Computational General Equilibrium Model with Maritime Route Choice: an application in the case of Suez Canal route and Arctic Shipping

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29th Annual Conference on Global Economic Analysis
June 2026

Abstract

While most world trade is transported by sea, their operation heavily depends on a few maritime choke points. A local shock at these choke points could significantly impact international trade. This paper aims to build a model quantifying these impacts by incorporating the route selection for sea transportation into the GTAP standard model. The route choice parameters are estimated from shipment data. The model is then applied to evaluate the effects of increasing the Suez Canal route price. The results highlight some interesting general equilibrium effects of a local maritime route shock.

Keywords: Route Choice, Maritime Transport, Computational General Equilibrium

1 Introduction

Maritime transport carries more than eighty percent of world merchandise trade by volume, with three main types of ships, including containership, dry bulk, and liquid bulk (UNCTAD 2019). The main container trade flows are among three economic centers – North America, Europe, and Asia – which constitute the East-West trade route (Stopford, 2009). The shortest way to travel on this trade route is to pass through the world's main maritime chokepoints, which are traditionally the Suez Canal and the Panama Canal. However, a growing trade volume, political and natural uncertainty on these trade routes, and ice retreat in Arctic regions have prompted interest in the Arctic Shipping Route. This paper aims to create a model to quantify the impacts of a shock on an maritime route and its relation with the potential impact of the Arctic Shipping Route.

We modified the GTAP standard model to include the selection for sea transportation. To apply the model empirically, we calibrated the demand and supply for each route as well as route substitution parameters by using voyage data for different maritime sectors. Using this model, we conducted a simulation to an increase in Suez Canal route price on all types of cargo. Transportation costs become higher for all trade between countries going through the Suez Canal. As a result, trade through other routes, including the Arctic Routes, increases. The model also observes the change in trade partners due to the heterogeneous change in transportation.

The literature on the feasibility of Arctic Shipping has pointed out three main factors in providing the services. They are service fees including ice-breaking or escorting fees[1], navigation period[2] as well as fuel cost[3]. Service

[1] See Liu and Kronbak (2010), Faury and Cariou (2016), Xu, Yang, and Weng (2018), Xu et al. (2011), Faury, Cheaitou, and Givry (2020), and Theocharis et al. (2021).

[2] See Schøyen and Bråthen (2011), Zhao, Hu, and Lin (2016), and Sibul and Jin (2021).

[3] See Verny and Grigentin (2009), Lasserre (2014), Sibul and Jin (2021), and Theocharis et al. (2021).

fees, which include ice-breaking and escort costs, significantly impact Arctic Shipping's appeal; studies suggest it may only be viable with reduced or zero tariffs. The navigation period also matters, as lower fees apply during summer when thinner ice allows some vessels to navigate independently, though specialized vessels for such conditions can be costly. Fuel costs further influence Arctic Shipping's competitiveness, as shorter distances can lead to savings, though high bunker prices may negate these benefits by raising operational costs and requiring more capital for ice-class vessels (Kavirathna and Shibasaki, 2021).

The literature on the economic impacts of Arctic Shipping is still scarce. Many papers focus on the potential cost savings of certain trade routes and commodities (Xu et al., 2011; Schøyen and Bråthen, 2011; Rajagopal and Zhang, 2021; Furuichi and Otsuka, 2013). A few papers discuss the potential impacts on the world's economy. A few papers discuss the potential impacts on the world's economy. Using a general equilibrium framework, a scenario of all-year-round commercial use of NSR in 2030 could increase the total trade value by 0.3 percent, and all these increased trade values are concentrated in the route between East Asia and North Europe (Bekkers, Francois, and Rojas-Romagosa, 2018). Our paper addressed feedback effects from transport demand on transport prices inside the model by adding the route choice decision in the standard GTAP model.

In terms of methodology, our paper enriches the CGE literature by considering the route choices in international transport sectors. While the considerations of route choices in the CGE framework are abundant in the urban transport sector (Robson and Dixit, 2017), there are very few papers in the context of international transport sectors. While the choice of transportation modes (air, land, and sea) has been incorporated in the standard GTAP model (Avetisyan and Hertel, 2021), no papers have addressed route choice problem in this class of model. As a results, the route-specific shock is essentially a change in technology to transport a commodity between origin and destination in the model, regardless of modes or routes of transportation (Shibasaki et al., 2018). By explicitly incorporating the maritime route choices, our paper can consider the substitution effects from one route to another, and the indirect effects on the aggregate price of maritime transportation.

This study is also related to papers studying economic geography changes that affect trade. The gravity literature has used distance as a proxy for trade cost. However, it was pointed out the estimates of distance elasticity of trade cost were unrealistically high and have not dropped over time despite globalization[4]. While these estimates have been revised using empirical tools (Borchert and Yotov, 2017), these changes could be attributed to the changes in transportation costs. Hummels, Lugovskyy, and Skiba (2007) and Feyrer (2019) exert that the change in transportation technology (i.e., the rise of air freight) has shaped global trade and the world economy though changing distance elasticity of trade la.

Our study also relates to structural gravity literature, with the considerations of international transport sectors. The changes in bilateral transportation costs in the container network was input into a structural gravity model to examine the effects on the Panama Canal expansions on trade Heiland et al. (2019). The dry bulk sectors are modelled as a matching market to evaluate the effects of high fuel prices on international trade Brancaccio, Kalouptsidi, and Papageorgiou (2020). While these models considered the detailed network of each maritime sector's network, they don't consider the decisions on both modes and routes for all sectors as in our paper.

Our paper also adds to the maritime logistics literature, where the route choices are modeled using the discrete choice framework (Shibasaki, Azuma, and Yoshida, 2016) or assignment models (Shibasaki, Kanamoto, and Suzuki, 2020). These models are concerned mostly with the changes in the share of

[4]See Anderson and Van Wincoop (2004) for a thorough discussion.

each route where the total demands are determined outside the model. In contrast, our paper allows for the change in route as well as the change in demand.

Our paper contributes to the literature in two aspects. First, the paper illustrates a way to incorporate maritime route choice into the CGE framework, allowing us to analyze the impact of maritime route-specific shock on the world economy. Second, the economic impact of Arctic Shipping is considered in an integrated framework considering both the detailed cost component of shipping services and the macro environment from the CGE framework.

The paper is organized into five sections. In section 2, we describe how we modify the standard GTAP model to include the route choice. Section 3 shows our calibration of the model including the elasticity of substitutions among routes and their supply and demand. In section 4, we run simulations assuming shock on the Suez Cana route and discuss their results. Section 5 concludes.

2 The Model

2.1 Basic Setup

The model described here is largely based on Hertel (1997) for the economic environment. Since the model is largely based on previous works, we describe only the main parts in the main text. Mathematical representations are shown in Appendix A.

There is J countries. In each $j \in J$, a representative agent has a Cobb-Douglas utility function over consuming three goods: private goods q_j^{pr}, public goods q_j^{go} and savings q_j^{sa}. Household consumption follows a constant-difference of elasticities (CDE) function, while preferences for public goods and savings are modeled by a Cobb-Douglas form (See A.1).

Perfectly competitive firms in each country i and sector s produce the final good bundle q_{is}^{prod} with a Leontief production on the value added bundle q_{is}^{va} from factor endowment $e \in E$ and intermediate input bundles sourced from the different sectors q_{ius}^{int}. Value-added bundle joins all endowment through CES functions (See A.2). This production structure induces a price for final good c_{js}. Intermediate input bundles source inputs from both domestic and foreign markets. International trade is discussed in section 2.2 and transport in section 2.3

Capital and labor is perfectly mobile across sectors. The factor price w_{id} is identical across sector and the factor market equilibrium requires that the sum of factor demands is equal to factor supply. Land and natural resource are not perfectly mobile across sectors; their allocation is modelled by a transformation function. The total supply of capital, labor, land, and natural resources is exogenous.

A "global bank" distribute saving to all regions until the rates of return on investment for all regions are equalized. A regional households buy the saving from the global bank with the price of savings as a weighted avearge of the price of investment goods acquired by the global bank. Investment goods are treated like intermediates and are a Leontief function of goods used for investment from different industies. In equilibrium, the total amount of savings is equal to the total quantity of net investments (see A.3).

The equilibrium prices and quantity can be solved by applying the goods market equilibrium conditions and regional income identity. The model is solved using GEMPACK 12.1.

2.2 International Trade

All intermediate goods are tradable for four groups of agents (households, government, firms, and investors). Suppose that each agent allocates domestic and foreign inputs using CES function, the price index is the average of domestically produced and imported goods:

$$\Phi_{js}^{ag} = \left[(t_{js}^{imp,ag} \Phi_{js}^{imp})^{1-\rho_s^{arm}} + (t_{js}^{dom,ag} c_{js})^{1-\rho_s^{arm}} \right]^{\frac{1}{1-\rho_s^{arm}}} \tag{1}$$

where $t_{js}^{u,ag}$ is the group specific tax for $u = import, domestic$, Φ_{js}^{imp} is the price of import bundle, c_{js} is the price of domestically produced bundle (see section A.2 for its derivation).

The regional import demand for these inputs is the sum of all agents' demand:

$$q_{js}^{imp} = \sum_{ag \in \{pr,go,fi,in\}} \left(\frac{t_{js}^{imp,ag} \Phi_{js}^{IMP}}{\Phi_{js}^{ag}} \right)^{\rho_s^{arm}} q_{js}^{ag}. \tag{2}$$

where q_{js}^{ag} is the total demand for goods in sector s in country j by group ag.

Similarly, the regional domestic demand is

$$q_{js}^{dom} = \sum_{ag \in \{pr,go,fi\}} \left(\frac{t_{js}^{dom,ag} c_{js}}{\Phi_{js}^{ag}} \right)^{\rho_s^{arm}} q_{js}^{ag}. \tag{3}$$

There is an import aggregator that sources regional import demand from all countries. The common import price in the destination is equal to the cif price multiplied by one plus the import tariff (t_{ijs}^{imp}):

$$p_{ijs}^{imp} = (t_{is}^{prod} c_{is} t_{ijs}^{exp} + \gamma_{ijs} p_{ijs}^{ts}) t_{ijs}^{imp} \tag{4}$$

where c_{is} is the price of input bundles, t_{is}^{prod} is the tax on input bundles from country i, and t_{ijs}^{exp} is the detination-specific export tax. p_{ijs}^{ts} is the price of transportation and γ_{ijs} is the share of cif-value spent on transportation services. Notice that the term in bracket is the cost, insurance, and freight (CIF) price of delivering from source i to destination j in sector s.

