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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 DECARBONISATION PROCESS

JAVIER HO* AND PAUL BERNAL

Panama Canal Authority, Balboa, Ancón, Panamá, Republic of Panama.

**Corresponding author: jho@pancanal.com*

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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 article 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, the research hypothesised 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 decarbonisation 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 decarbonisation studies related to the maritime industry, and examines articles related to Panama Canal shipping demand, thus, closing the gap in 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 to 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 to 2021, it battled for the top spot against soybeans, relinquishing first place in FY 2005, between FY 2009 to 2017, and FY 2019 to 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 (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 (Table 1). Derived from the same Panama Canal proprietary information, between FY 2017 to 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.

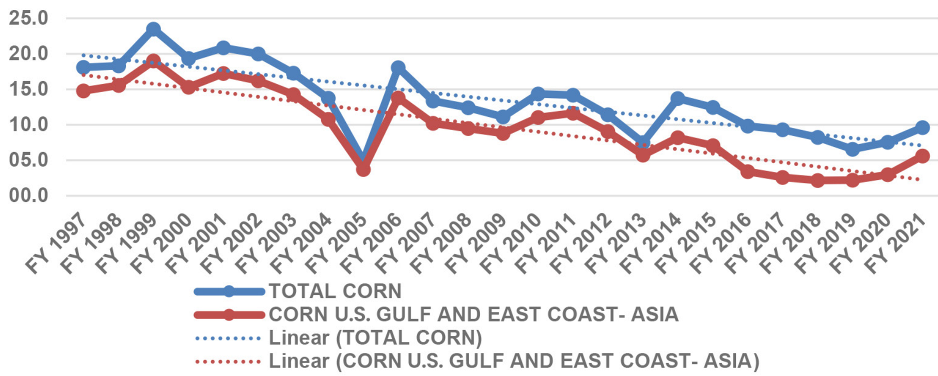

Figure 1: Corn movements through the Panama Canal: Total corn movements and U.S. Gulf and East Coast to Asia, in million-long tons
Source: Datawarehouse of the Panama Canal (Proprietary)

Table 1: Top 10 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 to 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 (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 to 2021, and between

FY 2012 to 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 to 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 to 2021 of U.S. corn flows to China, Japan, and South Korea was 6.7% compared to a 9.6% the 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 to 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.

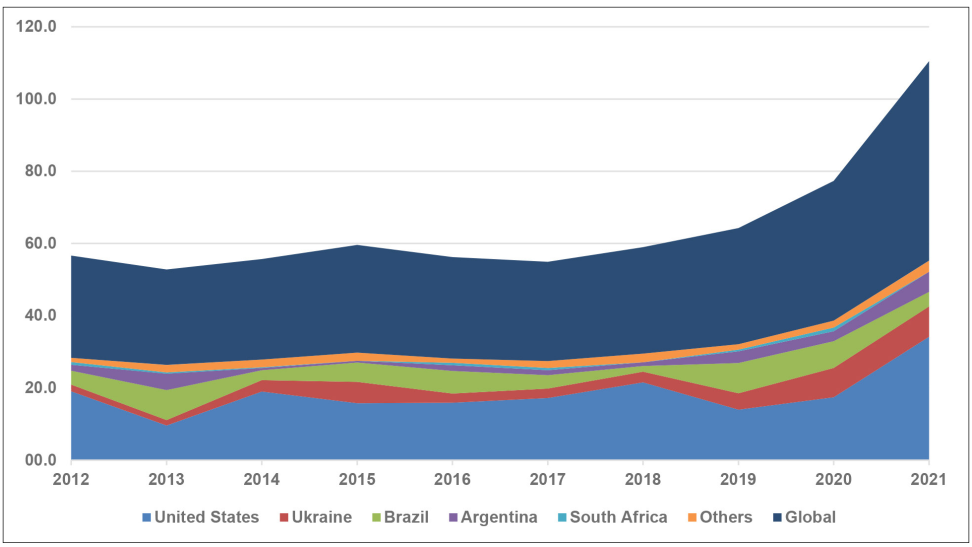

Figure 2: Main corn exporters to China, Japan, and South Korea in million metric tons

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

[1]No data on Taiwan in UN Comtrade.

