 2012–2021 according to Panama Canal data. Why do we have an overall upward corn movement from the U.S. to China, Japan and South Korea but an overall downward flow of corn from the U.S. Gulf and East Coast to Asia? Although the examination of the exports- imports of corn by countries from the United Nations Comtrade indicates an upward trend in the movements of corn, the market share behaviour between 2012–2021 indicates a downward trend for U.S. exports destined to China, Japan and South Korea (Figure 3), with ups and downs when non-U.S. origins (Ukraine, Brazil, Argentina, South Africa and others) are grouped. This is called inter-origin competition by Wilson and Ho (2018). At the same time, the compound yearly growth rate between 2012–2021 of U.S. corn flows to China, Japan and South Korea was 6.7% compared to a 9.6% growth rate for non-U.S. corn movements. Perhaps part of the volatility of corn exports depends on the availability of corn, influenced by weather patterns. On the other hand, there is an upward, volatile trend in the market share of the U.S. Pacific Northwest (PNW) exports to the same three Asian destinations but a downward trend in exports from the U.S. Gulf to the East Coast to the same destinations (Figure 4). The yearly compound growth rate of U.S. corn exports through the PNW to China, Japan and South Korea is 10.6% between 2012–2021, compared to 6.6% from the U.S. Gulf and East Coast (Figure 5). The PNW region is closest to the Asian market and is part of the growing competition facing the Panama Canal in terms of grain trade in general, representing the interport competition between both U.S. port regions.

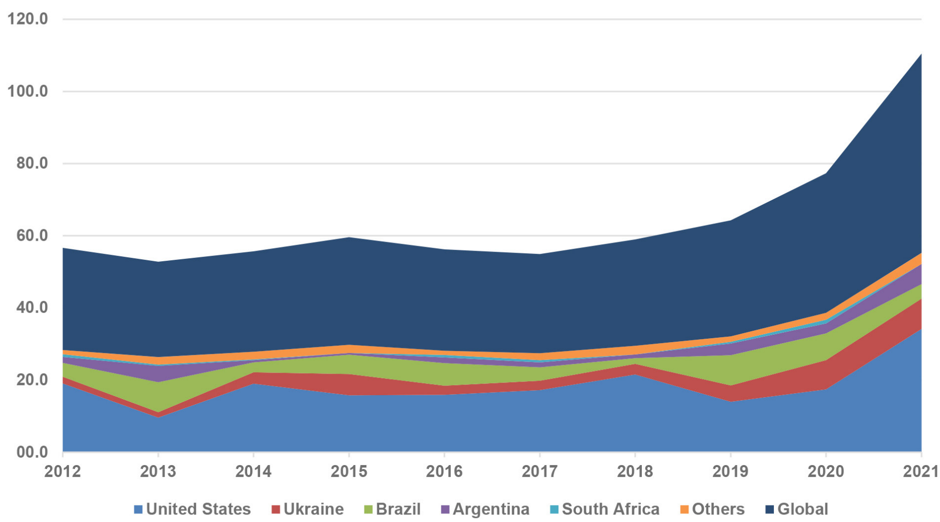

Figure 2: Main corn exporters to China, Japan and South Korea in million metric tons.

Source: United Nations Comtrade, not including Taiwan[1]

[1] No data on Taiwan in UN Comtrade.

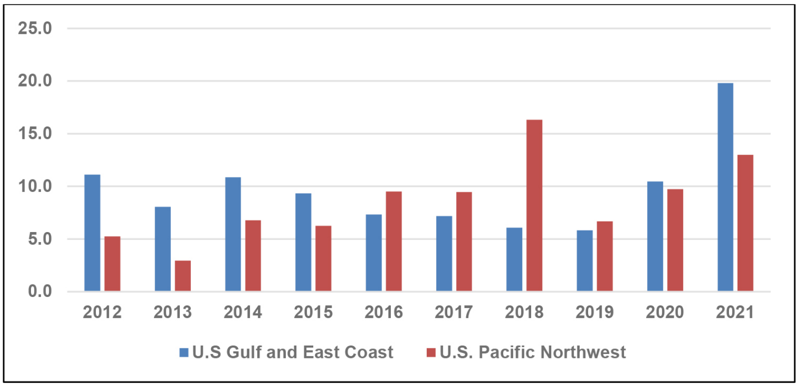

Figure 3: Market Share of Corn Exports to China, Japan and South Korea: United States vs Non- United States Shares (%)

Source: United Nations Comtrade

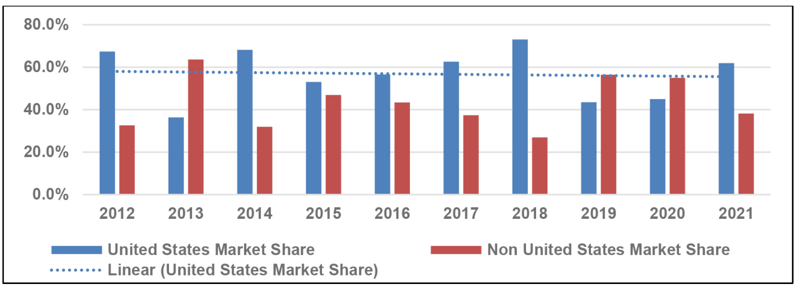

Figure 4: Market Share of Corn Inspections for Exports to China, Japan and South Korea: U.S. Gulf and East Coast vs Pacific Northwest in percentages

Source: Federal Grains Inspection Service (FGIS) of the U.S. Department of Agriculture

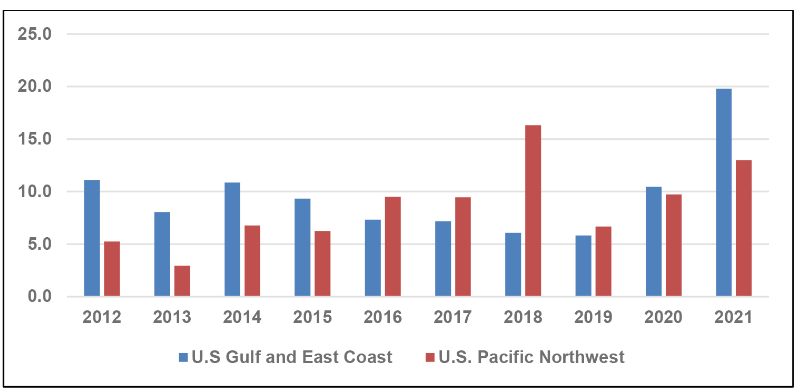

Figure 5: Yearly Corn Export Inspections to China, Japan and South Korea by Port Region, in million metric tons

Source: FGIS

Besides the growing share of non-U.S. corn exports and U.S. PNW corn inspections for exports to China, Japan and South Korea, another important factor compounding the declining flows of corn from the U.S. Gulf and East Coast to East Asia is the alternative routes competing against the Panama Canal, namely the Cape of Good Hope and the Suez Canal. For example, subtracting Panama Canal corn movements from the U.S. Gulf and East Coast to China, Japan and South Korea between calendar years 2012–2021 from total FGIS corn inspections for exports from the U.S. Gulf and East Coast to the same Asian countries, the difference approximates the amount of corn bypassing the Panama Canal, indicating a growing, volatile corn bypass in this route (Figure 6). The deviation of U.S. corn exports through alternatives is an example of the so-called "interroute" competition in Wilson and Ho (2018) and might be influenced by Panama Canal tolls and transit delays and by the price of fuel favouring the shorter route when fuel cost is high as in Shibasaki *et al.* (2018) for LNG and Theocharis *et al*. (2019) for product tankers.