The price of the import bundle is:

$$\Phi_{js}^{imp} = \left[\sum_{i=1}^{J} (\iota_{ij}^{imp})^{\rho_s^{imp}} (t_{is}^{prod} c_{is} t_{ijs}^{exp} + \gamma_{ijs} p_{ijs}^{ts})^{1-\rho_s^{imp}} (t_{ijs}^{imp})^{1-\rho_s^{imp}} \right]^{\frac{1}{1-\rho_s^{imp}}} \tag{5}$$

The bilateral import demand is:

$$q_{ijs} = \left(\iota_{ij}^{imp} \frac{\Phi_{js}^{imp}}{p_{ijs}^{imp}} \right)^{\rho_s^{imp}} q_{js}^{imp} \tag{6}$$

2.3 International Transport

Goods are transported from origin to destination using global transport services where the destination price (p_{cif}) is equal to the origin price (p_{fob}) plus the transport costs, which is the term in the bracket of equation 4. The demand for transport is proportional to the quantity of trade $ts_{ijs} = \gamma_{ijs} q_{ijs}$. The import aggregator can choose among different modes of transport m and among different routes of sea transportation g, according to a nested CES function:

$$ts_{ijs} = \left\{ \sum_{m=air,sur} (ts_{ijs}^{m})^{\frac{(\sigma^m - 1)}{\sigma^m}} + \left[\sum_{g} (ts_{ijs}^{sea,g})^{\frac{(\sigma^g - 1)}{\sigma^g}} \right]^{\frac{\sigma^g (\sigma^m - 1)}{(\sigma^g - 1)\sigma^m}} \right\}^{\frac{\sigma^m}{(\sigma^m - 1)}} \tag{7}$$

The demand for air and land transport service is:

$$ts_{ijs}^{m} = \left[\frac{p_{ijs}^{ts}}{p^m} \right]^{\sigma^m} ts_{ijs} \quad m = air, land \tag{8}$$

where the price of transport p_{ijs}^{ts} is:

$$p_{ijs}^{ts} = \left[\sum_{m=sea,land} (p^m)^{1-\sigma^m} + (p_{ijs}^{sea})^{1-\sigma^m} \right]^{\frac{1}{1-\sigma^m}}; \tag{9}$$

The demand for sea transport service is:

$$ts_{ijs}^{sea} = \left[\frac{p_{ijs}^{ts}}{p_{ijs}^{sea}}\right]^{\sigma^{sea}} ts_{ijs} \tag{10}$$

where the price of sea transport p_{ijs}^{sea} is:

$$p_{ijs}^{sea} = \left[\sum_{g} (p^{sea,g})^{1-\sigma^g}\right]^{\frac{1}{1-\sigma^g}}. \tag{11}$$

The demand for each route of sea transport is

$$ts_{ijs}^{sea,g} = \left[\frac{p_{ijs}^{sea}}{p^{sea,g}}\right]^{\sigma^g} ts_{ijs}^{sea} \tag{12}$$

where $p^{sea,g}$ is the price of each sea route.

On the supply side, transport services are provided by a global transport service for land, air, and different sea routes $sea(g)$

$$ts^m = \sum_{s=1}^{S} \sum_{i=1}^{J} \sum_{j \neq i} ts_{ijs}^m; \quad m = land, air, sea(g) \tag{13}$$

Global transport services are supplied by the transport sector in different countries with choice following Cobb-Douglas:

$$p^m = \prod_{i=1}^{J} (p_i^m)^{v_i^m}; \quad m = land, air, sea(g). \tag{14}$$

where p_i^m is the price of transport services supplied by country i. The supply of transport services in country i is

$$ts_i^m = \kappa_i^m \frac{p^m tr^m}{p_i^m}. \tag{15}$$

The price of transport services supplied by country i is equal to the price of gross output in the corresponding transport sector $p_i^m = c_{im}$.

3 Calibration

3.1 Region and Commodity

Calibration process is specific to the region and commodity classification. To match the trade flow with the route share of each ship type, commodities are largely grouped into three major groups: dry bulk cargo (wheat, grain, paddy rice; oil seeds; sugar; coal; ore; steel), liquid bulk cargo (oil, gas, petroleum, and chemical products), and container cargo (food and beverage, textiles and apparel, rubber and plastic, chemicals and non-metallic mineral products, metal products, electrical and machinery products, transport equipment, and other manufacturing goods). Details of commodities are shown in Table 1.

Countries and regions are also grouped into 24 regions. The grouping strategy considers both economic and political similarities among countries as well as their geographical locations. This facilitates the aggregation of voyage data from the port level to the region level. Details of region classification are shown in Table 2.

3.2 Voyage Data

Since data on demand, production, trade and transportation by mode, as well as behavioural parameters are provided in GTAP database version 11 (Aguiar et al., 2022), we only need to calibrate the route choice parameters as well as route supply and demand. To do so, we need information on the quantity and unit cost of transport on each route for different commodities.

To estimate this information, we use voyage data for each route for each maritime sector: container from MDS (annual data), dry bulk from AXS Dry (quarterly data), and liquid bulk from Alpha Tanker (quarterly data) from 2013 to 2019. The unit costs are the weighted average of all voyage's

Table 1: GTAP Version 11 Commodities by Category

Commodity	**GTAP Version 11 Commodity**
Dry Bulk	
AgriBulk	paddy rice; wheat; cereal grains; oil seeds
Coal	coal
Ore	other extraction
Steel	ferrous metals
Liquid Bulk	
Oil	oil
Gas	gas
Products	petroleum products
Chemicals	chemical products
Container Cargo (incl. General Cargo and Vehicle Carrier)	
Agricultural products	bovine animals, horses, and other equines; other animals and animal products; forestry and logging products
Food and Beverage	fishing products; vegetable oils and fats; vegetables, fruit, nuts; sugar crops; crops (coffee, cinnamon, etc.); raw milk; bovine meat products; meat products; dairy products and egg products; processed rice; sugar and molasses; food products; beverages and tobacco products
Textiles and Apparel	plant-based fibers; wool, silk-worm cocoons; textiles; wearing apparel; leather products
Wood and Paper	wood products; paper products, printing
RPMM	rubber and plastic products; basic pharmaceutical products; mineral products
Metal Products	metals other; metal products
Electrical Machinery	computer, electronic, and optical products; electrical equipment; machinery and equipment
Transport Equipment	transport equipment; motor vehicles and parts
Other Manufacturing	other manufactures

Table 2: List of regions and countries

No	Region
1	**US** (US): US, Rest of North America (Bermuda, Greenland, Saint Pierre and Miquelon)
2	**Canada** (Canada): Canada
3	**West Coast South America** (WCSA): Peru, Ecuador, Chile, Bolivia
4	**East Coast South America** (ECSA): Brazil, Argentina, Uruguay, Paraguay
5	**Central America** (CAM): Mexico, Central America
6	**Caribbean Area Countries** (CARI): Caribbean countries, Venezuela, Colombia, Rest of South America (Falkland Islands (Malvinas), French Guiana, Guyana, South Georgia and the South Sandwich Islands, Suriname)
7	**North Europe (excl. Russia)** (NEU): Belgium, Netherlands, Germany, Denmark, Poland, the Baltics (Latvia, Lithuania), UK, Ireland, Norway, Sweden, Finland, Iceland, Switzerland, France, Czech Republic, Slovakia
8	**Russia** (Russia): Russia, Belarus
9	**Black Sea** (BlkSea): Bulgaria, Romania, Ukraine, Georgia, Moldova, Armenia, Azerbaijan
10	**West Mediterranean** (WestMed): Italy, Malta, Spain, Portugal
11	**East Mediterranean** (EastMed): Albania, Croatia, Slovenia, Hungary, Greece, Cyprus, Israel, Turkey, Rest of Europe (Montenegro, Andorra, Bosnia and Herzegovina, Faroe Islands, Gibraltar, Guernsey, Vatican City State, Isle of Man, Jersey, Monaco, North Macedonia, San Marino), Serbia, Syria, Lebanon, Palestine
12	**North Africa** (Nafrica): Libya, Tunisia, Algeria, Morocco, Egypt
13	**West Africa** (Wafrica): West African coastal countries from Mauritania to Congo DPR, Canary Islands
14	**Southern Africa** (Safrica): Angola, Namibia, South Africa, Eswatini
15	**East Africa** (Eafrica): Kenya, Tanzania, Mozambique, Madagascar, Mauritius, (Seychelles, Sudan, Eritrea, Djibouti, Somalia, Mayotte, Burundi), Ethiopia, Comoros
16	**Middle East** (ME): Oman, UAE, Qatar, Bahrain, Kuwait, Iran, Saudi Arabia, Iraq, Yemen, Jordan
17	**India** (India): India
18	**East South Asia (excl. India)** (ESAsia): Bangladesh, Sri Lanka, Nepal
19	**West South Asia (excl. India)** (WSAsia): Pakistan, Rest of South Asia (Maldives, Bhutan), Row (Antarctica, Bouvet Island, British Indian Ocean Territory, French Southern Territories)
20	**Southeast Asia** (SEA): Myanmar, Thailand, Malaysia, Singapore, Brunei, Indonesia, Cambodia, Vietnam, Philippines, Timor Leste
21	**China** (China): China, Hong Kong
22	**East Asia** (excl. China) (EastAsia): Japan, South Korea, Taiwan, Mongolia, Rest of East Asia (North Korea, Macao)
23	**Central Asia** (Casia): Afghanistan, Kazakhstan, Kyrgyzstan, Tajikistan, Uzbekistan, Rest of Former Soviet Union (Turkmenistan)
24	**Oceania** (Oceania): Australia, New Zealand, Pacific Islands countries

unit costs for each route-origin-destination. The weighted shares are based on vessel capacity (TEU for container and deadweight ton -DWT for other types of vessels). Unit cost is voyage cost divided by vessel capacity.

The voyage costs include fuel costs, operating costs, capital costs, port dues, insurance costs, canal tolls. Operating costs and capital costs are estimated using time-charter costs from Clarkson Intelligence. Port dues are assumed to be 0.428 USD/GT/call and the insurance fee is 0.343 percent of the building price per year (Furuichi and Otsuka, 2013). Arctic shipping includes additional costs of icebreakers (5 USD/GT), ice-pilot (673 USD/day), insurance premium (10 USD/GT/year), specific fuel coefficient premium (10% on top of SFC for normal vessels), shipping building cost premium (10% on top of building cost for normal vessels).

The fuel consumption of a voyage is calculated by multiplying the daily fuel consumption of the main engine with the number of days at sea for that voyage. Daily fuel consumption is the product of specific fuel consumption (SFC) and engine power. SFC values are taken from the IMO's report (IMO, 2020) for different fuel types (heavy fuel, marine gas, or LNG) and SSD engine types. Engine powers are taken from the IHS ship database. When engine powers are not available, they are filled based on a regression between known value and vessels' length, speed, and DWT). Fuel prices (HSFO, MGO, and LNG) are taken from Clarkson Intelligence.