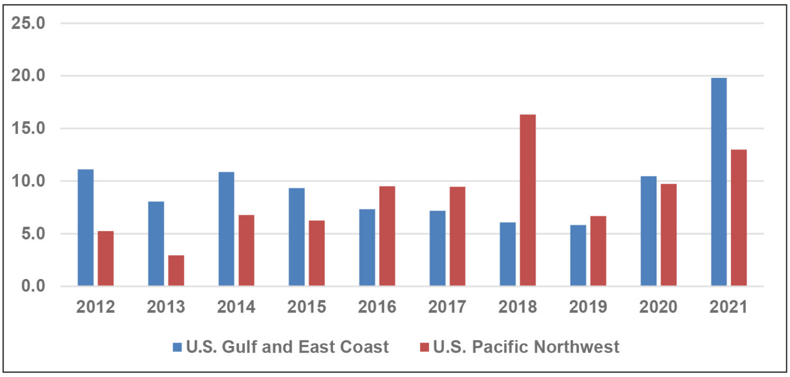

Figure 3: Market share of corn exports to China, Japan, and South Korea: United States vs. Non-united States shares (%)

Source: United Nations Comtrade

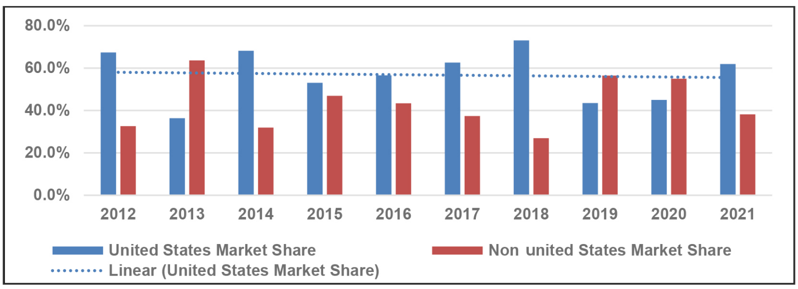

Figure 4: Market share of corn inspections for exports to China, Japan, and South Korea: U.S. Gulf and East Coast vs. Pacific Northwest in percentages (%)

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

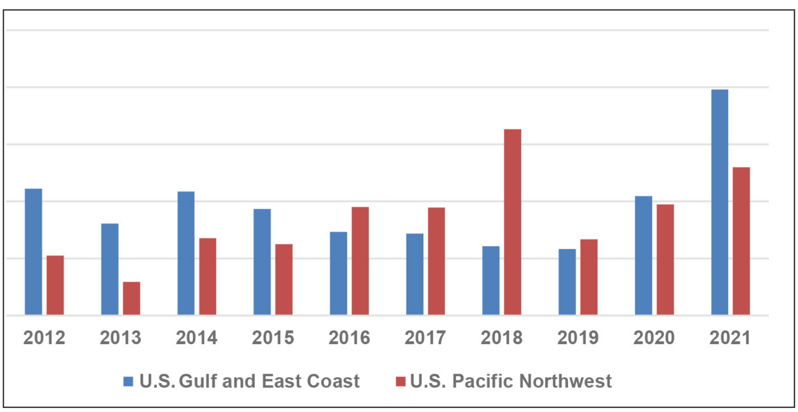

Figure 5: Yearly corn export inspections to China, Japan, and South Korea by port region, in million metric tons

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 to 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 article 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 decarbonisation 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 20 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 organisation of this research, this article 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 decarbonisation 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 article will discuss the decarbonisation process of the shipping industry and the supply chain in general, including vessels, barges, railroads, and the Panama Canal.