The Panama Canal faces interroute competition of corn from the U.S. Gulf and East Coast to Asia. Also, the waterway is competing against growing non-U.S. corn exports and dealing with the interport competition between ports in the United States. Given that these forces are playing against the Panamanian route, what factors influence the corn movements from the U.S. Gulf and East Coast to East Asia, particularly China, Japan, South Korea, and Taiwan? Can we propose a model accounting for the interport competition, non-U.S. corn exports and the alternative routes to the Panama Canal? This paper suggests fitting a preliminary general demand model for corn traffic through the Panama Canal for the proposed route, considering the literature and data availability to answer the questions. At the same time, this research will examine the future of corn flow through the Panama Canal and the impact of decarbonization on the Panama Canal and the U.S. corn supply chain.

Given the forces impacting corn movements from the U.S. Gulf and East Coast to East Asia, there is a gap in the Panama Canal literature related to the specific factors that affect grain flows in general and corn movements in particular. Although some studies directly assess the impact of Panama Canal tolls on grain flows, they are more than twenty years old, and the most recent relevant studies do not address the corn trade of the Panama Canal. As per its relevance and given the limitations of the most recent studies, this research will contribute to the Panama Canal grain trade literature and may provide insights to the Panama Canal Authority in terms of the main factors influencing corn movements through the waterway. As per the organization of this research, this paper will first examine the literature, looking for factors that may play into a prospective corn demand model, the forces shaping future corn flows, and the decarbonization process dictating the fuels of the future. Secondly, it will propose the explanatory variables for the corn demand model through the waterway and discuss the implications for future toll policy. Finally, the paper will discuss the decarbonization process of the shipping industry and the supply chain in general, including vessels, barges, railroads, and the Panama Canal.

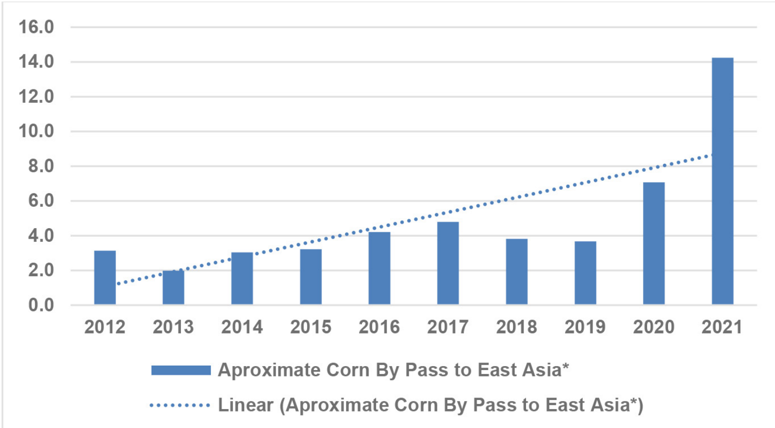

Figure 6: Estimated Corn Movements from the U.S. Gulf and East Coast to China, Japan and South Korea bypassing the Panama Canal, in a million metric tons

Source: Datawarehouse of the Panama Canal Authority and FGIS. *Not including Taiwan

Literature Review

General View

The literature review will attempt to provide the background of the methodology for the estimation of a preliminary demand model for corn from the U.S. Gulf and East Coast to East Asia through the Panama Canal as a derived demand of corn consumption in East Asia, considering voyage cost proxies, macroeconomics factors and the interport competition between the U.S. Gulf and East Coast versus the U.S. Pacific Northwest. Also, this literary review will provide us with the framework regarding the decarbonization process in the maritime industry, specifically applied to the supply chain of corn in our origin-destination under study, including the Panama Canal. This review will not only support our choice of explanatory variables but will permit us to examine the studies on the Panama Canal, especially the limited literature related to estimating a demand model for any commodity through the waterway, including grains in general. At first glance, the literature on the Panama Canal shipping demand mostly involves the importance of the Panama Canal in general, the container market in particular, and the effects of the Panama Canal expansion, including the competitiveness of the waterway versus alternatives and market share. For example, we have the studies by Ungo and Sabonge (2012), Fan *et al*. (2012) Martinez *et al*. (2016), Wang (2017), Xue (2017), Pham *et al*. (2018), and Miller and Hyodo (2021). However, more related to the topic of this research, we have the dry bulk cargo and grains projections with an expanded Canal by Nathan and Associates (2012), a study examining not only grains flow from the U.S. Gulf through the Panama Canal but also including the growing production and export of grains through the Pacific Northwest export elevators. To examine the literature and address the main questions posited in this research, we have divided the literature review into three subsections: the corn traffic demand model, the future of corn flows, and the general decarbonization process related to grain movements.

Corn Traffic Demand Model

About the corn traffic demand model, estimations related to corn demand, potential regressors, procedures and model specifications for the preliminary demand model for corn traffic through the Panama Canal to be proposed, Saghaian *et al*. (2014) estimated import demand functions for U.S. corn and soybeans for China, Japan, the European Union (EU) and Mexico. This study applied log-linear equations, obtaining its own price, cross-price, and income elasticities. Explanatory variables included the price for corn and soybeans (in U.S. dollars), GDP for China, Japan, EU, and Mexico as a proxy for the income of each country, exchange rates and pig and poultry inventory. Regarding the U.S. corn demand in particular, the authors established that corn price, cross-price and income are price elastic, and the positive cross-price elasticity reveals that corn and soybeans are substitutes in the importing countries. Likewise, U.S. corn demand was inelastic for exchange rate and pig inventory. The authors also mentioned the issue of improving grain quality to obtain a larger market share. Another estimation useful to our exploratory modelling but applied to U.S. wheat is the work by Konandreas *et al*. (1978) estimating demand functions for U.S. wheat using Ordinary Least Square (OLS), mixed estimation procedure and Conditional Least Square with yearly data between 1954–1972. The five importing regions were Latin America, Asia, Africa, USSR and Eastern Europe, and the developed world. The list of regressors included effective U.S. export price for wheat, concessional exports, effective per capita income, domestic wheat production by the importing region, and lagged exports. Heien and Pick (1991) modelled a demand equation for soybean and soymeal using explanatory variables such as the gross national product of the importing countries, overall price level and the price index for soybean products from the United States, Argentina, and Brazil. The study estimated own and cross-price elasticities but faced data validity and multicollinearity in the modelling. However, the concept can be applied in our formulation. Beghin *et al*. (2009) estimated a derived demand for U.S. corn seeds used by foreign corn producers, est. The major finding of this research was the statistical significance of all trade costs, that is, distance, phytosanitary regulations and others, negatively impacting exports of U.S. corn seed.