Table 3 reports descriptive statistics of estimated shipment quantities by route and commodity group. For dry bulk, shipments routed through other routes, including the Cape of Good Hope show the largest average quantities, reflecting the importance of long-haul trade flows that bypass canal constraints. The Suez and Panama routes also handle large volumes on average, while Arctic routes remain marginal in both frequency and scale. In liquid bulk, the "others" category also has the highest mean quantity, suggesting that many tanker routes operate outside major chokepoints, mainly via the Cape of Good Hope. For container trade, the Suez route stands out with the largest mean shipment size, followed by the Panama canal route, which reflect the needs for faster transit. Across all commodities, the standard deviations are large relative to the means, indicating highly skewed shipment distributions characterized by occasional very large flows.

Table 4 reports descriptive statistics for estimated unit transport costs across routes and commodity groups. For dry bulk, average unit costs are relatively moderate, ranging from about 18.47 USD/mt on alternative routes ("others") to 47.79 USD/mt via Arctic. Costs through the Panama and Suez canals are similar, reflecting the balance between shorter sailing distances and canal toll expenses. In liquid bulk, unit costs are generally higher and more dispersed, with Arctic exibits the highest mean costs (around 77.47 USD/mt). The other route shows moderately lower average costs (25.55 USD/mt), mostly showing regional routes or through Cape of Good Hope. For container transport, costs are not directly comparable to other sectors due to different unit of measurment (TEU instead of metric tons). The Suez and Panama route exhibits the highest mean cost, much more than regional routes. Across all commodities, the large standard deviations and wide min–max ranges indicate considerable heterogeneity in realized transport costs, reflecting variation in vessel size, fuel prices, operational conditions, and route-specific constraints.

3.3 Route Choice Elasticity

The parameter of interest is the coefficient σ_s. To estimate this parameter, we divide both sides of Equation (12) for Suez, Panama, Cape, and Arctic on the route Other, and replace the price variable with unit cost. We have:

$$\ln \frac{Q_{g,ijs}}{Q_{g=Other,ijs}} = -\sigma_s^g \ln \frac{UC_{g,ijs}}{UC_{g=Other,ijs}} + d_{it} + d_{jt} + d_g + \epsilon_{g,ijst}, \qquad (16)$$

Table 3: Estimated Quantity

Route	mean	sd	min	max
Dry Bulk (thousand mt)				
Suez	217.46	465.31	2.01	5572.31
Panama	211.13	541.24	4.21	10022.94
Arctic	38.06	35.28	5.47	129.43
Others	1313.71	7719.37	2.07	198630.88
Liquid Bulk (thousand mt)				
Suez	304.84	732.90	0.00	8097.16
Panama	186.40	518.47	2.17	7046.82
Arctic	67.06	118.12	2.97	804.26
Others	1167.83	3943.82	0.90	72211.81
Container (thousand TEU)				
Suez	91.12	33.13	24.98	234.76
Panama	53.04	22.38	9.49	159.46
Others	42.87	31.07	1.74	179.70

Table 4: Estimated Unit Cost

Route	mean	sd	min	max
Dry Bulk (USD/mt)				
Suez	26.60	16.26	5.35	208.11
Panama	28.14	15.68	4.39	227.67
Arctic	47.79	28.71	16.62	153.07
Others	18.47	12.19	0.30	224.64
Liquid Bulk (USD/mt)				
Suez	40.24	39.55	3.17	662.52
Panama	38.99	33.74	3.32	456.70
Arctic	77.47	90.44	11.77	713.19
Others	25.55	28.85	0.39	991.69
Container (USD/TEU)				
Suez	1719.59	438.43	914.90	3061.86
Panama	1821.22	702.97	630.64	3672.89
Others	769.28	331.73	201.35	2323.63

where $Q_{g,irs}$ is the quantity of goods or services, σ_s^g is the elasticity of substitution for commodity s, $P_{g,irs}$ is price of each route, and $d_{v=i,j,g,t}$ are fixed effects capturing specific influences for origin i, destination j, route g and time t. This approach help alleviate the affects from total and sea transport price and demand in the equation, keeping only the difference in route prices as the factor affecting the demand of these routes. Because information on route-specific prices is unavailable, we construct a unit cost variable using vessel characteristics and route characteristics. Under the assumption of no market power, this unit cost can be used as a proxy for the price on each route. Moreover, because the variable is based on technical characteristics of ships and routes, it is plausibly exogenous and does not suffer from the simultaneity problem that could lead to price endogeneity.

Estimation results are shown in Table 5. All commodities, except containers, demonstrate significant results with σ^g values less than one. Tanker commodities exhibit higher elasticity values. Since the container estimates do not meet the parameter condition, they are replaced with a value of 1, which modifies the CES aggregation function to a Cobb-Douglas form in this case. Details of estimation results are shown in Table B.1 in Appendix B.1.

Table 5: Route Choice Elasticity

Commodity	Estimate	Std. Error	sigma
Container	0.46	0.42	1
Agribulk	-1.80	0.35	1.80
Coal	-1.55	0.26	1.55
Ore	-1.23	0.09	1.23
Steel	-1.00	0.58	1.00
Chemicals	-0.01	1.54	1
Gas	-1.26	0.33	1.26
Oil	-1.49	0.29	1.49
Products	-1.75	0.36	1.75
Other	-1.26	0.03	1.26

3.4 Splitting Sea Transport Margin

The demand for each route is calculated from the share of each route and the sea transport cost taken from the header VTWR (mode-specific transport demand for each commodity-source-destination triplet) in the GTAP 11 Database (Aguiar et al., 2022). The share is estimated using the total cost for each route for each commodity-source-destination triplet. Details of the cost matrix is shown in Appendix B.3.

As for the supply of each route, we modified the SplitCom procedure by M. Horridge[5] to apply for the case of a margin commodity. The procedure first splits national accounts and trade by provided shares and then adjusts the balance between demand and supply. The supply shares are assumed to be the same for all regions. This share must equal the demand shares in equilibrium at the global level. It is estimated using the global total cost for each route (Suez: 39.57%, Panama: 10.297%, Arctic: 0.002% Other 50.131%).

The splitting procedure also requires allocating trade in maritime transport services across routes. In the absence of route-level statistics for service trade, we assume that services are distributed proportionally to the physical quantity flows of commodities along each route. Bilateral shares of maritime transport services between regions are therefore determined by the shares of commodity quantity flows on routes connecting those regions.

The estimated results are shown in Figure 1. The figures illustrate transport demand and supply across various regions in billions of 2017 USD for four sea routes: Suez, Panama, Arctic, and Other. The group Other includes regional routes that do not cross any ocean. In terms of transport demand, the NEU (Northern Europe), China, East Asia, and Southeast Asia region exhibits the highest demand, with substantial reliance on both the Suez and Other routes. The Middle East, Oceania, and East and West Coast of South

[5] https://www.copsmodels.com/splitcom.htm

America also have high demand on Panama and Other routes. Canada and the US show more balanced usage across all routes.

On the supply side, NEU stands out with exceptionally high transport supply. China, East Asia, and Southeast Asia also display substantial supply levels. Other supplying regions are the East Mediterranean, West Mediterranean, India, and the Middle East. The Arctic route is still in its infancy, mostly supplied by Russia with the expansion of LNG trade in the Northern Sea Route.

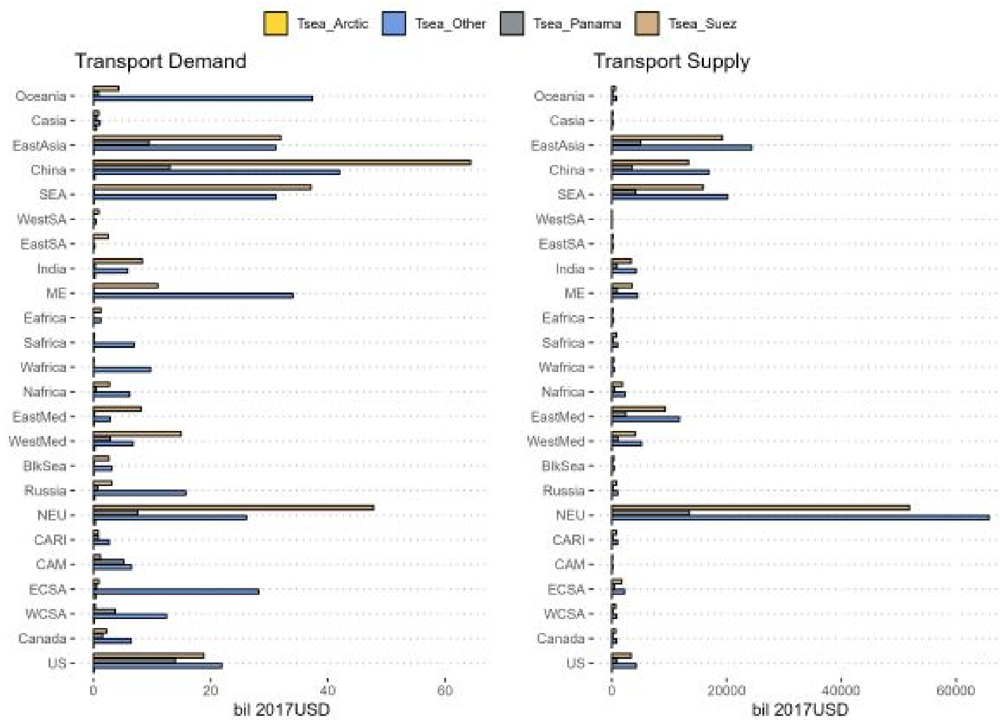

Figure 1: Estimated Transport Demand and Supply by Route

The ranking among regions for both demand and supply comes from the ranking in sea transport from the GTAP database, where transport demand and supply by mode (air, land, sea) across regions in billions of 2017 USD. NEU, China, east Asia, Southeast Asia, and the US show a large volume of demand and supply. While sea transport dominates in both demand and supply, European regions show higher demand for land than for sea (as shown in Figure 2).

