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Breaking Away from Icebreakers: The Effect of Melting Distances on Trade and Welfare

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Highlights

- Climate models predict the yearlong opening of shipping routes across the Arctic Ocean before 2050.
- Arctic routes will significantly reduce shipping distances between Northern Europe and Northeast Asia.
- These new routes will considerably increase trade between China, Korea, Japan and Northern Europe.

Abstract

This article assesses the effect of the opening of Arctic shipping routes on world trade patterns and welfare. We begin by computing shortest bilateral maritime distances with and without Arctic routes. Then, we predict trade flows by combining counterfactual distances with distance elasticities of trade estimated using historical episodes that also affected maritime distances. Our general equilibrium exercise extends beyond by using a structural gravity model that allows trade reallocation across country pairs. As a result, all country pairs are now affected by the opening of Arctic routes, including those for which bilateral distance remains unchanged. In our preferred estimation, world trade is predicted to increase by 0.32% and welfare by 0.02%. The positive effects concentrate in Europe and Northeast Asia, while minor losses affect countries in the Caribbean, West Africa, the Mediterranean and the Indian Ocean.

Keywords

Arctic Shipping, International Trade, Trade Costs, Distance Effect.

JEL

F14, F15.

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RESEARCH AND EXPERTISE
ON THE WORLD ECONOMY

Breaking Away from Icebreakers:
The Effect of Melting Distances on Trade and Welfare

Jules Hugot* and Camilo Umana Dajud†

1. Introduction

The melting of the Arctic ice cap due to global warming has fostered projects to open year-long shipping routes across the Arctic Ocean. Figure 1 shows the three major routes that are currently envisioned: the Northern Sea Route, the Northwest Passage and the Transpolar Route. The Northern Sea Route follows the coast of Russia. The Northwest Passage follows the coasts of Canada and Alaska. Finally, the Transpolar Route would pass through the middle of the Arctic Ocean. The Northwest Passage and the Northern Sea Route are already open during a fraction of the year, but they still require the usage of icebreakers,[1] which makes them extremely costly.[2] Most climate models predict that the Northwest Passage and the Northern Sea Route will be open yearlong to regular commercial ships by mid-century (Smith and Stephenson, 2013). On the other hand, the opening of the Transpolar Route remains uncertain, even if some climate models predict that it could be permanently open by the end of this century.

We estimate the effect of the distance reductions resulting from these new routes on trade flows and welfare.[3] We start by using a Dijkstra algorithm to compute the shortest maritime distance for each country pair, considering Arctic routes as fully open for navigation.[4] We then use the structural gravity model of trade (Head and Mayer, 2014) to compute counterfactual trade flows based on the computed maritime distance changes. In the partial equilibrium exercise, the multilateral resistance and income terms of the gravity equation are not affected by changes in

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[1]A commercial ship used the Northern Sea Route without the aid of icebreakers for the first time in August 2017 (New York Times, Aug. 25, 2017).

[2]Only 18 vessels used the Northern Sea Route in 2016 – including only 8 cargo ships – for a total of 214,513 tonnes of cargo, which is approximately the capacity of the current largest container ships. The statistics are provided by the CHNL Information Office, a joint initiative between Norway and Russia.

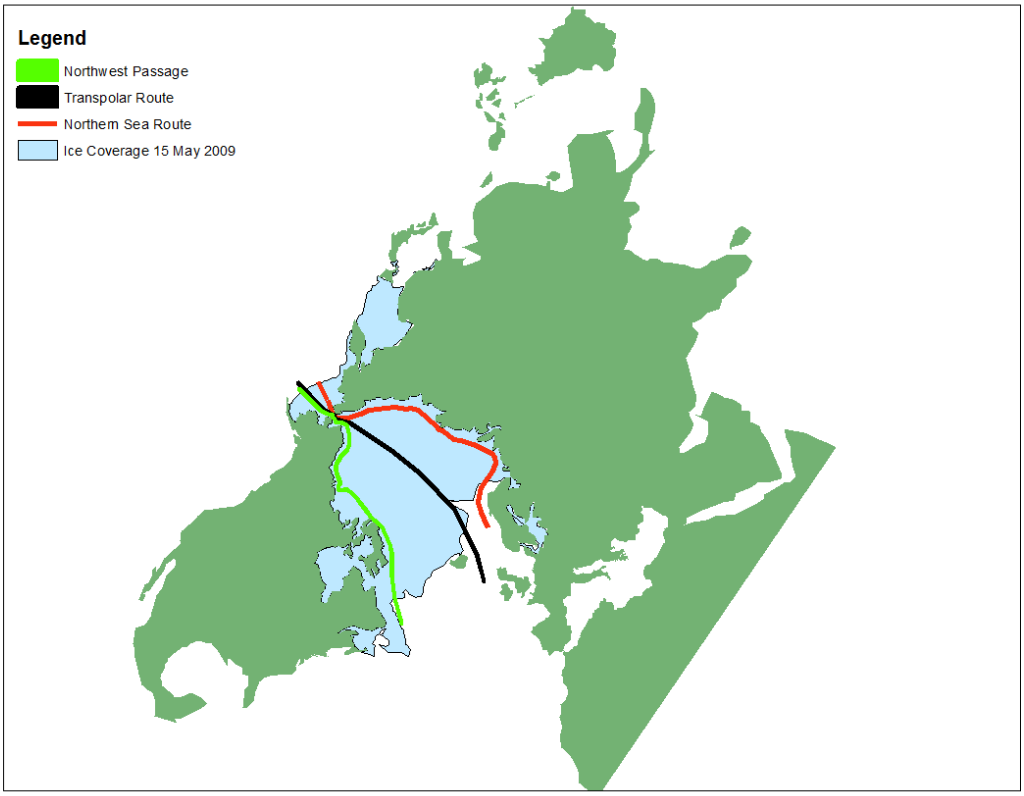
[3]We do not estimate the aggregate economic effect of the melting of the Arctic ice cap, nor of global warming in general. Our estimated positive welfare gains do not preclude the existence of other – potentially disastrous – economic and non-economic effects.