For the topic of the interroute competition against the Panama Canal affecting a prospective corn traffic demand, Wilson and Ho (2018) explained commodity traffic through the waterway and included examples of voyage calculations applied for different commodities, especially grains, contrasting the Panama Canal route compared to the Cape of Good Hope route. Furthermore, Harrison and Boske (2017) mentioned the importance of fuel cost influencing route choice decisions, although this factor is highly volatile. Similarly, Ho and Bernal (2018b) attempted to model a logarithmic demand function with toll elasticity for dry bulk vessels transiting the Panama Canal, incorporating regressors such as effective toll rate, the Baltic Dry Index (BDI) and per capita GDP. In addition, Ho and Bernal (2020) estimated a logit model to explain grain movements from the U.S. Gulf and East Coast to Asia, using data from July 1, 2017, to September 30, 2018, comparing the Panama Canal to the Cape of Good Hope route. The authors attempted to explain the probability of grain movements through the waterway, hypothesizing explanatory variables such as Panama Canal transit costs, transit draft, bunker prices, one-year time charter and Canal Waters Time, concluding that transit draft was the only significant regressor explaining the probability of grain movements through Panama. Furthermore, Ho and Bernal (2021) estimated a model for soybean movements through the Panama Canal, including final significant variables such as toll rate, seasonality, soybean basis, average dollar index and the cargo difference of soybeans exported through the U.S. Gulf compared to the Pacific Northwest.

Because the interport competition between U.S. Gulf and East Coast versus the U.S. Pacific Northwest is important, it is essential first to understand the domestic U.S. grain transportation system. For example, important information about the modal share of U.S. grain transportation from the interior of the U.S. grain-producing regions to export elevators was provided by Chang *et al*. (2019). For the barge component of U.S. domestic transportation of grains in the Mississippi River, the studies by Yu and Fuller (2004), Yu and Fuller (2005), and Wetzstein *et al.* (2021) pointed to the importance of competitive barge rates for the grain market, which is characterized by low margins and requiring high volumes. Yu and Fuller (2005) state that the long-run barge rate on the upper Mississippi River is −1.015, but it is inelastic in the short run (−0.5). Barge cost is an important piece of the final F.O.B. price of U.S. grains, including corn, from the U.S. Gulf, and, therefore, a component of the interport competition in the United States. Chi and Baek (2014) established that, in the long run, domestic production of corn in the United States and barge rates have important results on the transportation of corn by barge. The authors utilized a Johansen cointegration analysis and a vector error correction model (VECM) to examine the relationships between corn movements by barge, local corn consumption, barge, and rail rates on the Mississippi River. About the importance of ocean freight cost, Harris (1983) explained the relevance of landed cost, including ocean freight rates, on the destination of the importing country. For example, a more competitive ocean freight rate out of the U.S. Pacific Northwest compared to the U.S. Gulf may be an incentive to export more corn out of the Pacific Northwest−ceteris paribus−from the interior producing regions, if F.O.B price for corn on both coasts are the same. Thus, the ocean freight rate is part of the grain price comparison. According to the author, more grain export demand from the Pacific Northwest may incentivize greater railroad efficiencies and investment to fulfil that traffic.

Fuller *et al.* (1984) proposed a spatial model testing the sensitivity of U.S. grain exports from the U.S. Gulf to Asia and the West Coast of South and Central America to Panama Canal toll rate increases, assuming a revenue-maximizing Panama Canal administration post-U.S. control. The study confirmed a nearly inelastic relationship between toll rates and grain movements through the Panama Canal and underlined the importance of comparative port costs and ocean freight rates between U.S. Gulf versus U.S. PNW export terminals. Given the toll increases of the Panama Canal and the port cost and ocean freight rates differentials, ceteris paribus, Fuller *et al.* (1984) estimated the number of grains diverted to the PNW export elevators at the expense of the U.S. Gulf share. Similar conclusions in terms of the diversion of grain cargo are confirmed by Fuller *et al.* (2000), including the diversion of grains through the Cape of Good Hope from the U.S. Gulf. Grains diverted to the PNW may include wheat, soybean, corn, sorghum, and others. The related literature on the Panama Canal is a plus for the Panama Canal Authority as a useful source of referential analysis on Canal traffic.

Future of Corn Flow

In terms of the factors impacting the future of corn flows through the Panama Canal, Beckman et al. (2023) estimated how climate change might affect corn and soybean yields in the United States, with implications to the U.S. exports. Ho and Bernal (2018a) calculated what they call “contested area” of competition for grain deliveries from the U.S. grain production hinterland to export terminals to the Pacific Northwest or the U.S. Gulf and East Coast. The authors delimited this “contested area” based on a table of shuttle and unit trains to U.S. Gulf and East Coast, PNW, and other export terminals provided in the Grain Transportation Report of the USDA. The “contested area” was based on shuttle and unit trains from origin elevators located more than 200 miles away from the Mississippi River system, beyond the normal reach of grain trucks for delivery to elevators on the Mississippi River. In other words, Ho and Bernal (2018a) illustrated graphically the areas on the U.S. hinterland most likely to ship grains to export elevators located on the U.S. Gulf, East Coast or Pacific, as well as the “contested area” in which grains could be delivered to any export elevators depending on demand and transportation cost. Related to the domestic grain transportation system in the United States, Wilson (1984a), Wilson (1984b), Norton *et al.* (1992), Vachal *et al.* (1997), Wilson and Dahl (2005), Sarmiento and Wilson (2005), Prater *et al.* (2013), Ndembe,(2015), and Ndembe and Bitzan (2018) discussed the importance pricing, innovation, mode allocation, elevator consolidation, and deregulation in the auction of railroad wagons for grains. The rail car allocation following the deregulation of the U.S. railroads and the development of shuttle and unit train services for grains are important elements in the port competition between the U.S. Gulf and East Coast versus the Pacific Northwest. Korinek and Sourdin (2009) indicated, with a series of gravity models, that, for the case of cereals, doubling the cost of shipping between and origin destination pairs results in a 37% drop in that trade, stressing the importance of sourcing food imports from origins with low transportation costs. Wilson *et al.* (2005b) also anticipated China's growing demand for corn because of its expanded meat consumption, which requires corn for animal feeding. In a nutshell, this interport dynamic may be complex and several other factors may play a part in this interaction.

About studies concerning U.S. cost of grain transportation compared to overseas competitors, that is, inter-country competition, it is important to cover parallel studies by Salin and Somwaru (2014), Salin and Somwaru (2018) and Gale *et al.* (2019). Although these studies focus uniquely on the soybean market, similar conclusions could be drawn for corn or any grain type. Because the soybean market is concentrated in a few suppliers, namely Brazil, Argentina and the United States, and China is the dominant soybean buyer, the authors underscore the linkage between the United States and Brazil as the top soybean supplier and China as the main buyer. In the studies, the cost of transportation influences the U.S, market share for soybeans, a situation in which South America, particularly Brazil, is the main beneficiary of a larger market share. The authors computed the changes in U.S. market share for soybeans over the years. Also, studies such as Allen and Valdes (2016) and Byung and Whistance (2019) pointed out the effect of seasonality in the price interaction of U.S. versus Brazilian soybean prices because of different harvest months and alteration of the seasonal pattern of U.S. corn exports because of the Brazilian competition. Nonetheless, and focused on the corn market, Wilson *et al.* (2022), through an Optimized Monte Carlo Simulation (OMCS), determined that variations in barging costs and ocean freight rates can influence the market share for corn between the United States and competitors, especially Ukraine. The study found that the United States is the lowest cost exporter of corn for several markets, with less volatile costs than Ukraine. However, corn deliveries through railroads to export terminals in Ukraine are very competitive compared to the United States. The authors included in their scenario analysis cost functions such as ocean and barge rates, rail delivery car values, export capacity and the Mississippi River dredging; and trade factors such as eliminating the European Union´s import tariffs on U.S. corn, removing phytosanitary measures by China, greater corn export by Ukraine, higher corn imports by China, among others. The research called attention to China´s preference for Ukrainian corn, which is most likely to diversify suppliers and the willingness to pay a premium for non-US origin because of quality issues and to avoid genetically modified grains. Mattos (2019) discussed the changes in the corn market in the last twenty years, with Brazil and Ukraine playing a larger role as corn exporters competing against the United States.