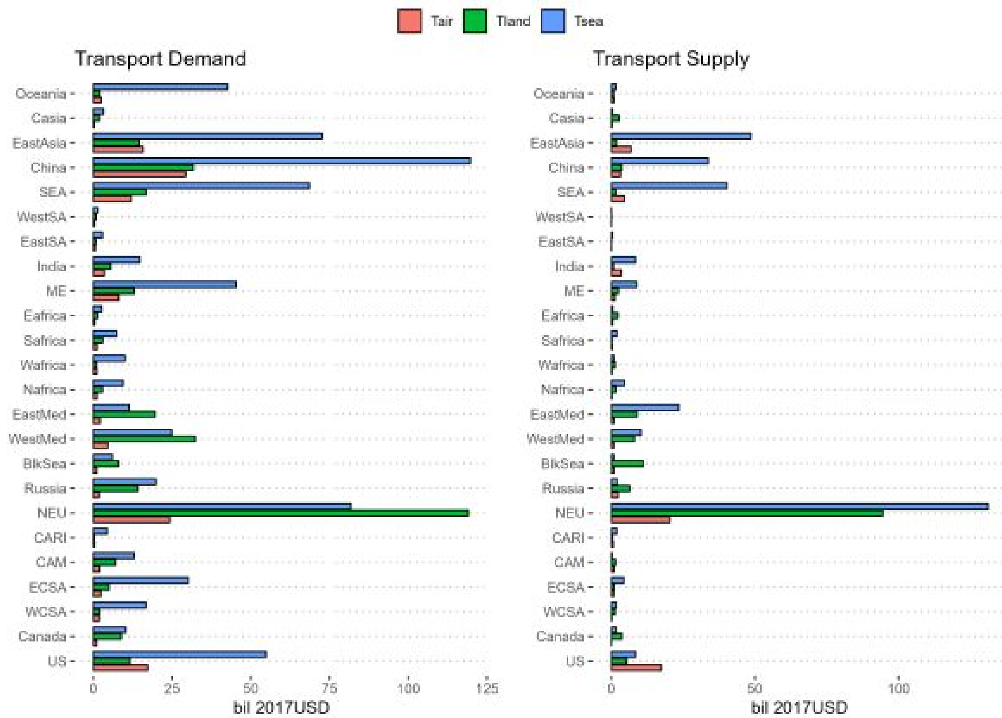

Figure 2: Estimated Transport Demand and Supply by Mode

4 Effect of Suez Canal Shock

4.1 Scenario

To generate economic projections, we start by updating the economy from the GTAP database reference year (2017) to 2022, followed by an extension to 2024 using GDP growth rates from the IMF World Economic Outlook, then project to 2030 using SPP2 projection from IIASA version 3 (January 2024). In applying the GTAP-route model, we use a standard GTAP closure, where the factor price is the numeraire. Investment funds are allocated across regions to equate the change in the expected rates of return.

For the policy case, we apply the change in the transport price of Suez Canal route for all regional pairs and commodity groups. Following the discussion in Notteboom, Haralambides, and Cullinane (2024), we set three levels of price change 100, 200, and 300 percent, which are called low, middle, and high Suez shocks. To evaluate the importance of Arctic shipping, we simulate these three scenarios with and without Arctic, by either removing or adding a constraint on the supply of Arctic shipping for the global transport services.

4.2 Results and Discussion

Figure 3 shows the change in transport price of the four sea route for different scenarios. The increase in the transport price of Suez Canal route is directly input from outside of the model. In the case of constrained Arctic supply, the price of this route increase in accordance with the input shock of the Suez Canal route. The prices of Panama and other route also increase less than the increase oin the price of Suez Canal route increase. This is due to the allocation of resources from Suez canal route to other routes. Furthermore, if we allow for the Arctic supply to adjust, supply prices all routes (except for the exogenous Suez Canal route price) increase less. It is worth noting here that that other modes of transport (air and land) also experience a decrease in their prices. This suggests a more resoures allocation toward these routes and modes under these scenarios.

The changes in these routes price contribute to the change in transportation price index (figure 4) for different regions. As a reminder, this price index is the weighted average price of all modes and routes of transportation. They differ due to the share of each mode and route for each commodity-origin-destination triplet as well as the price of each mode and route. North Europe, Mediterannean, South and Southeast Asia experience a higher increase in transport price compared to other regions due to their larger share

Figure 3: Estimated Change of Transport Supply Price

of cargo being transported through Suez Canal route. Larger reduction of all routes other than Suez Canal route contributes to a lesser increase in transport price when Arctic supply is free to adjust.

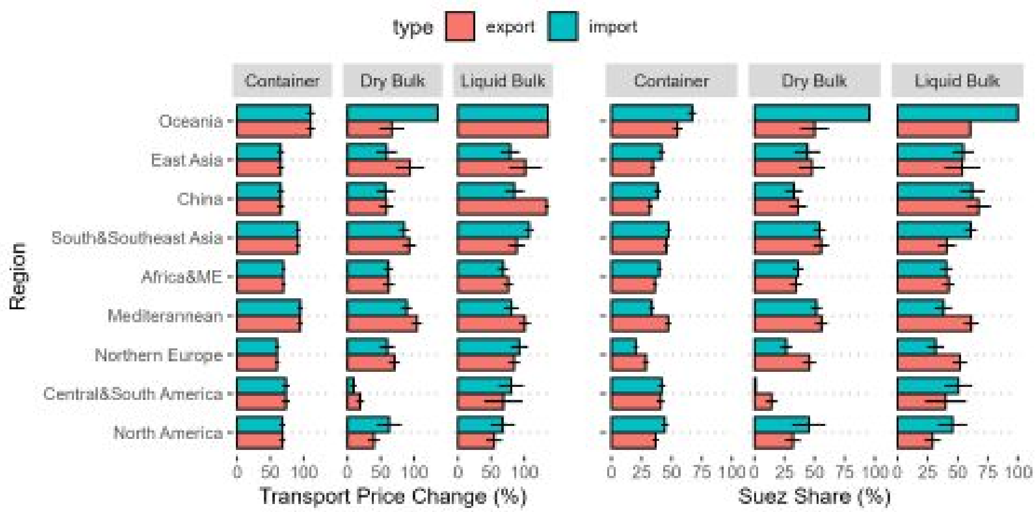

Figure 4: Estimated Change of Transport Price Index (High Shock + Arctic)

The changes in transport price results in the changes in transport margin. Figure 5 shows the change in transport margin for both export and import sides for the high Suez Shock with and without Arctic route, in comparision to the baseline (no Suez shock and no Arctic). The upper panel shows that all regions experience the decrease in transport margin through the Suez canal route. East Asia, China, North Europe, and North America experiences in the increase of other modes, including air and land transportation. China also increase in other searoute and Panama route. The difference between the case of with and without Arctic is only clearly visible for margin through Arctic. All regions experience an increase in this route's margin, although with much smaller magnitudes than other routes and modes.

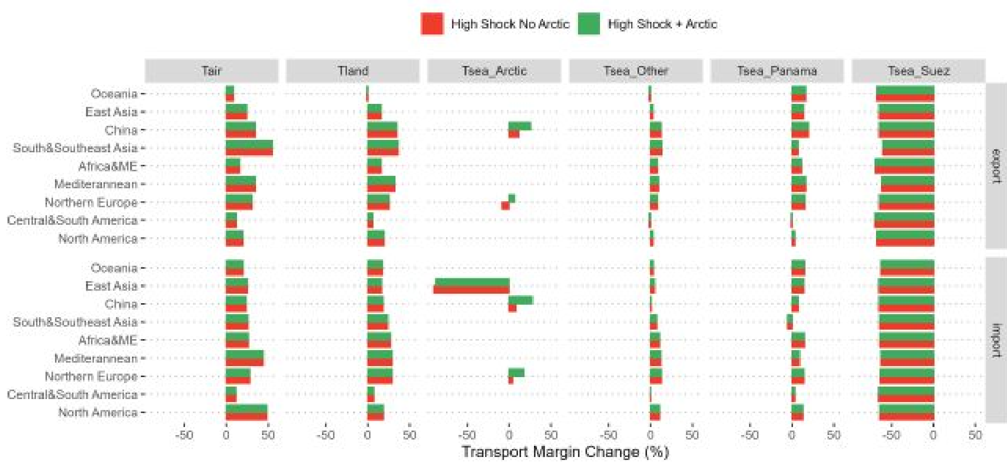

Figure 5: Estimated Change of Transport Margin

The lower panel shows the change demand from import. All regions show a decrease in margin through Suez. All regions show increases in air, land transport and other routes' margin except for East Asia. As in the case of export, margins from imports for Arctic increase more when Arctic supply is not under constraint.

From both export and impot sides, regions that have high share of trade through Suez have a highest divergence from Suez to other modes and routes.

While Europe (including North Europe and Mediterannean) mostly diverged to land and air, China and North America diverge to land, air and Panama more proportionally. The changes in transport demand is the results of the changes in transport prices. As Suez Canal route become more expensive, transport demand is diverged toward land, air, and other sea routes. However, the magnitude of divergence depends on the geography of each region. Europe switch to land the most as they can use rail, pipeline to connect with other regions. North America swicth to Panama as they can easily access East Asia and China through this searoute (figures 6).

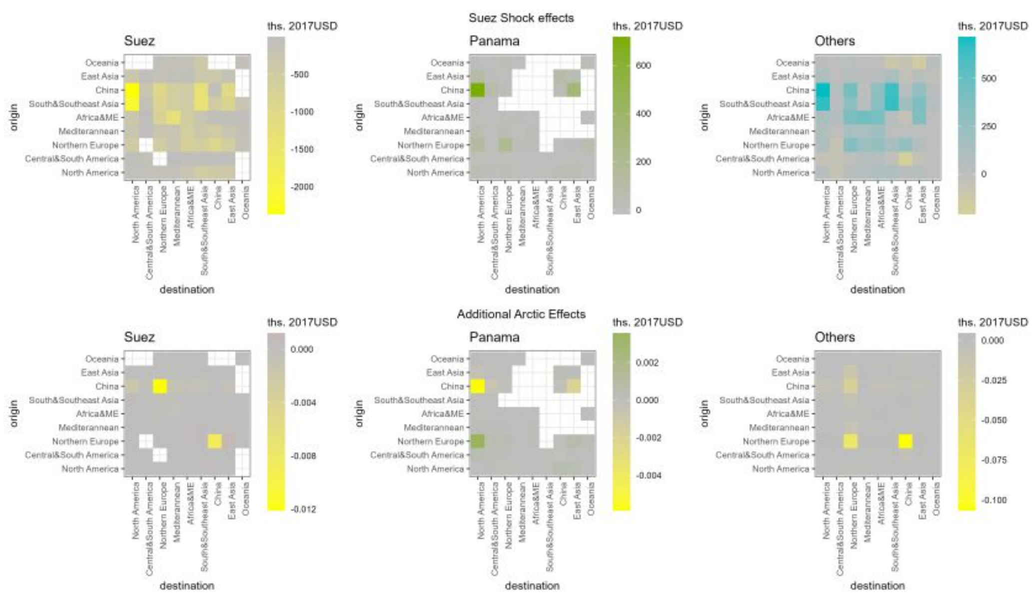

Figure 6: Estimated Change of Transport Margin (High Shock)

4.2.1 Trade and Welfare

The change in transport demand reflects the change in export and import of each region. Figure 7 shows the change of bileteral trade for high Suez Shock effects and Arctic effects. The former is the gap between the scenario of High Suez Shock without Arctic and the case baseline case without shock and Arctic (Suez Shock Effect without Arctic). The latter is the gap between the scenario of High Suez Shock with Arctic and the case of same high Suez Shock but without Arctic (With vs without Arctic). The highest decrease in trade flows are mostly from Asia to Europe. There adjustment of route from Suez to other routes and modes between these two countries is not enough to offset the negative shocks from the increase in the price of Suez canal route. There are some trade divergence effects toward partners with better routes. China increases export toward Oceania and more regional trade (within American or European regions) are observed.