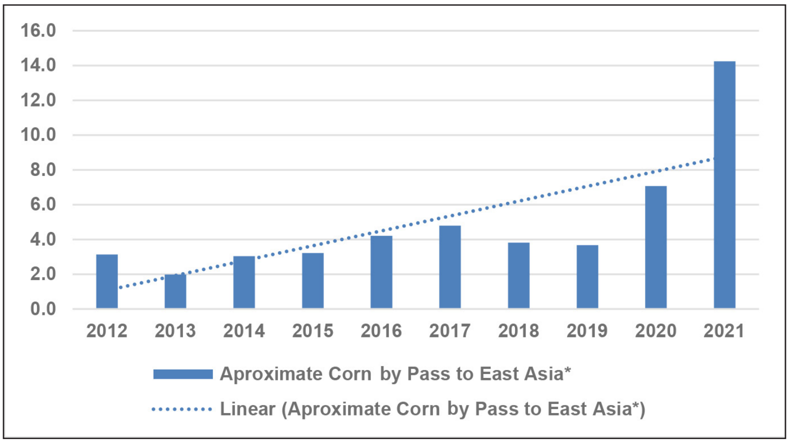

Figure 6: Estimated corn movements from the U.S. Gulf and East Coast to China, Japan, and South Korea bypassing the Panama Canal, in a million metric tons

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 decarbonisation 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 decarbonisation 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 to 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 1st July 2017 to 30th September 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 characterised 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 utilised 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 incentivise 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-maximising 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 the 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, 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-U.S. 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 Decarbonisation Process

Lastly, regarding the decarbonisation process of shipping and the supply chain of corn, we are including a review article by Mallouppas and Yfantis (2021) about the possible fuels and technologies available to achieve zero emissions by 2050. Other related studies on decarbonisation 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 Decarbonisation 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 decarbonisation in the shipping industry, 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 decarbonisation 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 article 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[2]. Besides animal feeding, corn can also be processed into ethanol, beverages, corn syrups, corn flour, corn meal, corn cereal, cosmetics, and other industrial applications[3]. 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 urbanisation positively correlate to higher demand for animal proteins in the diet, as food consumption changes into a meat-based diet when real income increases[4]. 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[5]. 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[6]. 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

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

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

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

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

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

several U.S. competitor's – we are suggesting predictors we hypothesised have an impact on corn traffic through the Panama Canal for the route under consideration. Therefore, we 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 until May, July, and September are the high-traffic months[7]. 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 hypothesised to reflect part of the voyage cost 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.

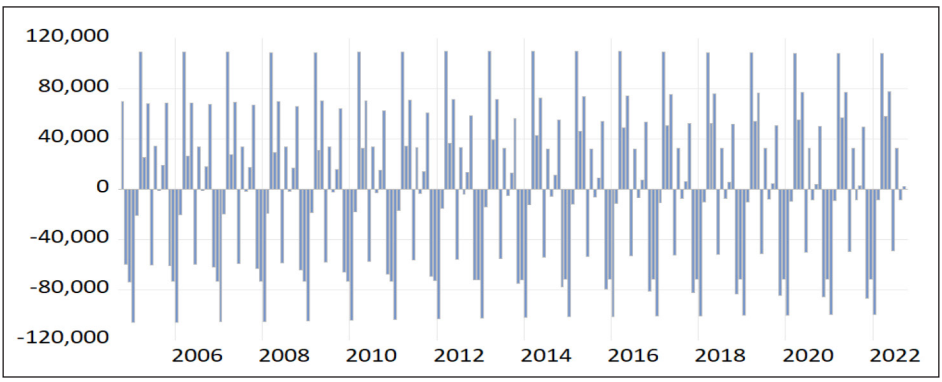

Figure 7: Seasonality of corn movements through the Panama Canal from the U.S. Gulf and East Coast to East Asia using STL Decomposition. October 2004 to September 2022

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

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

[7]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.