The Decarbonization Process

Lastly, regarding the decarbonization process of shipping and the supply chain of corn, we are including a review paper by Mallouppas and Yfantis (2021) about the possible fuels and technologies available to achieve zero emissions by 2050. Other related studies on decarbonization are covered by Foretich *et al.* (2021), Van Leeuwen and Monios (2022), Psaraftis and Zis (2022), Law *et al.* (2022), Lindstad *et al.* (2022), and institutional research by the World Bank and ProBlue (2021), IRENA 2021 (International Renewable Energy Agency), UMAS and the Getting to Zero Coalition (2021), and The U.S. National Blueprint for Transportation Decarbonization of the Environmental Protection Agency (EPA) of the United States (2023). However, it is important to mention that there is no clear path regarding a dominant alternative fuel to achieve zero decarbonization in the shipping industry, and industry participants are constantly experimenting and piloting different choices. For this reason, much information about new alternative fuels will be based on open-source publications such as magazines and online publications to obtain the latest direction. In summary, the literary review provided the framework for the methodology for the estimation of a corn demand function, the prospective regressors, and the relevance and possible impact of the decarbonization process on the whole supply chain of corn, considering that ocean transportation demand for corn is derived from the global demand for feedstock, in our case from the demand in East Asia. This paper will contribute to the growing Panama Canal literature and, specifically, to the modelling of grains.

Research Model, Data and Methodology for the Study

Hypothesis and Research Model

According to the U.S. Department of Agriculture (USDA), feed grains are mostly corn, sorghum, barley, and oats used to feed domestic livestock and poultry, including cattle, pigs, and chickens[1]. Besides animal feeding, corn can also be processed into ethanol, beverages, corn syrups, corn flour, corn meal, corn cereal, cosmetics, and other industrial applications[2]. In the case of East Asia, imported corn is mostly consumed for poultry and pork production, which is a function of meat demand. Higher per capita income levels and urbanization positively correlate to higher demand for animal proteins in the diet, as food consumption changes into a meat-based diet when real income increases[3]. Part of the demand for corn in East Asia is fulfilled by the United States, in competition with other important producers such as Argentina, Brazil, Ukraine, and several others. According to the USDA, in the 2021/2022 marketing year, the U.S. share of global corn exports was 32.5%, followed by Argentina (20%), Brazil (16.7%) and Ukraine (13.9%), representing together around 83.1% of total exports[4]. The same source indicates a wide variety of importers of corn including China with 11.3% of global imports, followed by the European Union (10.2%), Mexico (9.1%), Japan (7.7%), South Korea (5.9%), Vietnam (4.7%), Colombia (3.3%), and Taiwan (2.3%). Together, these destinations represented close to 54.5% of worldwide corn imports. In the case of East Asia, this region represented just 27.2% of the total corn imports but 60.2% of total corn imports to Asia[5]. Because shipping demand for corn transportation depends on the demand for corn, mainly feed corn, at the destination and is driven by meat demand, global corn movements through the Panama Canal−including from the U.S. East Coast and Gulf to East Asia, a derived demand from corn consumption. Strictly speaking, corn production is an input for meat production and the Panama Canal corn traffic is part of that demand.

In the estimation of the introductory global demand for corn traffic from the U.S. Gulf and East Coast to East Asia as a derived demand for corn consumption, considering the limited availability of data−especially the lack and sufficient historical monthly export data of several U.S. competitor's'−we are suggesting predictors we hypothesized have an impact on corn traffic through the Panama Canal for the route under consideration. Therefore, we

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[1] https://www.ers.usda.gov/topics/crops/corn-and-other-feed-grains/

[2] https://www.weforum.org/agenda/2021/06/corn-industries-sustainability-food-prices and https://www.urmc.rochester.edu/childrens-hospital/nutrition/corn-free.aspx

[3] https://www.ers.usda.gov/webdocs/outlooks/105853/oce-2023-01.pdf?v=994.4

[4] From "World Corn Trade" table, *Grain: World Market and Trade*, USDA. Pg. 30.

[5] Ibid. Including Middle East countries on the table.

are submitting regressors that consider voyage costs, direct interport competition between the U.S. Gulf and East Coast ports compared to U.S. Pacific Northwest ports, and macroeconomic inputs such as the U.S. dollar exchange rate. Any element or factor in the East Asian decision to import corn from the United States, either the U.S. Gulf and East Coast or the Pacific Northwest, is important and must be included in our modelling. To have corn movements to East Asia from the U.S. Gulf and East Coast, it is necessary to have corn inspected for exports in this region as opposed to the Pacific Northwest, the latter an alternative source in competition to the Panama Canal route. On the other hand, we suggest that the U.S. Gulf to Japan freight rate be another component related to voyage cost and interport competition. According to Harris (1983), freight rates are part of the landed costs of grains at the destination.

Considering the probable pattern of corn movements through the Panama Canal, we suggest including seasonality in the exploratory models (Figure 7). Seasonality is directly related to the U.S. corn marketing year and, indirectly, to U.S. competitors´ marketing year, especially Argentina and Brazil in the Southern Hemisphere. The seasonality is expressed as a dummy variable: October, March-May, July, and September are the high-traffic months[6]. As mentioned, our formulation includes the U.S. exchange rate as an explanatory variable. Economic theory states that, as the value of the U.S. dollar increases, U.S. corn becomes more expensive to corn importers; therefore, as the value of the U.S. dollar increases, U.S. corn flows through the waterway shall decline, mainly in the U.S. Gulf and East Coast to East Asia route. In contrast, the energy index is hypothesized to reflect part of the voyage cost

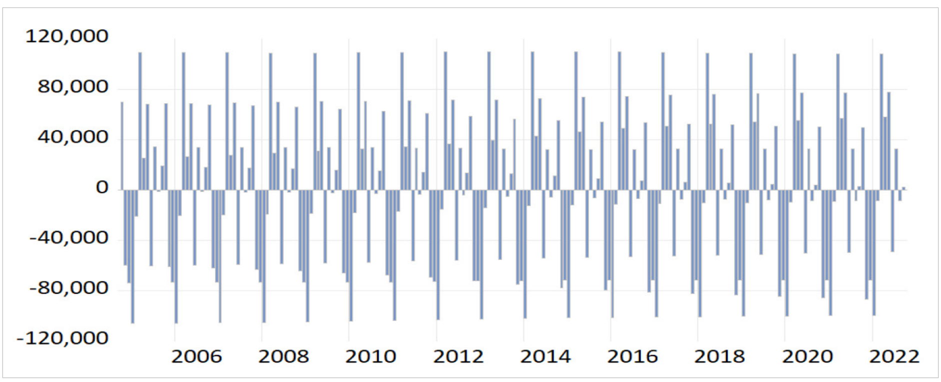

Figure 7: Seasonality of corn movements through the Panama Canal from the U.S. Gulf and East Coast to East Asia using STL Decomposition. October 2004–September 2022

Source: Derived using information from the data warehouse of the Panama Canal (Proprietary)

of transiting the Panama Canal route compared to alternatives and represents the fuel cost of dry bulkers with corn departing the U.S. Gulf and East Corn destined for Asia. Hence, as fuel prices increase, the shorter Panama Canal route is more attractive than longer alternatives, namely the Suez Canal or the Cape of Good Hope routes.