As for the additional effects from allowing Arctic supply to adjust, there are increases in export of North Europe and China but decrease in import of North Europe. The increase in export is the results of some divergence from Suez Canal route to other routes as their prices become cheaper under adjustable Arctic supply. The decrease in import for Europe is because the large decrease through Suez canal dominate the smaller increase in other modes and routes.

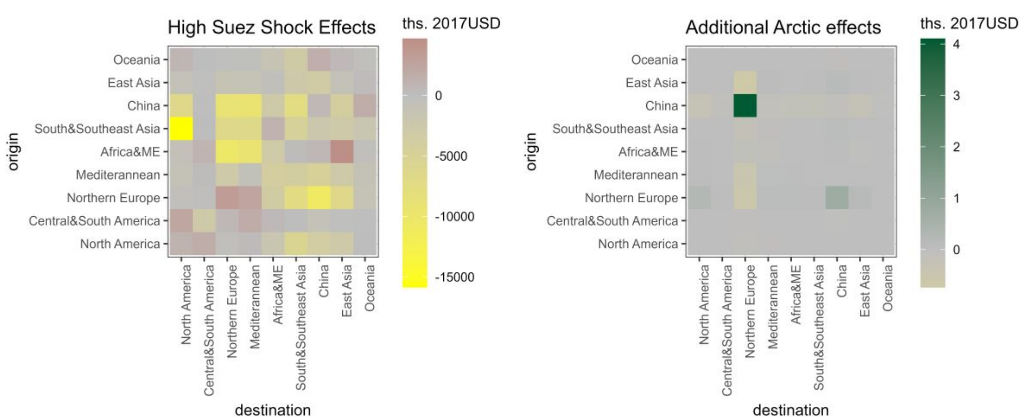

Figure 7: Estimated Change of Bilateral Trade

Most regions do not show a large change in welfare comparing to baseline (see figure 8). Higher increase in Suez canal route price results in more decrease in welfare. Additional Arctic effects are not observed in this case due to its small contribution to the dampening of transport price hike.

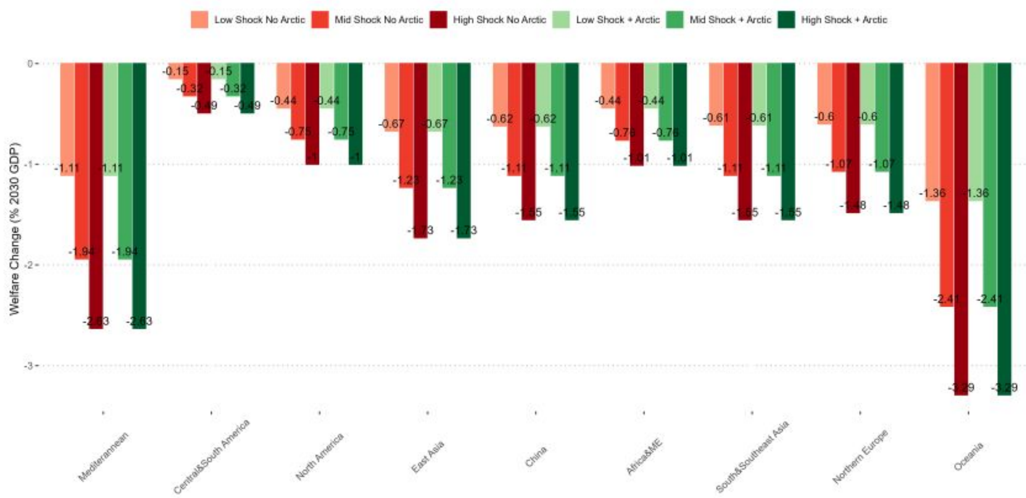

Figure 8: Estimated Change of Welfare Change

5 Conclusion

In this paper, we modified the GTAP standard model to incorporate a selection mechanism for sea transportation routes. Route cost shares and substitution parameters were estimated based on voyage data from various maritime sectors. Using these cost shares, along with sea transport service data from GTAP Database version 11, we estimated supply and demand for each route. In terms of transport demand, Northern Europe, China, East Asia, and Southeast Asia region exhibits the highest demand, with substantial reliance on both the Suez and Other routes. On the supply side, NEU stands out with exceptionally high transport supply, followed by China, East Asia, and Southeast Asia.

To demonstrate the model's functionality, we presented a simulation of a local shock on the Suez Canal route, which increase the its by 100, 200, and

300 percent. We also compared these scenarios for the case with and without Arctic supply. The results show the adjustment from Suez canal route to other routes in terms of transport demand. The role of Arctic shipping is to allow more adjustment in price of not only itself but other routes and modes, although with very small magnitude. There is also trade divergence toward partners with better routes, showcasing the model's capability to capture the local and global effects of a local shock on a maritime route.

There are several areas where the paper could be improved. Revising the route elasticity parameter may address existing anomalies and enhance the model's projection accuracy. Additionally, gaining a deeper understanding of the maritime sector's supply structure could improve data quality and simulation outcomes.

References

Aguiar, A., M. Chepeliev, E. Corong, and D. v. d. Mensbrugghe (2022). "The Global Trade Analysis Project (GTAP) Data Base: Version 11". en. In: *Journal of Global Economic Analysis* 7.2. Number: 2.

Anderson, J. E. and E. Van Wincoop (2004). "Trade Costs". In: *Journal of Economic Literature* 42.3, pp. 691–751.

Avetisyan, M. and T. Hertel (Dec. 2021). "Impacts of trade facilitation on modal choice and international trade flows". en. In: *Economics of Transportation* 28, p. 100236.

Bekkers, E., J. F. Francois, and H. Rojas-Romagosa (2018). "Melting Ice Caps and the Economic Impact of Opening the Northern Sea Route". en. In: *The Economic Journal* 128.610, pp. 1095–1127.

Borchert, I. and Y. V. Yotov (2017). "Distance, globalization, and international trade". In: *Economics Letters* 153, pp. 32–38.

Brancaccio, G., M. Kalouptsidi, and T. Papageorgiou (2020). "Geography, Transportation, and Endogenous Trade Costs". In: *Econometrica* 88.2, pp. 657–691.

Faury, O. and P. Cariou (Dec. 2016). "The Northern Sea Route competitiveness for oil tankers". en. In: *Transportation Research Part A: Policy and Practice* 94, pp. 461–469.

Faury, O., A. Cheaitou, and P. Givry (Apr. 2020). "Best maritime transportation option for the Arctic crude oil: A profit decision model". en. In: *Transportation Research Part E: Logistics and Transportation Review* 136, p. 101865.

Feyrer, J. (2019). "Trade and Income Exploiting Time Series in Geography". In: *American Economic Journal: Applied Economics* 11.4, pp. 1–35.

Furuichi, M. and N. Otsuka (2013). *Effect of the Arctic sea routes (NSR and NWP) navigability on port industry*. Tech. rep. Tokyo: International Association of Port and Harbour (IAPH).

Heiland, I., A. Moxnes, K. Helene Ulltveit-Moe, and Y. Zi (2019). *Trade From Space: Shipping Networks and The Global Implications of Local Shocks*. Tech. rep. 14193. CEPR.

Hertel, T. W. (1997). *Global Trade Analysis: Modeling and Applications*. en. Cambridge University Press.

Hummels, D., V. Lugovskyy, and A. Skiba (2007). *The Trade Reducing Effects of Market Power in International Shipping*. Working Paper 12914. National Bureau of Economic Research.

Kavirathna, C. A. and R. Shibasaki (2021). "Economic feasibility of Arctic shipping from multiple perspectives: a systematic review". en. In: *Okhotsk Sea and Polar Oceans Research* 5.

Lasserre, F. (Aug. 2014). "Case studies of shipping along Arctic routes. Analysis and profitability perspectives for the container sector". en. In: *Transportation Research Part A: Policy and Practice* 66, pp. 144–161.

Liu, M. and J. Kronbak (May 2010). "The potential economic viability of using the Northern Sea Route (NSR) as an alternative route between Asia and Europe". en. In: *Journal of Transport Geography*. Tourism and climate change 18.3, pp. 434–444.

Notteboom, T., H. Haralambides, and K. Cullinane (Mar. 2024). "The Red Sea Crisis: ramifications for vessel operations, shipping networks, and maritime supply chains". In: *Maritime Economics & Logistics* 26.1, pp. 1–20.

Rajagopal, S. and P. Zhang (Mar. 2021). "How widespread is the usage of the Northern Sea Route as a commercially viable shipping route? A statistical analysis of ship transits from 2011 to 2018 based on empirical data". en. In: *Marine Policy* 125, p. 104300.

Robson, E. N. and V. V. Dixit (Sept. 2017). "A General Equilibrium Framework for Integrated Assessment of Transport and Economic Impacts". en. In: *Networks and Spatial Economics* 17.3, pp. 989–1013.

Schøyen, H. and S. Bråthen (July 2011). "The Northern Sea Route versus the Suez Canal: cases from bulk shipping". en. In: *Journal of Transport Geography* 19.4, pp. 977–983.

Shibasaki, R., T. Azuma, and T. Yoshida (2016). "Route Choice of Containership on a Global Scale and Model Development: Focusing on the Suez Canal". In: *International Journal of Transport Economics / Rivista internazionale di economia dei trasporti* 43.3, pp. 265–290.

Shibasaki, R., K. Kanamoto, and T. Suzuki (Feb. 2020). "Estimating global pattern of LNG supply chain: a port-based approach by vessel movement database". In: *Maritime Policy & Management* 47.2, pp. 143–171.

Shibasaki, R., T. Usami, M. Furuichi, H. Teranishi, and H. Kato (May 2018). "How do the new shipping routes affect Asian liquefied natural gas markets and economy? Case of the Northern Sea Route and Panama Canal expansion". In: *Maritime Policy & Management* 45.4, pp. 543–566.

Sibul, G. and J. G. Jin (May 2021). "Evaluating the feasibility of combined use of the Northern Sea Route and the Suez Canal Route considering ice parameters". en. In: *Transportation Research Part A: Policy and Practice* 147, pp. 350–369.