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 waterway. For this regressor, we want to test how significant the 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) theorised, 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 article 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 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 minimises the sum of squared differences or residuals, between the observed data points and the predicted values from the estimated linear model[8]. 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 article 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 (Table 3). The energy index, provided by the World Bank is composed of coal (4.7%), crude oil (84.6%), and natural gas (10.8%), 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.

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

Table 3: Descriptive statistics

Variables	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	

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

Corn mt = F(C, *Canal Tolls*$^{(-)}$, *U.S.Gulf Freight Rate*$^{(-)}$, *U.S.Gulf Corn Inspections*$^{(+)}$, *PNW Corn Inspections*$^{(-)}$, *U.S.Dollar Index*$^{(-)}$, *Energy Index*$^{(+)}$, *Seasonality*$^{(+)}$)

where,

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

C: Constant term

Canal Tolls: The cost of transits through the Panama Canal in U.S. dollars per PC/UMS[9]. 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 one for the high season for corn through the Panama Canal (October, March to May, July, and September); or otherwise.

Energy Index: An index taking into consideration the cost of different type 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[10]. 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 analyse the statistical significance of the explanatory variables proposed (Chart 1).

[9]Panama Canal Universal Measurement System. The volumetric measurement of Panama Canal capacity.
[10]Also called a double log form.

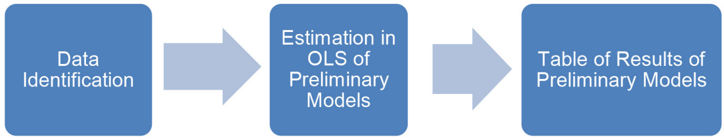

Chart 1: Flowchart of the methodology section

Results and Discussion

Results

Tables 4 and 5 show 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.

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 hypothesised 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[11]. 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[12]. By fixing Model 1, we obtained Model 2 with no evidence of high multicollinearity but with autocorrelation fixed, heteroscedasticity solved using heteroscedasticity corrected standard error and covariance[13], the latter procedure improving the estimation of the standard errors of our estimates[14]. 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.

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	-

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

[12]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.

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

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

	(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	41.246_{10}
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**

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 to 6 estimate elasticities of corn demand in East Asia to Panama Canal the tolls, which may help explain the probable impact of any Panama Canal toll change on corn traffic in 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 the 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[15]. 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, alternative routes, and alternative origins (i.e., Brazil, Argentina, Ukraine, and South Africa)[16]. 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

[15]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

[16]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

and, 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[17]. The price of alternative animal feed such as soybeans, soy meal, 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). 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 increase, 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 decarbonisation of the supply chain of grains. Besides the growing impact of alternative routes and sources, the future movement of corn through the Panama Canal need to consider the future decarbonisation path.

Related to the decarbonisation transition process of the maritime transportation and grain supply chain-including corn-the shipping industry is fitting scrubbers, carbon capture, and storage[18], 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[19]. “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; and (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[20]. 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[21].

[17]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.

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

[19]“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

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

[21]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

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)[22]. Clarksons also includes ammonia-ready ships (90 orders), 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 is in the service of reducing emissions in dry bulkers[23]. Dual-fuel testing may also involve combinations such as LPG, hydrogen and ammonia engines for oceangoing ships[24]. 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 of biodiesels"[25]. 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 decarbonisation 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[26]. According to the U.S. National Blueprint for Transportation Decarbonisation, the rail system has large long-term opportunities in using sustainable liquid fuels, battery/electricity, and hydrogen[27]. 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), as well as 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[28]. 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_2 per year can be eliminated"[29]. 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[30].

Regarding the decarbonisation of the barge system of the United States, the alternatives are similar to maritime transportation, including

[22]2022: Shipbuilding Review from Clarkson. January 12, 2023. https://www.clarksons.net/wfr/

[23]"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).

[24]"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.