In terms of the Panama Canal cost, Fuller *et al.* (1984) assumed that Panama Canal tolls are part of ship costs and, therefore, included in ocean shipping rates for the routes engaging the waterway. For the case of our study, the Panama Canal effective toll rate is the most important predictor that we shall include in our demand model for corn from the U.S. Gulf and East Coast to East Asia through the interoceanic

[6] The seasonality was determined from the STL Decomposition of the historical monthly corn flows from the U.S. Gulf and East Coast to East Asia.

waterway. For this regressor, we want to test how significant Panama Canal transit cost is for corn traffic through the waterway. Through voyage cost calculations, we can assess the significance of toll rate in the interport competition between corn from the U.S. Gulf compared to the PNW, in the competition between corn from the U.S. Gulf and East Coast through Panama compared to alternative routes (i.e., Cape of Good Hope and Suez Canal for the export to East Asia) and perhaps the origin competition of U.S. corn from the U.S. Gulf and East Coast compared to, for example, Brazil, Argentina and Ukraine. As Fuller *et al.* (1984) theorized, the increase in the toll rate may have a negative impact on the flow of corn through the U.S. Gulf and East Coast in favour of the PNW. Consequently, as Panama Canal toll rates increase, corn movements through the waterway shall decrease, diminishing the attractiveness of Panama as a route for corn in our route under study.

Data, Variables and Sample

For the estimation of the preliminary corn demand model through the Panama Canal from the U.S. Gulf and East Coast to East Asia, considering voyage costs, interport competition and data limitations, we are using seven different datasets with different periods, metrics, and periodicities (e.g., weekly and monthly) to represent the dependent and independent variables proposed in this. This paper proposes using open-source statistics from different agencies of the U.S. Department of Agriculture (USDA), World Bank, Investing.com for the average U.S. dollar index, and proprietary data from the Panama Canal Authority (Table 2). Given the different periodicities of the data proposed for our research, the final statistics representing our dependent and independent variables were unified into monthly numbers to run the prospective OLS models. The period of the study is from October 2004 to September 2022.

Table 2: List of data sources

Data	Source	Unit of Measurement	Periodicity	Beginning Date	Explanation
Corn flows U.S. Gulf and East Coast to East Asia	Panama Canal	Long Tons	Monthly	October 2004	Converted to metric tons. East Asia: China, Japan, South Korea and Japan.
Panama Canal Effective Toll Rate	Panama Canal	U.S.$ per PC/ UMS	Monthly	October 2004	Obtained by dividing the total toll of vessels loaded with corn (including other marine charges*), divided by the Panama Canal Universal Measurement System (PC/ UMS), a volumetric measurement.
U.S. Gulf Freight Rate to Japan	Grain Transportation Report (USDA)	U.S.$ per metric ton	Monthly	January 1996	Freight rate from the U.S. Gulf to Japan
U.S. Gulf Corn Inspections for Exports	Federal Grain Inspection Service (FGIS-USDA)	Metric Tons	Weekly	January 1983	Weekly data converted into monthly data

U.S. Pacific Northwest Corn Inspections for Exports	Federal Grain Inspection Service (FGIS-USDA)	Metric Tons	Weekly	January 1983	Weekly data converted into monthly data
U.S. dollar index	Investing.com	Index	Monthly	February 1971	The value of the U.S. dollar relative to a basket of foreign currencies.
Energy Index	World Bank	Index	Monthly	January 1960	Monthly index representing the overall cost of energy

Not including bookings and auction income because they are optional charges.

Methodology- Model Specification

Given the proposed set of explanatory variables discussed – voyage costs, interport competition, previous studies and methodologies, the need to consider seasonality, and Panama Canal tolls to fit a demand model for corn traffic through Panama assuming that ocean transportation demand for corn is a derived demand for feedstock in the receiving countries under study and taking into consideration the different availabilities of our data, we are estimating a preliminary general demand function for corn through the waterway using Ordinary Least Square (OLS), assuming that corn traffic through the Panama Canal is a derived demand from the general demand for corn consumption in East Asia. OLS is a statistical method used to estimate the parameters of a linear regression model and find the best-fitting linear relationship between a dependent variable and one or more independent variables. Ordinary Least Square minimizes the sum of squared differences, or residuals, between the observed data points and the predicted values from the estimated linear model[7]. OLS assumes linearity between the variables, independence and constant variance of residuals, and normally distributed errors. To answer the questions posed in the introduction section, this paper proposes explanatory variables related to Canal and transit costs, corn sales, and the value of the U.S. dollar. The preliminary variables considered are Panama Canal tolls, U.S. Gulf to East Asia freight rates, U.S. Gulf and Pacific Northwest (PNW) corn inspections for exports, seasonality, the U.S. dollar index and the energy index. The energy index, provided by the World Bank, is composed of coal (4.7%), crude oil (84.6%) and natural gas (10.8%) and it is proposed because it takes into consideration the current fuel types. Data is from October 2004 through September 2022, mostly from the U.S. Department of Agriculture, World Bank and Panama Canal transit information.

Table 3: Descriptive statistics

Variable	**Mean/ Standard Deviation**
Corn flows U.S. Gulf and East Coast to East Asia	561,042 / 344,094
Panama Canal Effective Toll Rate	5.60 / 1.43
U.S. Gulf Freight Rate to Japan	52.76 / 20.35
U.S. Gulf Corn Inspections for Exports	995,109 / 448,584
Pacific Northwest Corn Inspections for Exports	809,226 / 501,401
U.S. dollar index	87.83 / 8.53
Energy Index	95.76 / 31.59

Total observations = 216

[8] Based on Using econometrics: A Practical Guide. A.H. Studenmund. 4th Edition. 2001.

The general specification-including the expected signs for each of the regressors- is the following:

Corn mt = F(C, ,)

where,

Corn mt: corn cargo through the Panama Canal from the U.S. Gulf and East Coast to East Asia. In metric tons. Criterion.

C: Constant term

Canal Tolls: the cost of transits through the Panama Canal in U.S. dollars per PC/UMS[8]. It includes tolls plus other transit costs not including bookings or auctions.

U.S. Gulf Freight Rate: the freight rate of transporting grains from the U.S. Gulf to Japan, as a reference for the cost of transportation from the U.S. Gulf and East Coast to East Asia.

U.S. Gulf Corn Inspections: corn inspections for exports out of grain terminals on the U.S. Gulf and East Coast to East Asia.

PNW Corn Inspections: corn inspections for exports from grain terminals in the Pacific Northwest of the United States to East Asia.

U.S. Dollar Index: the average value of the U.S. dollar compared to the currencies of the rest of the world.

Seasonality: a dummy variable with a value of 1 for the high season for corn through the Panama Canal (October, March-May, July, and September); or otherwise.

Energy Index: an index taking into consideration the cost of different types of energy products (coal, petroleum, and natural gas). A proxy for fuel cost in a voyage calculation.

Two models will be specified: linear functional and logarithmic models[9]. Depending on a regressor's expected sign and statistical significance, some models will include the same set of explanatory variables. However, the model in logarithmic form will allow us to obtain elasticities. The flowchart describes the steps in the methodology section: the identification of possible regressors to explain corn movements from the U.S. Gulf and East Coast to East Asia, the estimation of the preliminary models of corn demand functions in linear and logarithmic form using OLS, and finally the presentation of the table of results to analyze the statistical significance of the explanatory variables proposed (Chart 1).