Stopford, M. (2009). *Maritime economics*. en. 3rd ed. OCLC: ocn212432568. London ; New York: Routledge.

Theocharis, D., V. S. Rodrigues, S. Pettit, and J. Haider (Sept. 2021). "Feasibility of the Northern Sea Route for seasonal transit navigation: The role of ship speed on ice and alternative fuel types for the oil product tanker market". en. In: *Transportation Research Part A: Policy and Practice* 151, pp. 259–283.

Verny, J. and C. Grigentin (Nov. 2009). "Container shipping on the Northern Sea Route". en. In: *International Journal of Production Economics*. Transport Logistics and Physical Distribution 122.1, pp. 107–117.

Xu, H., D. Yang, and J. Weng (May 2018). "Economic feasibility of an NSR/SCR-combined container service on the Asia-Europe lane: a new approach dynamically considering sea ice extent". en. In: *Maritime Policy & Management* 45.4, pp. 514–529.

Xu, H., Z. Yin, D. Jia, F. Jin, and H. Ouyang (Sept. 2011). "The potential seasonal alternative of Asia–Europe container service via Northern sea route under the Arctic sea ice retreat". In: *Maritime Policy & Management* 38.5, pp. 541–560.

Zhao, H., H. Hu, and Y. Lin (May 2016). "Study on China-EU container shipping network in the context of Northern Sea Route". en. In: *Journal of Transport Geography* 53, pp. 50–60.

A Model Details

A.1 Demand

There is J countries. In each $j \in J$, a representative agent has a Cobb-Douglas utility function over consuming three goods: private goods q_j^{pr}, public goods q_j^{go} and savings q_j^{sa}

$$u_j = \sum_{c \in \{pr,go,sa\}} (q_j^c)^{\kappa_j^c} \tag{A.1}$$

where $\sum_{c \in \{pr,go,sa\}} \kappa_j^c = 1 \quad \forall j$.

While savings and government has homothetic sub-utility function, private goods are non-homothetic. Assume $e_j^c(q_j^c)$ is the expenditure function for bundle goods c, the budget constraint is

$$\sum_{c \in \{pr,go,sa\}} e_j^c = x_j \tag{A.2}$$

Maximize utility u_j w.r.t to the above budget constraint, the expenditure function for each goods bundle is

$$x_j^c = \kappa^c \left(\frac{\Psi_j^c}{\Psi_j} \right) x_j \tag{A.3}$$

where Ψ_j^c is the elasticity of quantity q_j^c w.r.t expenditure x_j^c and Ψ_j is the elasticity of utility u_j w.r.t total expenditure x_j. For public goods and savings, $\Psi_j^{go} = \Psi_j^{sa} = 1$.

For private goods, the preference is described by the non-homothetic constant distance elasticity (CDE)

$$\sum_{s \in S} \alpha_{js} \left(q_j^{pr} \right)^{\gamma_{js}\eta_{js}} \left(\frac{p_{js}^{pr}}{x_j^{pr}} \right)^{\gamma_{js}} = 1 \tag{A.4}$$

Differentiate this utility w.r.t quantity q_j^{pr} and expenditure x_j^{pr} gives the elasticity of quantity q_j^{pr} w.r.t expenditure x_j^{pr}

$$\Psi_j^{pr} = \frac{1}{\sum_{s \in S} s_{js}^{pr} \eta_{js}} \tag{A.5}$$

The aggregate elasticity is

$$\Psi_j = \sum_c \Psi^c \kappa^c = \Psi_j^{pr} \kappa^{pr} + \kappa^{go} + \kappa^{sa} \tag{A.6}$$

Using Shepherd's lemma, the demand for private goods can be derived as

$$q_{js}^{pr} = \frac{\alpha_{js} (q_j^{pr})^{\gamma_{js} \eta_{js}} \left(\frac{p_{js}^{pr}}{x_j^{pr}} \right)^{\gamma_{js} - 1} \gamma_{js}}{\sum_{u \in S} \alpha_{ju} (q_j^{pr})^{\gamma_{ju} \eta_{ju}} \left(\frac{p_{js}^{pr}}{x_j^{pr}} \right)^{\gamma_{ju}} \gamma_{ju}} \tag{A.7}$$

For public goods and savings, the demand function is derived from the Cobb-Douglas utility

$$q_{js}^c = \beta_{js} \frac{p_j^c q_j^c}{p_{js}^c} \tag{A.8}$$

where $q_j = x_j^c / p_j^c \quad c = go, sa$.

Price of public goods is $p_j^{go} = \prod_{s \in S} (p_{js}^{go})^{\beta_{js}}$. Price of saving is $p^{sa} = \sum_{k \in J} (p_k^{in})^{\xi_k}$. The total private quantity q_j^{pr} and expenditure q_j^{pr} are implicitly defined through the indirect expenditure function in equation (A.4).

A.2 Production

Perfectly competitive firms produce input bundle q_{is}^{prod} with a Leontief production over value-added (factor input) bundle q_{is}^{va} and intermediate input bundles sourced from the different sectors u, q_{ius}^{int}:

$$q_{is}^{prod} = \phi_s min\{\omega_{is}^{va}, \omega_{i1s}^{int} q_{i1s}^{int}, \cdots, \omega_{iSs}^{int} q_{iSs}^{int}\}, \tag{A.9}$$

where ϕ_{is} is the total factor productivity of gross output. The demand for value added and intermediates is defined as:

$$q_{is}^{va} = \frac{\omega_{is}^{va} q_{is}^{prod}}{\phi_{is}}, \tag{A.10}$$

$$q_{ius}^{int} = \frac{\omega_{ius}^{int} q_{is}^{prod}}{\phi_{is}} \tag{A.11}$$

The total number of intermediate inputs bought by firms from sector u, q_{iu}^f, is:

$$q_{iu}^f = \sum_{s=1}^{S} q_{ius}^{int} \tag{A.12}$$

The price of input bundles c_{is} is a function of the price of intermediates bought by firms from the different sectos u, p_{iu}^f, and the price of value-added c_{is}^{va}:

$$c_{is} = \frac{c_{is}^{va} + \sum_{i=1}^{S} \omega_{ius}^{int} p_{iu}^f}{\phi_{is}} \tag{A.13}$$

There are E endowment factors used to produce value-added bundles, which follow Constant Elasticity of Substition (CES). This results in the following price of value-added c_{is}^{va} and demand for endowments e, q_{ise}^{end}:

$$c_{is}^{va} = \left[\sum_{e=1}^{E} (\iota_{ise})^{\rho_s} (t_{ise}^{end} \omega_{ise})^{1-\rho_s} \right]^{\frac{1}{1-\rho_s}}, \tag{A.14}$$

$$q_{ise}^{end} = \left(\iota_{ise} \frac{c_{is}^{va}}{t_{ise}^{end} \omega_{ise}} \right)^{\rho_s} q_{is}^{va}, \tag{A.15}$$

where ω_{ise} is the price of and t_{ise}^{end} is the tax on production factor e in sector s, and ρ_s is the substitution elasticity between factors of production in sector

s.

Capital and labor are perfectly mobile across sectors. The factor price w_{id} is identical across sector and the factor market equilibrium requires that the sum of factor demands is equal to factor supply:

$$\omega_{ise} = w_{ie}; \quad e = capital, labor, \tag{A.16}$$

$$q_{ie}^{end} = \sum_{s=1}^{S} q_{ise}^{end}; \quad e = capital, labor. \tag{A.17}$$

Land and natural resource (nr) are not perfectly mobile across sectors. Their allocation is modelled by a transformation function:

$$q_{id}^{end} = \left[\sum_{s=1}^{S} \nu_{isd} (q_{isd}^{end})^{\frac{\mu_d+1}{\mu_d}} \right]^{\frac{\mu_d}{\mu_d+1}}; \quad d = land, nr, \tag{A.18}$$

The supply of these factors and their price index are:

$$q_{isd}^{end} = \left(\frac{\omega_{isd}}{\nu_{isd} w_{id}} \right)^{\mu_d}; \quad d = land, nr, \tag{A.19}$$

$$w_{id} = \left(\sum_{i=1}^{N} (\nu_{isd})^{-\mu_d} w_{id}^{\mu_d+1} \right)^{\frac{1}{\mu_d+1}}; \quad d = land, nr. \tag{A.20}$$

The total supply of capital, labor, land, and natural resources is exogenous. The relationship between investment and capital is described in Section A.3.

A.3 Saving and Investment

A "global bank" distribute saving to all regions until the rates of return on investment for all regions are equalized. A regional households buy the saving from the global bank with the price of savings as a weighted avearge of the price of investment goods acquired by the global bank.

The rate of return on capital r is equal to the rental rate on captial w_{iK}

divided by the price of capital p_i^K minus the rate of depreciation δ_i:

$$r = \frac{w_{iK}}{p_i^K} - \delta_i \tag{A.21}$$

where r is equalised globally. In steady state, investment q_i^{in} is the function of the quantity of captial q_{iK}^{end}:

$$q_i^{in} = \delta_i q_{iK}^{end} \tag{A.22}$$

Investment goods are treated like intermediates and are a Leontief function of goods used for investment from different industies, q_{is}^{in}:

$$q_i^{in} = \min\{\omega_{i1s}^{in} q_{i1}^{in}, \cdots, \omega_{i1S}^{in} q_{iS}^{in}\} \tag{A.23}$$

The demand for investment goods from each sector and the corresponding price are:

$$q_{is}^{in} = \omega_{is}^{in} q_i^{in} \tag{A.24}$$

$$p_i^{in} = \sum_{s=1}^{S} \omega_{is}^{in} p_{is}^{in} \tag{A.25}$$

The price of savings is a weighted average of the price of investment goods

$$p^{sa} = \sum_{k=1}^{J} (p_k^{in})^{sh_k} \tag{A.26}$$

where x_k is the share of net investment in country k:

$$sh_k = \frac{p_k^{in}(q_k^{in} - \delta_k q_{iK}^{end})}{p^{in} \sum_{j=1}^{J}(q_j^{in} - \delta_j q_{jK}^{end})} \tag{A.27}$$

In equilibrium, the total amount of savings is equal to the total quantity of net investments:

$$\sum_{i=1}^{J} pop_i q_i^{sa} = \sum_{i=1}^{J} (q_i^{in} - \delta_i q_{iK}^{end}) \tag{A.28}$$

A.4 Goods Market Equilibrium

The goods market reach equilibrium when the value of gross output equal the value of import demand from different partners, including their domestic demand and the transport service for the case when $m = land, air, sea(g)$.