[25]2023 Marine Fuel Market Predictions in Hellenic Shipping News, February 17, 2023. https://www.hellenicshippingnews.com/2023-marine-fuel-market-predictions/

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

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

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

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

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

biofuels, LNG, methanol, ammonia, hydrogen, and battery propulsion. However, more research and piloting are needed, 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, decarbonisation 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[31]. The decarbonisation efforts of terminals include electricity generation using more renewable energy sources and hydrogen and power generation of industrial processes within the port[32]. 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[33]. Eventually, the Panama Canal will eventually study programs to reduce emissions and decarbonise its electricity production and maritime operations.

Conclusions and Contributions

After taking into consideration previous studies related to the corn demand using the Panama Canal and studies on decarbonisation, this article 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 article 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 decarbonisation process in the maritime industry. This decarbonisation process will include the fuel types used by oceangoing ships and the type of fuels utilised 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 and 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 America and East Asia.

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[31]Clean Air Guide for Ports & Terminals: Technologies and Strategies to Reduce Emissions and Save Energy. https://www.edf.org/sites/default/files/content/edf_clean_air_guide_for_ports_terminals_0.pdf

[32]"A practical guide to decarbonising ports", eit InnoEnergy. https://eit.europa.eu/sites/default/files/decarbonising_ports-catalogue_of_innovative_ solutions_f.pdf

Also, the U.S. is planning to spend $4 billion to electrify U.S. ports. https://www.reuters.com/business/sustainable-business/us-launches-4-billion-effort-electrify-us-ports-cut-emissions-2023-05-05/#:~:text=U.S.%20launches%20%244%20billion%20effort%20to%20electrify%20U.S.%20 ports%2C%20cut%20emissions,-By%20David%20Shepardson&text=WASHINGTON%2C%20May%205%20 (Reuters),disproportionate%20impacts%20on%20nearby%20communities

[33]Panama Canal Authority. https://pancanal.com/en/improved-sustainability-initiatives-inches-the-panamacanal-closer-to-a-carbon-neutral-future/

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Conflict of Interest Statement

The authors declare that they have no conflict of interest.

References

Allen, E., & Valdes, C. (2016). *Brazil's corn industry and the effect on the seasonal pattern of U.S. corn exports* (AES-93). Economic Research Service, United States Department of Agriculture (USDA). https://www.ers.usda.gov/webdocs/outlooks/35806/59643_aes93.pdf?v=9502.9

Beckman, J., Ivanic, M., & Nava, N. (2023). *Estimating market implications from corn and soybean yields under climate change in the United States* (Economic Research Report Number 323). Economic Research Service, U.S. Department of Agriculture (USDA).

Beghin, J., Jayasinghe, S., & Moschini, G. (2009). Determinants of world demand for U.S. corn seeds: The role of trade costs. *American Journal of Agricultural Economics*, *92*(4), 999-1010. https://www.jstor.org/stable/40931062

Byung, M., & Whistance, J. (2019). Seasonal soybean price transmission between the U.S. and Brazil using the seasonal regime-dependent vector error correction model. *Sustainability*, *11*(19), 5315. https://doi.org/10.3390/su11195315

Chang, K., Cafarelli, P., Gastelle, J., & Sparger, A. (2019). *Transportation of U.S. grains: A modal share analysis 1978-2016 update*. United States Department of Agriculture, Agricultural Marketing Service. https://www.ams.usda.gov/sites/default/files/media TransportationofUSGrainsModalShare1978_2016.pdf

Chi, J., & Baek, J. (2014). Identifying the policy implications of barge shipments of grains on the U.S. inland waterway system: The case of corn movements on the Mississippi Waterway. *Maritime Policy & Management*, *42*(3), 293-303. https://doi.org/10.1080/03088839.2013.870356

Environmental Protection Agency of the United States (EPA). *The U.S. national blueprint for transportation decarbonisation: A joint strategy to transform transportation*. https://www.energy.gov/sites/default/files/2023-01/the-us-national-blueprint-for-transportation-decarbonisation.pdf

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.