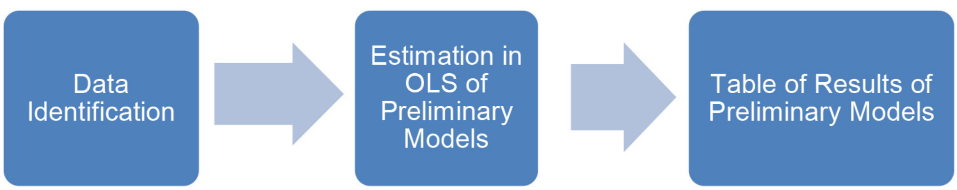

Chart 1: Flowchart of the methodology section

Results and Discussion

Results

The following are the tables with the sequence of preliminary results with the proposed regressors explaining corn traffic through the Panama Canal from the U.S. Gulf and East Coast to East Asia, using OLS, and based on monthly and monthly transformed data. This sequence of preliminary models considers both the statistical significance and expected signs of our proposed explanatory variables. We also examine for any violation of the assumptions of the classical linear model, such as autocorrelation, heteroscedasticity, and multicollinearity.

[8] Panama Canal Universal Measurement System. The volumetric measurement of Panama Canal capacity.

[9] Also called a double log form

Models 1- 3

Table 4: Table of First Preliminary Corn Demand Models- Linear Functional Form

Regressor	Model 1	Model 2	Model 3
Constant	896320.7***	636967.6***	537913.7***
	(213445.9)	(204192.0)	(94659.92)
Canal Tolls	-151257.7***	-137421.2***	-147548.3***
	(17231.24)	(25439.42)	(20829.19)
U.S. Gulf Freight Rate	-4335.141***	-3774.299***	-3680.514***
	(827.9920)	(1050.777)	(1046.663)
U.S. Gulf Corn Inspections	0.401886***	0.436146***	0.435870***
(0.033350)		(0.046167)	(0.045848)
PNW Corn Inspections	-0.045952#	-0.072314*	-0.072149*
	(0.028334)	(0.034224)	(0.034350)
Seasonality	62457.11*	64266.56*	64218.62*
	(26729.66)	(23829.6)	(23817.53)
U.S. Dollar Index	-91.89512	-2165.734	-
	(2649.038)	(3642.437)	-
Energy Index	3086.294***	2257.459***	2439.559***
	(560.78)	(859.3115)	(739.5639)
R- squared	0.698833	0.586669	0.585869
Adjusted R- squared	0.688697	0.572692	0.573923
F- statistic	68.94942	41.97273	49.04285
Prob (F- statistic)	0.000	0.000	0.000
AIC	27.20920	26.97624	26.96887
SIC	27.33421	27.10166	27.07861)
Durbin Watson	1.192272	2.221129	2.228115
Observations	216	215	215

Standard errors in parentheses. P- values ranges: *** (0, 0.001), ** (0.001, 0.01), *(0.01, 0.05), # (0.05, 0.1)

Model 1 is a general, preliminary model attempting to include all the hypothesized relevant explanatory variables discussed previously. All the predictors exhibited the expected signs and statistical significance, except the U.S. dollar index, which was not statistically significant but with the correct expected sign[10]. In our examination of any violation of the classical linear model assumptions, we found no evidence of high multicollinearity; however, we found evidence of autocorrelation of first order and heteroscedasticity[11]. By fixing Model 1 we obtained Model 2 with no evidence of high multicollinearity, but with autocorrelation

[10] At least at the 10% significance level as in the case of seasonality.

[11] For purpose of this study, we used the Variance Inflation Factors (VIF) to detect multicollinearity, for serial correlation the LM test for autocorrelation, and the Breusch- Pagan- Godfrey to test for heteroscedasticity. We also check for higher order autocorrelation throughout the research.

fixed, and heteroscedasticity solved using heteroscedasticity corrected standard error and covariance[12], the latter procedure improving the estimation of the standard errors of our estimates[13]. Finally, Model 3 is derived from Model 2 but eliminates the statistically insignificant "U.S. Dollar Index" variable. After taking into consideration multicollinearity, autocorrelation, and heteroscedasticity, preliminarily Panama Canal tolls, freight rates, corn inspections on both U.S. coasts and the energy index all are important factors that may explain the flows of corn from the U.S. Gulf and East Coast to East Asia, but also leaving seasonality in the formulation, which is barely statistically significant.

Models 4 - 6 in Logarithmic Form

Table 5: Table of Corn Demand Models- Logarithmic Form

Regressor	**Model 4**	**Model 5**	**Model 6**
Constant	5.265755#	3.590369#	3.421416#
	(2.744302)	(2.120394)	(2.105011)
Canal Tolls	-0.954448***	-0.909085***	-0.882995***
	(0.200857)	(0.265734)	(0.260458)
U.S. Gulf Freight Rate	-0.821874***	-0.719177***	-0.715193***
	(0.124974)	(0.143315)	(0.143104)
U.S. Gulf Corn Inspections	1.010102***	1.049247***	1.074171***
	(0.080317)	(0.118730)	(0.116043)
PNW Corn Inspections	-0.024256#	-0.045220***	-0.047916***
	(0.013993)	(0.012147)	(0.012351)
Seasonality	0.108157#	0.075583	-
	(0.065298)	(0.060039)	-
U.S. Dollar Index	-1.061940#	-1.227548#	-1.230961#
	(0.547862)	(0.704413)	(0.698006)
Energy Index	0.807762***	0.647853**	0.646749**
	(0.131555)	(0.201826)	(0.205497)
R- squared	0.681351	0.545864	0.543335
Adjusted R-squared	0.670627	0.531541	0.530162
F- statistic	63.53644	35.68814	41.24610
Prob (F- statistic)	0.000	0.000	0.000
AIC	1.348561	1.149222	1.147677
SIC	1.473572	1.274641	1.257419
Durbin Watson	1.20095	2.103269	2.075034
Observations	216	215	215

[12] The autocorrelation in this study was solved using the Hildred- Lu procedure and heteroscedasticity using the Huber- White Hinkley procedure.

[13] From Halbert White, "A Heteroskedasticity-Consistent Covariance Matrix Estimator and a Direct Test of Heteroskedasticity", Econometrica, 1980, pp. 817-838.

Standard errors in parentheses. P- values ranges: *** (0, 0.001), ** (0.001, 0.01), *(0.01, 0.05), # (0.05, 0.1)

Model 4 is the general, preliminary, and logarithmic form of Model 1 with no evidence of high multicollinearity but, again, with evidence of autocorrelation of first order and heteroscedasticity. Fixing Model 4, we obtain Model 5 with no evidence of high multicollinearity, the autocorrelation of first-order fixed/solved, and heteroscedasticity consistent standard errors and covariance, as in the case of Model 2. Lastly, Model 6 comes from Model 5 but eliminates the variable "Seasonality", which is statistically insignificant in this formulation. After considering the violations to the classical models' assumptions, variables such as Canal tolls, freight rates, corn inspections on both U.S. coasts and the energy index are important factors that may explain the flows of corn from the U.S. Gulf and East Coast to East Asia, with the U.S. dollar index barely significant.