$$c_{is} t_{is}^{prod} q_{is}^{prod} = \sum_{ag} \frac{p_{is}^{ag} q_{is}^{dom,ag}}{t_{is}^{dom,ag}} + \sum_{j \neq i} \left[\left(\iota_{ij}^{imp} \frac{\Phi_{js}^{IMP}}{p_{ijs}^{imp}} \right)^{\rho_s^{imp}} \sum_{ag} \frac{p_{js}^{ag} q_{js}^{ag}}{t_{ijs}^{imp} t_{ijs}^{exp} t_{js}^{imp,ag}} - \frac{p_{ijs}}{t_{ijs}^{exp}} ts_{ijs} \right] + c_{is} ts_i^s. \tag{A.29}$$

Gross factor income is equal to aggregate expenditures on savings plus expenditures on consumption goods and payments of direct income tax and tax revenue from trading emission/carbon tax:

$$y_i = (x_i^s + x_i^c) + tr_i^{income} \tag{A.30}$$

Define the budget deficit as $bd_i = x_i^g - (tr_i^{indirect} + tr_i^{income})$ and the budget deficit ratio as $bdr_i = bd_i/(y_i + tr_i^{indirect})$, we have:

$$x_i = \sum_{u=s,c,g} x_i^u = y_i + tr_i^{indirect} + db_i = (y_i + tr_i^{indirect})(1 + dbr_i). \tag{A.31}$$

dbr_i is assumed to be exogenous. Income is also equal to the sum of gross factor income minus capital depreciation:

$$y_i = \sum_{i}^{E} t_{ie}^{income} \omega_{ie} q_{ie}^{end} - \delta \omega_{iK}^{end} q_{iK}^{end} \tag{A.32}$$

A.5 Tax revenues

Revenues of tax is calculated by muptiplying tax rate (tax power minus one) with the value of the corresponding tax (endowment, direct income tax, production, intermediate purchase tax by agent and source, import tariff and export tax):

$$tr^{end}_{ise} = (t^{end}_{ise} - 1)\omega_{ise} q^{end}_{ise}, \tag{A.33}$$

$$tr^{inc}_{ise} = (t^{inc}_{ie} - 1) w_{ie} q^{end}_{ie}, \tag{A.34}$$

$$tr^{prod}_{ise} = (t^{prod}_{is} - 1) c_{is} q^{prod}_{is}, \tag{A.35}$$

$$tr^{so,ag}_{js} = (t^{so,ag}_{js} - 1) q^{so,ag}_{js}, \tag{A.36}$$

$$tr^{imp}_{ijs} = (t^{imp}_{ijs} - 1) p^{cif} q_{ijs}, \tag{A.37}$$

$$tr^{exp}_{ijs} = (t^{exp}_{ijs} - 1) t^{prod}_{is} c_{is} q_{ijs}. \tag{A.38}$$

B Estimation Details

B.1 Route Elasticity

Details of estimation results are shown in Table B.1. As in explained in the main text, all commodity in dry bulk and liquid bulk shows the range of coefficient within the range of assumption, that is significanly negative and the magnitude is less than unity. However, the coefficient in the container sector show a positive value instead.

B.2 Trade Matrix

Figure B.1 show the estimated trade in service for different routes. It is highly concentrated in a small number of region pairs and is strongly shaped by the geography of major chokepoints. The Suez Canal handles the largest volume of service trade, exceeding 6,000 million USD for some origin–destination pairs, particularly linking Europe, the Middle East, and Asia. This reflects the central role of Suez in facilitating trade between Atlantic and Indo-Pacific markets. The Panama Canal shows smaller but still significant flows (up to about 2,000 million USD), mainly connecting the Americas with Asia and supporting inter-coastal trade within the Western Hemisphere. In contrast, the Arctic route carries negligible service trade, indicating that despite its potential to shorten distances between Europe and Asia, it remains commercially marginal due to seasonal constraints, infrastructure limitations, and risk factors. Trade routed through Other passages is more dispersed across many region pairs but generally at lower magnitudes than Suez, suggesting a mix of alternative routes that complement the main canal corridors.

B.3 Transport Cost Matrix

Using the same voyage data, we can estimate the total transport cost for each route for three types of ship. The results show some interesting insights (see Figure B.2, B.3, and B.4. In general, most cargo flows are in neighboring trade partners, which do not cross any choke points. Since total transport

Table B.1: Estimation Results

Dependent Variable:	Quantity				
Commodity	Container	Agribulk	Coal	Ore	Steel
Model:	(1)	(2)	(3)	(4)	(5)
Variables					
Unit Cost	0.4616	-1.803**	-1.548**	-1.234***	-0.9956
	(0.4173)	(0.3523)	(0.2587)	(0.0915)	(0.5841)
Fit statistics					
Observations	1,752	1,728	398	360	479
R^2	0.61279	0.67010	0.82425	0.88601	0.64859
Within R^2	0.04414	0.26815	0.20379	0.20450	0.09868
Commodity	Chemicals	Gas	Oil	Products	Other
Model:	(6)	(7)	(8)	(9)	(10)
Variables					
Unit Cost	-0.0079	-1.262*	-1.488**	-1.746**	-1.263***
	(1.537)	(0.3344)	(0.2871)	(0.3605)	(0.0260)
Fit statistics					
Observations	79	400	447	1,410	610
R^2	0.79760	0.74302	0.76813	0.62045	0.77605
Within R^2	9.84×10^{-6}	0.22484	0.20897	0.25598	0.30365
Fixed-effects					
Origin-Time	Yes	Yes	Yes	Yes	Yes
Destination-Time	Yes	Yes	Yes	Yes	Yes
Route	Yes	Yes	Yes	Yes	Yes

Clustered (Route) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

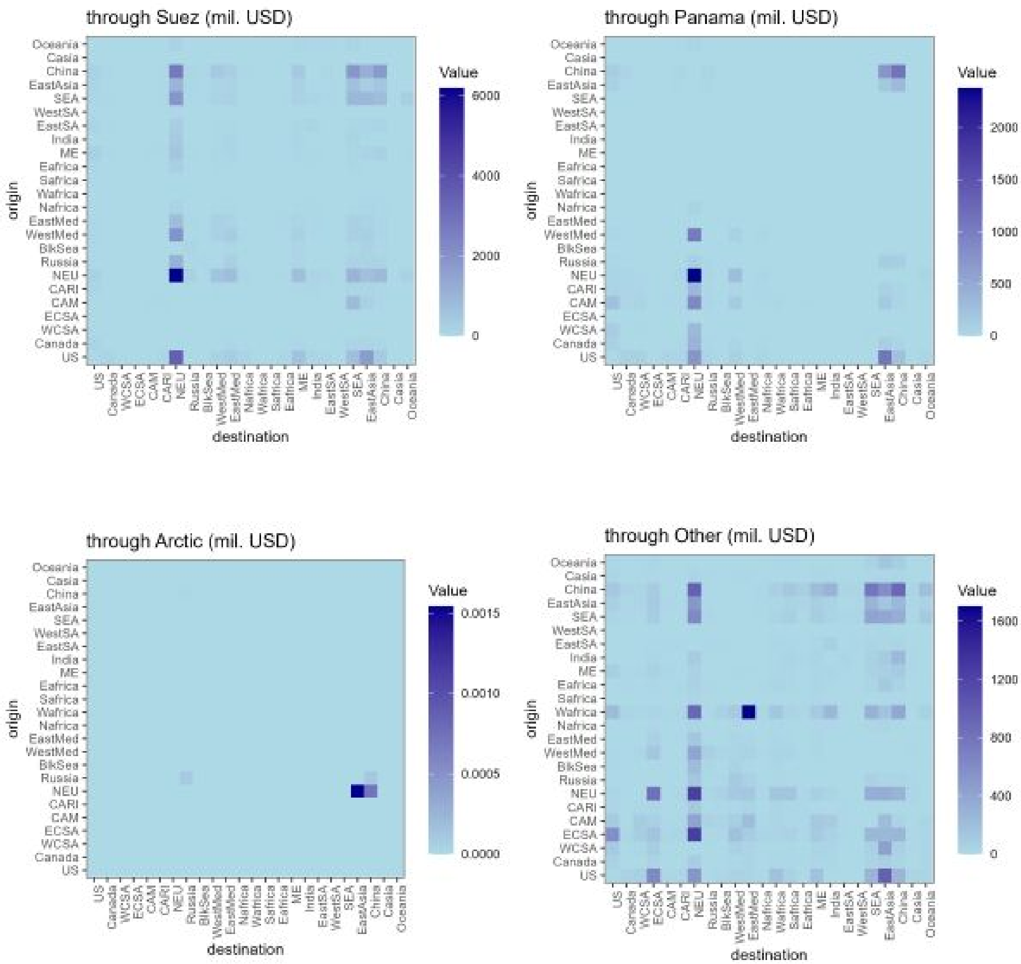

Figure B.1: Estimated Trade Matrix

cost reflect the magnitude of total trade flows, the darker color of the grid suggest that there are more trade flows in the corresponding origin destination pair. Trade flows through the Suez Canal are mostly between Asia and Europe for containers, Oceania and Europe for dry bulk, and the Middle East and Europe for liquid bulk. Trade flows through the Panama Canal are mostly between North America and East Asia, and between North America (on the West Coast) and Europe for container, and between the US and East Asia for liquid bulk.

The Arctic route accounts for only negligible shares, indicating that current infrastructure and seasonal constraints limit its economic relevance for bulk shipping. Meanwhile, the "other routes" category dominates overall transport cost shares, capturing large trade volumes that bypass major canals, particularly intra-Asia Pacific bulk flows.

B.4 Margin Commodities Splitting Procedure

This section describes the modification of SplitCOM procedure to apply in the case of margin commodity, abbreviated as SplitMar. This procedure will modify the TRADE and NATIONAL arrays to replace the old margin with new margins. Other arrays such as EVOA, SAVE, VKB will not be altered.

The TRADE arrays include bilateral trade flow for each commodity at producer basic price, export tax, import tax, and transport. The NATIONAL arrays shows, for each region, all expendidures by intermediate producers and final demanders (household, investment, and government). The expenditures are for inputs of commodities, primary factors, and output tax. They can be sources from domestic markets or imports and are separated into value at a basic price and additional tax components. For each identity, flows are measured at basic prices, which include production tax (for domestic goods) and tariff tax (for imported goods).