Foretich, A., Zaimes, G., Hawkins, T., & Newes, E. (2021). Challenges and opportunities for alternative fuels in the maritime sector. *Maritime Transportation Research*, *2*, 100033. https://doi.org/10.1016/j.martra.2021.100033

Fuller, S., Makus, L., & Gallimore, W. (1984). Effects on increasing Panama Canal toll rates on U.S. grain exports. *Southern Journal of Agricultural Economics*, *16*(2), 9-20. https://core.ac.uk/download/pdf/6553291.pdf

Fuller, S., Fellin, L., & Eriksen, K. (2000). Panama Canal: How critical to U.S. grain exports? *Agribusiness*, *16*(4), 435-455. https://doi.org/10.1002/1520-6297(200023)16:4<435::AID-AGR4>3.0.CO;2-I

Gale, F., Valdes, C., & Ash, M. (2019). *Interdependence of China, United States, and Brazil in Soybean Trade* (OCS-19F-01). Report from the Economic Research Service (ERS). USDA. https://www.researchgate.net/publication/334139509_Interdependence_of_China_United_States_and_Brazil_in_Soybean_Trade

Harris, M. J. (1983). *Ocean fleet shipping rates, capacity, and utilization for grains* (Staff

Reports 276784). United States Department of Agriculture, Economic Research Service.

Harrison, R., & Boske, L. (2017). *The impact of the new Panama Canal locks on Texas ports and the Texas economy* (Technical Report: 5-6690-01-1). The University of Texas at Austin, Center for Transportation Research. https://rosap.ntl.bts.gov/view/dot/32863

Heien, D., & Pick, D. (1991). The structure of international demand for soybean products. *Southern Journal of Agricultural Economics*, *23*(1), 137-146. http://dx.doi.org/10.1017/S008130520001791X

Ho, J., & Bernal, P. (2018a). The importance of the U.S. inland transportation and navigation system for the Panama Canal grain trade. *Proceedings of the 34th PIANC World Congress, Panama, May 7-12, 2018*. https://coms.events/pianc-panama/data/full_papers/full_paper_106.pdf

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. (2020). 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

Ho, J., & Bernal, P. (2021). Estimating a global demand model for soybean traffic through the Panama Canal. *Journal of Shipping and Trade*, *6*(11), 1-23. https://doi.org/10.1186/s41072-021-00086-2

International Renewable Energy Agency. (2021). *A pathway to decarbonize the shipping sector by 2050*. IRENA https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Oct/IRENA_Decarbonising_Shipping_2021.pdf

Konandreas, P., Bushnell, P., & Green, R. (1978). Estimation of export demand functions for U.S. wheat exports. *Western Journal of Agricultural Economics*, *31*, 1-12. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Oct/IRENA_Decarbonising_Shipping_2021.pdf

Korinek, J., & Sourdin, P. (2009). *Clarifying trade costs: Maritime transport and its effect on agricultural trade* (OECD Trade Policy Paper No. 92). OECD Publishing. https://doi.org/10.1787/18166873

Law, L., Mastorakos, E., & Evans, S., (2022). Estimates of the decarbonisation potential of alternative fuels for shipping as a function of vessel type, cargo and voyage. *Energies*, *15*, 7468. https://doi.org/10.3390/en15207468

Leeuwen, J., & Monios, J. (2022). Decarbonisation of the shipping sector-time to ban fossil fuels? *Marine Policy*, *146*, 105310. https://doi.org/10.1016/j.marpol.2022.105310

Lindstad, E., Stokke, T., Altesjaer, A., Borgen, H., & Sandass, I. (2022). Ship of the future: A slender dry bulker with wind assisted propulsion. *Maritime Transportation Research*, *3*, 100055. https://doi.org/10.1016/j.martra.2022.100055

Mallouppas, G., & Yfantis, E. (2021). Decarbonisation in shipping industry: A review of research, technology development, and innovation proposal. *Journal of Maritime Science and Engineering*, *9*(4), 415. https://doi.org/10.3390/jmse9040415