From the list of models, Model 6 is the best preliminary estimation for the global demand for corn traffic through the Panama Canal in terms of significant variables with the expected signs, violations of the classical assumptions for OLS estimation solved, and relatively high. and, more importantly, the lowest Akaike Information Criterion (AIC) and Schwarz Information Criteria (SIC) of all the previously estimated models. On the other hand, models 4-6 estimate elasticities of corn demand to East Asia to Panama Canal tolls, which may help explain the probable impact of any Panama Canal toll change on corn traffic to East Asia from the U.S. Gulf and East Coast.

Discussion

From the available monthly and monthly transformed data, assuming corn demand through the Panama Canal from U.S. Gulf and East Coast to East Asia as a derived demand of corn consumption, we were able to fit two preliminary general corn demand models with OLS estimation: Model 3 and Model 6, the latter in logarithmic form as applied in Saghaian, Y. *et al.* (2014) and Ho and Bernal (2021). These two models may help explain the global, general corn traffic from the U.S. Gulf and East Coast to East Asia, the main destination market for corn for the Panama Canal and the world, by including predictors with the expected signs and statistical significance. For Model 3 and Model 6 we applied remedies for autocorrelation and heteroscedasticity, showing no evidence of high multicollinearity. In general, the logarithmic model exhibited the best fit for the global corn demand under study, using the lowest Akaike Information Criterion (AIC) and Schwarz Information Criteria (SIC) as indicators. Therefore, based on the AIC and SIC criteria, Model 6 represents the best formulation to explain corn movements for the route under study. Nonetheless, the R^2 and adjusted R^2 values and autocorrelation in our models suggest that our exploratory formulations may be improved with additional relevant explanatory variables if enough historical data is available in the future, including export data of alternative corn exporting countries.

In terms of the proposed independent variables explaining corn traffic from the U.S. Gulf and East Coast to East Asia represented in Model 3 and Model 6, factors such as the level of corn inspections for exports on both the U.S. Gulf and East Coast compared to the Pacific Northwest corn inspections for exports attest about the importance of the interport competition for corn exports from the U.S. to East Asia. In other words, the ultimate decision to purchase U.S. corn by China, Japan, South Korea, and Taiwan will rest on factors favouring the Pacific or the Atlantic seaboard (including the U.S. Gulf) for a particular corn purchase. Any factor favouring corn purchase from the U.S. Gulf and East Coast is a prerequisite that may favour corn traffic from this region to East Asia in both Model 3 and Model 6. However, the alternative routes for U.S. corn exports from the U.S. Gulf and East Coast to East Asia, particularly the Suez Canal and the Cape of Good Hope, reduce the number of corn movements through the Panama Canal, representing direct competitors to the waterway[14]. These alternative routes help to understand the expected negative sign and statistical significance of the Panama Canal cost of transit.

Voyage cost factors, such as the freight rate from the U.S. Gulf to Japan and Panama Canal tolls, were significant regressors that helped to explain corn traffic through the Panama Canal in Model 3 and Model 6. The freight rate from the U.S. Gulf to Japan is the reference cost of transportation of grains to East Asia from the U.S. Gulf, and it was expected to be negative and statistically significant to explain corn traffic through the Panama Canal. The higher the transportation freight rate from the U.S. Gulf and East Coast to East Asia, the higher the negative impact on corn flows through the waterway, ceteris paribus. The importance of the freight rate is in line with the assessment by Harris (1983). At the same time, the Canal toll variable is also significant, with the expected negative sign in both Model 3 and Model 6, indicating the probable negative effect of Canal costs on corn traffic. Although the elasticity of corn demand to Canal toll is still in the inelastic range, that is −0.882995 as in Model 6, this value is close to unit elasticity, indicating the sensitivity of corn traffic to East Asia from the U.S. Gulf and East Coast to further Panama Canal tolls, attesting to the effect of toll rates similar to Fuller *et al.* (1984), Fuller *et al.* (2020), and Ho and Bernal (2021) in a similar way. The Panama Canal toll rate estimates may reflect the growing competition between interport, Brazil, Argentina, Ukraine, South Africa)[15]. This elasticity level indicates the narrowing options, or smaller "wiggle room", for the Panama Canal in terms of increasing tolls to corn transits for this origin-destination, ceteris paribus.

For the case of the U.S. dollar index as a proxy of the exchange rate of the U.S. dollar compared to other world currencies, the introduction of this exchange rate regressor helps to explain the competitiveness or not of U.S. corn exports compared to alternative origins as in Model 6, although barely statistically significant at 10%. However, in Model 2 the U.S. dollar index was not statistically significant, therefore left out of Model 3. Nevertheless, the U.S. dollar index displayed the expected negative sign, implying the lack of relative competitiveness of U.S. corn exports when the value of the U.S. dollar is high compared to other currencies. It is very likely that, although intuitively, we can expect that importers will buy less U.S. corn when the value of the U.S. dollar is high compared to their currencies ceteris paribus but other factors related to the need to acquire corn for animal feed may override the higher cost of U.S. corn because of the exchange rate[16]. The price of alternative animal feed such as soybeans, soymeal, feed wheat, sorghum and others may also play a role. Furthermore, seasonality was another factor introduced to consider the possible fluctuations of corn movements through the Panama Canal related to the U.S. corn marketing cycle. However, seasonality was statistically significant in Model 3 but not statistically significant in Model 6, perhaps because of the lack of strong seasonality throughout the year, as in the case of soybeans, as stated in Ho and Bernal (2020).

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[14] The Suez Canal has a long-haul rebate system, providing discounts for dry bulk cargoes (and other ship types) from the U.S. Gulf and East Coast destined to East Asia (East of Port Klang, Malaysia) between 55%-75%. https://www.suezcanal.gov.eg/English/Navigation/Tolls/Pages/MarketingPoliciesAndTollRebates.aspx

[15] Brazil and China concluded agreement for the export of Brazilian corn to China. May 2022. https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/agriculture/052422-brazil-china-conclude-key-negotiations-on-starting-corn-trade

[16] The quality and/or specification of the grain may be a factor or issue during purchase. Also grains substitute (i.e., feed wheat, sorghum) may play a role.

Lastly, the energy index variable exhibited the expected sign and was statistically significant in both Model 3 and Model 6, representing a good proxy for the cost of fuel that applies in a voyage calculation. As fuel costs go up, the possibility of using the shortest Panama Canal route is higher compared to longer alternatives. Also, because this energy index is mostly comprised of fossil fuels, the components of this index will likely change over time throughout the decarbonization of the supply chain of grains. Besides the growing impact of alternative routes and sources, the future movements of corn through the Panama Canal needs to consider the future decarbonization path.

Related to the decarbonization transition process of the maritime transportation and grain supply chain‒including corn‒the shipping industry is fitting scrubbers, carbon capture and storage[17], and it is engaging in several trials involving the use of biofuels, methanol and other alternative fuels and sources of energy to reduce emissions. For example, Kawasaki Kisen Kaisha Ltd. ("K" Line) conducted trials using B24 marine biofuel (24% fatty acid methyl ester (FAME) blended with very low sulfur fuel oil (VLSFO)) in the capesize bulker "Cape Tsubaki" carrying iron ore[18]. "K" Line also informed of a similar trial on a Supramax dry bulker transporting steel coils. According to DNV, there are three types of biofuels relevant to shipping: 1) FAME (Fatty acid methyl ester) from animal fats, vegetable oils or waste cooking oils by transesterification, converting triglycerides into methyl esters; 2) BTL (Biomass to liquid) fuels produced from biomass through thermo-chemical conversion using the Fischer-Tropsch process or the methanol-to-gasoline process; 3) HVO/HDRD (Hydrogen vegetable oil / Hydrogenation derived renewable diesel) from fats or vegetable oils refined in a process called fatty acids-to-hydrocarbon hydrotreatment[19]. According to the same source, FAME is the leading biofuel applied in maritime transportation, blended with oil fuels, or 100% FAME. Biofuels have been tested in dry bulkers, containers, and tankers[20].