The procedure must ensure two balance conditions. The first condition is that industry cost equals sales of locally made goods. Industry cost is the

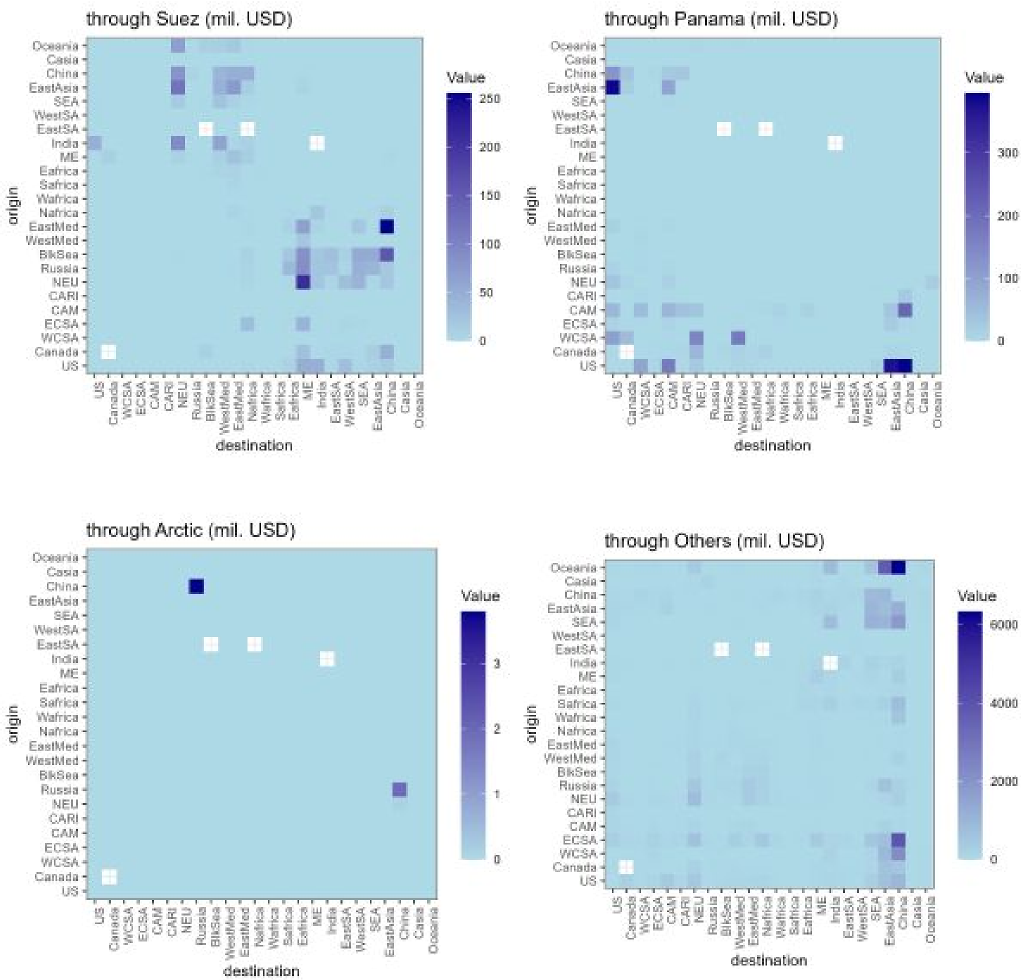

Figure B.2: Estimated Dry Bulk Transport Cost Matrix

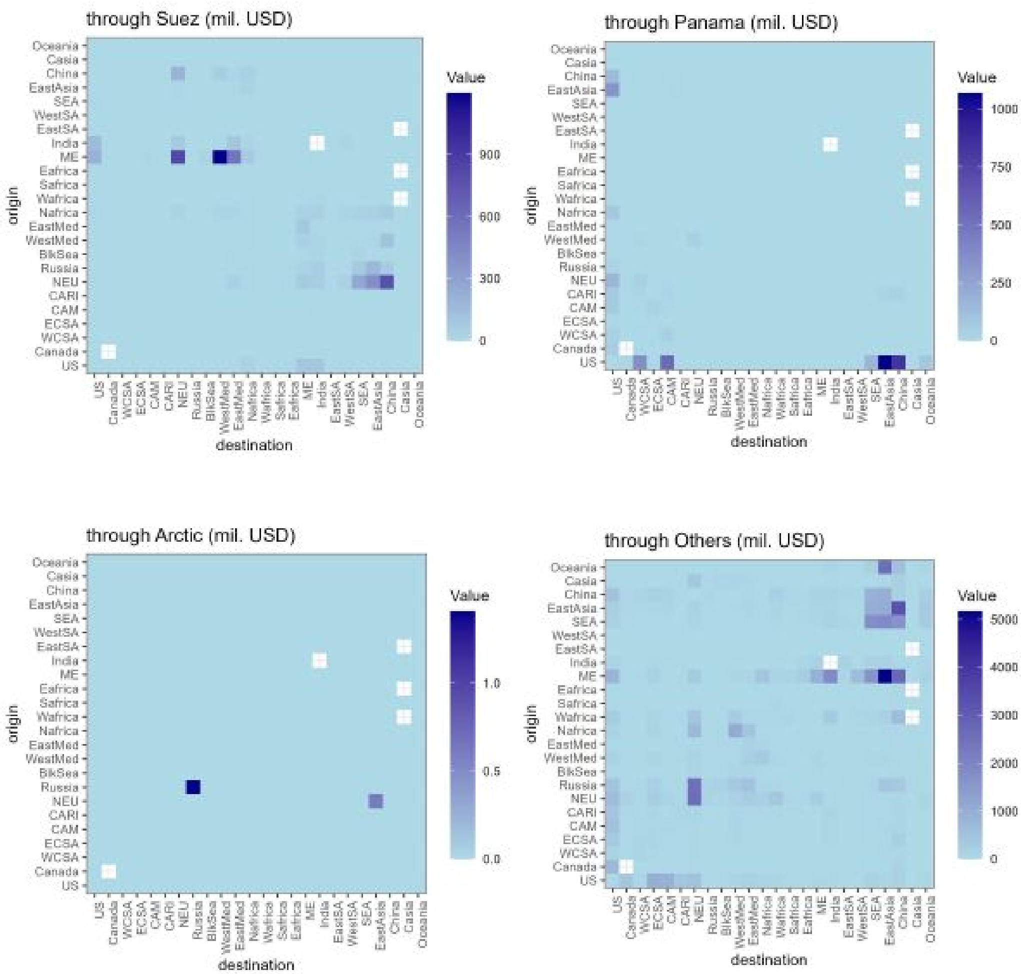

Figure B.3: Estimated Liquid Bulk Transport Cost Matrix

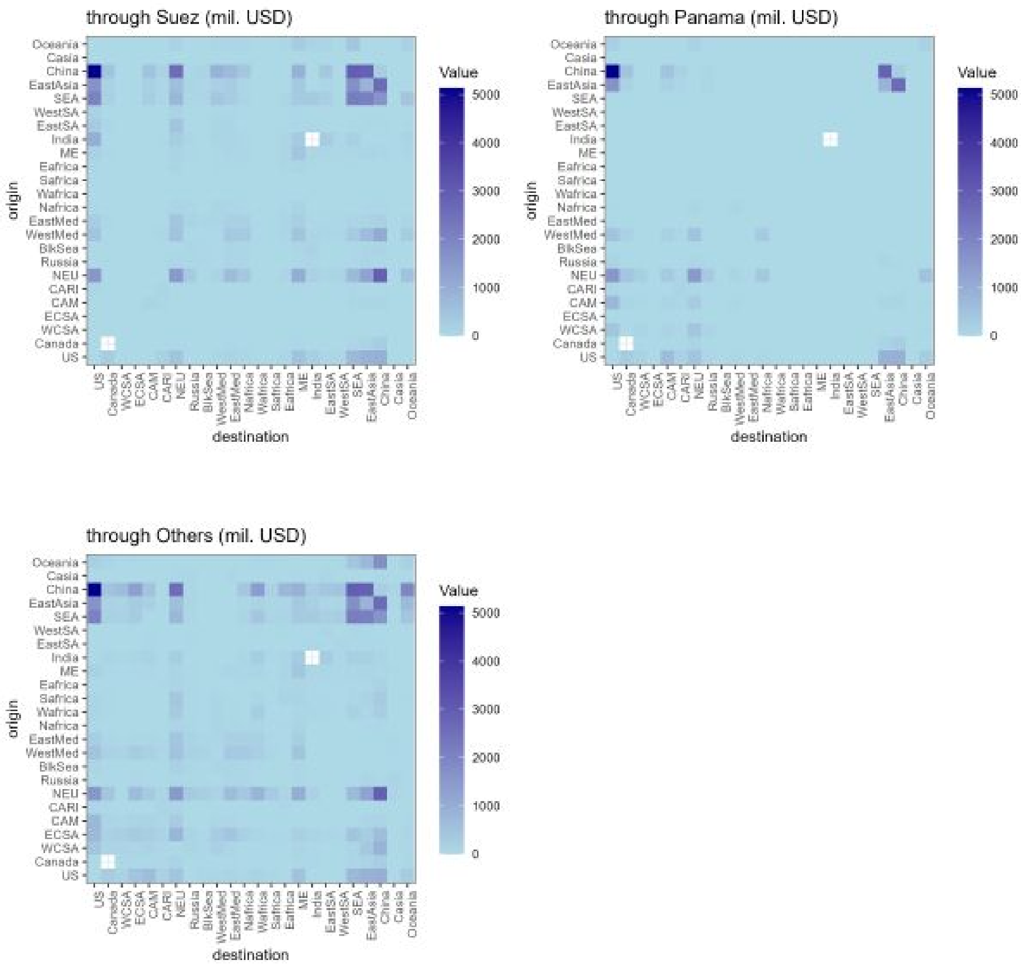

Figure B.4: Estimated Container Transport Cost Matrix sum of expenditures in the NATIONAL arrays over all inputs, sources and types of value (basic prices and taxes). The sales of locally made goods are the sum of domestic sales and export sales. Domestic sales are the sum of the NATIONAL arrays over all intermediate producers and final demand for domestic goods at basic prices. Export sales are the sum of TRADE arrays over all destinations at basic prices. For transportation services (margin commodities), sales are added by each region supply for global transport services. The second condition is that supply equals demand for imports. Import supply is the sum of TRADE arrays over all origins. Import demand is the sum of NATIONAL arrays for imports over all intermediate producers and final demanders at basic prices.

There is also a consistency condition that global transport margin supply must equal total demand. Because the data are constructed by splitting sea transport across routes using the same shares on both the supply and demand sides, this condition is satisfied by construction. The splitting procedure only adjusts the national and trade matrix while keeping total sea transport unchanged; therefore, this condition is preserved.

The shares used in the splitting procedure are assigned as follows. First, global supply shares are used to split regional VST, assuming that all regions share the same supply composition. Second, the trade matrix consists of two components: the margin component and the trade component. The margin component is allocated across routes using the route-specific cost matrix for each region pair, while the trade component is allocated using the route-specific quantity matrix for each region pair. Third, the national matrix is split using the same global supply shares applied in the VST splitting step.