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*, 274-289. https://doi.org/10.1016/j.tre.2016.04.012

Mattos, F. (2019). Corn market: Big changes, new perspectives, and fresh research opportunities. *Revista de Agroeconomia e Agronegócio*, *16*(3), 296-304. http://dx.doi.org/10.25070/rea.v16i3.7954

Miller, K., & Hyodo, T. (2021). Impact of the Panama Canal expansion on Latin American and Caribbean Ports: Difference in Difference (DID) method. *Journal of Shipping and Trade*, *6*, 8. https://doi.org/10.1186/s41072-021-00091-5

Nathan Associates. (2012). *Update and development of the dry bulk market segment study*. Arlington, Virginia: Nathan Associates.

Ndembe, E. (2015). Hard red spring wheat marketing: Effects of increased shuttle train movements on railroad pricing in the northern plains. *Journal of Transportation Research Forum*, *54*(2), 101-115. https://ideas.repec.org/a/ags/ndjtrf/241831.html

Ndembe, E., & Bitzan, J. (2018). Grain freight elevator consolidation, transportation demand, and the growth of shuttle facilities. *Research in Transportation Economics*, *71*, 54-60.

Norton, J., Bertels, P., & Buxton, F. (1992). *Transportation of U.S. grains: A modal share analysis*. United States Department of Agriculture, Agricultural Marketing Service, Transportation and Marketing Program. https://www.ams.usda.gov/sites/default/files/media/TransportationofUSGrainsModalShare1978_2019.pdf

Office of Transportation Air Quality. Environment Protection Agency (EPA). (2016). *National Port Strategy Assessment: Reducing Air Pollution and Green House Gases at U.S. Ports.* National port strategy assessment: Reducing air pollution and greenhouse gases at U.S. ports (EPA-420-R-16-011). https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100PGK9.pdf

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

Prater, M., Sparger, A., & O´Neil Jr., D. (2013). *The effects of increased shuttle-train movements of grain and oilseeds*. U.S. Department of Agriculture, Agricultural Marketing Service. http://dx.doi.org/10.9752/TS088.08-2013

Psaraftis, H., & Zis, T. (2022). Shipping decarbonisation and green ports. *Maritime Transportation Research*, *3*, 100068. https://doi.org/10.1016/j.martra.2022.100068

Saghaian, Y., Reed, M., & Saghaian, S. (2014). Export demand estimation for U.S. corn and soybeans to major destinations. *Presentation at the 2014 Southern Agricultural Economics Association (SAEA) Annual Meeting in Dallas, Texas. February 1-14, 2014*. https://ideas.repec.org/p/ags/saea14/162546.html

Salin, D., & Somwaru, A. (2014). Eroding U.S. soybean competitiveness and market shares: What is the road ahead? *U.S. Department of Agriculture, Agricultural Marketing Service*. https://www.ams.usda.gov/sites/default/files/media/Eroding%20U.S.%20Soybean%20Competitiveness%20and%20Market%20Shares%20What%20Is%20the%20Road%20Ahead.pdf

Salin, D., & Somwaru, A. (2018). *The impact of infrastructure and transportation costs on U.S. soybean market share: An updated analysis from 1992-2017*. U.S. Department of Agriculture, Agricultural Marketing Service. https://www.ams.usda.gov/sites/default/files/media/SoybeanMarketShare.pdf

Sarmiento, C., & Wilson, W. (2005). Spatial modelling in technology adoption decisions: The case of shuttle train elevators. *American Journal of Agricultural Economics*, *87*(4), 1034-1045. https://www.jstor.org/stable/3697788

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. https://doi.org/10.1080/03088839.2019.1657974