In terms of the oceangoing fleet, according to Clarksons´ World Fleet Register, dual fuel LNG topped the list of vessel new buildings (397 orders), trailed by methanol (43 orders) and LPG (17 orders)[21]. Clarksons also includes ammonia-ready ships (90 orders) and a small percentage of hydrogen ready and battery hybrid orders in the order book. Also, Lauritzen and Cargill are joining efforts to include two methanol dual-fuel Kamsarmax in the service to reduce emissions in dry bulkers[22]. Dual-fuel testing may also involve combinations such as LPG, hydrogen and ammonia engines for oceangoing ships[23]. For perspective, as stated by John Bergman of Auramarine, "While LNG and biofuels will be the main focus in the short term, the development of other fuels will continue at pace, including methanol and ammonia, as well as different sorts

[17] Shandong Shipping of China is piloting 12 kamsarmaxes with carbon storage and capture (Shandong Shipping signs for 12 kamsarmaxes - Splash247)

[18] "K" Line America, Inc., Advisories and Announcements. February 22, 2023. https://www.kline.com/news-and-press/2023/02/230222%20K%20LINE%20Conducts%20Trial%20Use%20of%20Marine%20Biofuel%20on%20Capesize%20Bulker%20to%20Help%20Decarbonize%20the%20Shipping%20Industry.pdf

[19] Use of biofuels in shipping (dnv.com)

[20] Global Centre for Maritime Decarbonization, February 21, 2023. https://www.gcformd.org/post/gcmd-led-consortium-successfully-completes-trialling-two-supply-chains-of-sustainable-biofuels

[21] 2022: Shipbuilding Review from Clarkson. January 12, 2023. https://www.clarksons.net/wfr/

[22] "Lauritzen and Cargill Expand Methanol-Fueled Bulker Orders from Japan", The Maritime Executive, April 3, 2023. Lauritzen and Cargill Expand Methanol-Fueled Bulker Orders from Japan (maritime-executive.com)

[23] "Japanese set out to develop engines for tomorrow´s alternative fuel mix". Splash 247.COM. April 6, 2023. Japanese set out to develop engines for tomorrow's alternative fuel mix - Splash247

[24] *2023 Marine Fuel Market Predictions* in Hellenic Shipping News, February 17, 2023. https://www.hellenic-shippingnews.com/2023-marine-fuel-market-predictions/

of biodiesels"[24]. However, methanol, tested on several ship types, is the preferred option because it is easier to handle than ammonia. Still, the fuel types that will prevail in the future are an open question. Bunkering hubs must be flexible enough to offer different varieties of fuels in the future. Additionally, the shipping industry is testing wind power, solar energy, and new vessel designs to reduce emissions from the sea.

For the decarbonization of the U.S. rail transportation system, although trains generate lower GHG emissions than trucks and air transportation, the railroad relies heavily on diesel, making it difficult to reduce emissions for this means of transportation[25]. According to the U.S. National Blueprint for Transportation Decarbonization, the rail system has large long-term opportunities in using sustainable liquid fuels, battery/electricity, and hydrogen[26]. Nonetheless, more research and long-term investments are needed, especially for hydrogen. For trucking, the same U.S. National Blueprint indicates the long-term perspective for battery/electricity (light trucks), and sustainable liquid fuels and hydrogen for heavy-duty trucks. The North American Council for Freight Efficiency (NACFE) and RMI published a report stating hydrogen as the long-run solution for zero emission for long-haul trucking, although it is still being trialed[27]. For example, Canadian Pacific, Burlington Northern Santa Fe, and several companies in Europe and around the world announced some hydrogen-powered piloting programs. According to Wabtec Corporation, "For each diesel-powered locomotive converted to alternative energy sources, up to 3,000 tons of CO_s per year can be eliminated"[28]. This number highlights the effect of using less diesel in rail transportation. On the trucking side, Hydrogen Vehicle Systems (HVS), a British consortium, is receiving funding to develop autonomous hydrogen-electric trucks[29].

Regarding the decarbonization of the barge system of the United States, the alternatives are similar to maritime transportation, including biofuels, LNG, methanol, ammonia, hydrogen, and battery propulsion. However, more research and piloting are needed, and the problem of fuel energy density is important, whereas low energy density fuels require larger fuel tanks on a vessel to match the power that the present diesel engines provide. Similarly, decarbonization of the port terminals can be achieved using more electrical equipment or alternative fuels for cargo handling equipment and slow steaming as vessels approach ports[30]. The decarbonization efforts of terminals include electricity generation using

[25] U.S. Department of Transportation, FederalRailroad Administration. https://railroads.dot.gov/rail-network-development/environment/rail-climate-considerations

[26] https://www.energy.gov/sites/default/files/2023-01/the-us-national-blueprint-for-transportation-decarbonization.pdf

[27] Hydrogen Trucks: Long-Haul´s Future? Hydrogen Trucks: Long-Haul's Future? – North American Council for Freight Efficiency (nacfe.org)

[28] "Decarbonization Rail Transportation, Freight 2030 White Paper". https://www.wabteccorp.com/Freight2030-white-paper?inline.

[29] British consortium to develop autonomous hydrogen truck. https://www.electrive.com/2023/02/07/british-consortium-presents-autonomous-hydrogen-truck/

[30] Clean Air Guide for Ports & Terminals, Technologies and Strategies to Reduce Emissions and Save Energy. edf_clean_air_guide_for_ports_terminals_0.pdf

more renewable energy sources and hydrogen and power generation of industrial processes within the port[31]. Finally, the Panama Canal requires vessels transiting the Canal to switch to low sulfur fuels and has an Environmental Premium Ranking, which provides customers with highly environmentally efficient ships the chance to achieve a better position in the Panama Canal's Customer Ranking System for reservation slots[32]. Eventually, the Panama Canal will eventually study programs to reduce emissions and decarbonize its electricity production and maritime operations.

Conclusion and Contributions

After taking into consideration previous studies related to the corn demand using the Panama Canal and studies on decarbonization, this paper imparted the first insights on the factors influencing corn flows through the waterway as a derived demand, especially Canal tolls, interport competition, freight rate and the energy index, the latter representing the cost of fuel in a voyage calculation. In other words, this research is an attempt to understand better the components that may impact the corn movements from the U.S. Gulf and East Coast to East Asia. This paper establishes the main factors impacting corn movements through the Panama Canal from the U.S. Gulf and East Coast to East Asia, filling a general gap in the Panama Canal literature for the grain trade. The energy index will evolve as the types of fuel change throughout the decarbonization process in the maritime industry. This decarbonization process will include the fuel types used by oceangoing ships and the types of fuels utilized along the corn supply chain, from farmers to export and import terminals. Conversely, further research will be needed to consider alternative sources of corn, such as South America, as well as route choice, depending on the readily available data. Although the U.S. Gulf and East Coast to East Asia route for the Panama Canal is the main corn route, other destinations such as the West Coast of Central and South America from the same origin, are also important. The latter routes could also be the subject of future studies, along with the possibilities of Northern Brazilian corn as an alternative source to the west coasts of the Americas and East Asia

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