Theocharis, D., Sanchez, V., Pettit, S., & Haider, J. (2019). Feasibility of the northern sea route: The role of distance, fuel prices, ice breaking fees and ship size for the product tanker. *Transportation Research Part E: Logistics and Transportation Review*, *129*, 111-135. https://doi.org/10.1016/j.tre.2019.07.003

The World Bank. (2021). *Charting a course for decarbonizing maritime transport*. ProBlue and the World Bank. https://www.u-mas.co.uk/wp-content/uploads/2021/04/Summary-for-policy-makers.pdf

UMAS on behalf of the Getting to Zero Coalition. (2021). *A strategy for the transition to zero-emission shipping: An analysis of transition pathways, scenarios, and levers for change*. https://www.u-mas.co.uk/wp-content/uploads/2021/10/Transition-Strategy-Report.pdf

Ungo, R., & Sabonge, R. (2012). A competitive analysis of Panama Canal routes. *Maritime Policy & Management*, *39*(6), 555-570.

Vachal K., Bitzan J., & Baldwin B. (1997). *Implications of a North American grain marketing system for prairie transportation & elevators* (MPC Report No. 97-84). Fargo Upper Great Plains Transportation Institute, North Dakota State University.

Wang, M. (2017). The role of Panama Canal in global shipping. *Maritime Business Review*, *2*(3), 247-260. http://dx.doi.org/10.1108/MABR-07-2017-0014

Wetzstein, B., Florax, R., Foster, K., & Binkley, J. (2021). Transportation costs: Mississippi River barge rates. *Journal of Commodity Markets*, *21*(c), 100123. https://doi.org/10.1016/j.jcomm.2019.100123

White, H. (1980). A heteroskedasticity-consistent covariance matrix estimator and a direct test of heteroskedasticity. *Econometrica*, *48*, 817-838. https://doi.org/10.2307/1912934

Wilson, W. (1984a). Modal shares, car shortages, and multiple-car rates in grain transportation. *North Central Journal of Agricultural Economics*, *6*(2), 59-69. https://doi.org/10.2307/1349251

Wilson, W. (1984b). Estimation of modal demand elasticities in grain transportation. *Western Journal of Agricultural Economics*, *9*(2), 244-258. https://www.jstor.org/stable/40987656

Wilson, W., Koo, W., Taylor, R., & Dahl, B. (2005b). Long-term forecasting of world grain trade and U.S. Gulf exports. *Transportation Research Record: Journal of the Transportation Research Board*, *1909*, 22-30.

Wilson, W., & Dahl, B. (2005). Railcar auctions for grain shipments: A strategic analysis. *Journal of Agricultural and Food Industrial Organization*, *3*(2), Article 3. https://doi.org/10.2202/1542-0485.1047

Wilson, W., & Ho, J. (2018). Panama Canal. Blonigen, B., & Wilson, W. (Eds.), *Handbook of international trade and transportation* (pp. 628-657). U.K.: Edward Elgar Publishing.

Wilson, W., Lakkakula, P., & Bullock, D. (2022). *Logistical competition for corn shipments from the United States and Ukraine to targeted international market* (Agribusiness and Applied Economics Report No. 811). Department of Agriculture, Agricultural Marketing Service. https://ageconsearch.umn.edu/record/319650/files/AAE811.pdf

Xue, R. (2017). *Impact of the Panama Canal Expansion on container liner shipping industry* (Master's Dissertations, World Maritime University). https://commons.wmu.se/cgi/viewcontent.cgi?article=2532&context=all_dissertations

Yu, T., & Fuller, S. (2004). *Briefing paper on the Upper Mississippi and Illinois Rivers Transportation Corridors: Grain transportation rates and associated market area*. Food and Agricultural Policy Research Institute. https://www.fapri.missouri.edu/wp-content/uploads/2015/03/FAPRI-MU-Briefing-Paper-05-04.pdf

Yu, T., & Fuller, S. (2005). The measurement of grain barge demand on inland waterways: A study of the Mississippi River. *Journal of Transportation Research Forum*, *44*(1), 27-39.