[4]The Suez and Panama Canals are considered fully navigable both currently and once Arctic routes will be open. In our baseline results, we assign the same cost to each section of the journey, including in the Arctic Ocean. The sensitivity of our results to this assumption is explored in figures 7 and 8.

bilateral trade costs.[5] In turn, the effect on trade flows is whether positive (if bilateral distance is reduced), or nil (if distance is not affected). In our general equilibrium exercise, we let multilateral resistance and income adjust to changes in bilateral trade costs. In turn, the Arctic routes also generate negative trade effects for some country pairs. In particular, this can be the case when trade flows are reallocated to shortest routes. Finally, we use the general equilibrium estimated trade flows to compute the welfare effect of the new routes for 99 countries.

Our paper takes advantage of a number of recent advances in the quantitative trade literature, including Anderson and van Wincoop (2003), Dekle et al. (2007, 2008), Arkolakis et al. (2012), Head and Mayer (2014). In particular, we use the results of these papers to compute general equilibrium counterfactual changes in bilateral trade, income and welfare.

Figure 1 – Projected Arctic shipping routes



Authors' own construction

This work is also related to other quantitative studies on the impact of Arctic shipping routes. Somanathan et al. (2009) analyze the impact of the Northwest Passage. Francois and Rojas-

[5]As explained in Head and Mayer (2014), multilateral resistance terms capture the exporting country's "*capabilities as a supplier to all destinations*" and the importing country's "*characteristics that promote imports from all sources*".

Romagosa (2014) and Bensassi et al. (2016) study the effect of the Northern Sea Route. Our paper differs from these studies in three aspects. First, previous studies focus on a given route while we estimate the impact of the three routes using a single analytical framework. Second, Somanathan et al. (2009) and Bensassi et al. (2016) rely on partial equilibrium analysis. To the best of our knowledge, Francois and Rojas-Romagosa (2014) is the only paper that performs a general equilibrium analysis, that combines the traditional computable general equilibrium (CGE) literature with the trade literature. Contrary to Francois and Rojas-Romagosa (2014), our paper closely follows the recent quantitative trade literature. This comes at the cost of reducing the level of detail regarding the number of sectors and factors of production. On the other hand, following the recent trade literature limits the number of assumptions and parameters, which makes our results more tractable (Arkolakis et al., 2012, Head and Mayer, 2014).

Finally, our paper builds upon previous estimations of the distance elasticity of trade, obtained using the opening and closure of the Suez and Panama Canals (Feyrer, 2011, Hugot and Umana Dajud, 2016). These historical events provide quasi-natural experiments to estimate the response to trade flows to changes in maritime routes. In particular, these settings allow including bilateral fixed effects in the estimations, to control for the unobserved bilateral features that are correlated with distance and also affect trade. Such factors include shared cultural characteristics, which are known to favor trade, but have no reason to be affected by a contemporary *change* in maritime distance. In turn, neglecting to control for these bilateral-specific time-invariant features result in over-estimated distance elasticities of trade to distance changes. In the end, we take advantage of these estimations to apply sensible parameters when computing our counterfactuals for Arctic routes.

The remained of the paper is organized as follows. In the next section, we compute shortest maritime distances including through the three Arctic routes and compare them to current distances. Section 3, details the methodologies we use to predict trade flows and welfare effects. Sections 4 and 5 present the main results, respectively in partial and general equilibrium. Section 6 evaluates the sensitivity of the results to changes in parameters. Section 7 concludes.

2. Distance and Trade data

We compute changes in maritime distance for each country pair using an algorithm closely related to Dijkstra's algorithm.[6] In our baseline results, we assign the same cost to any segment of navigable waterways – including the three Arctic routes –, and a prohibitive cost for routes through the ice cap outside the projected routes. We use the maximum extent of the ice cap in 2009 to determine which Arctic regions are assigned a prohibitive cost. The sensitivity of our results to assigning a greater relative cost to the Arctic segment of each route is presented in section 6. Because of the Suez and Panama Canals, the opening of Arctic routes only affects

[6]We compute shortest distances between the main ports of each countries. For the countries with major ports on two oceans/seas (e.g. New York and Los Angeles), we compute the shortest distance with any of the two.

distances between ports that are both located North of the Equator, and even North of the Tropic of Cancer for America and Africa. Our data includes 78 such ports. For the remaining routes – that are therefore not affected – we use the current shortest maritime distance.[7]

Table 1 shows that the average distance reduction for the country pairs that are affected ranges from 12.4% (Northwest Passage) to 16.5% (Transpolar Route). Average distance reductions appear much smaller when bilateral distance reductions are weighted by the corresponding trade flows in 2015 – in the range of 1.4% to 2% –, reflecting the well-established fact that most of world trade happens between countries that are relatively close.[8] In turn, most of current world trade will not be directly affected by the Arctic routes, simply because they will only shorten shipping routes for countries that are currently separated by at least 18,000 km.[9]

Table 2 reports the largest distance reductions associated with each Arctic route, where the benchmark is the shortest existing maritime route, including via the Suez and Panama Canals. The largest reduction would affect distance between Iceland and Japan, which would fall by 36 to 46%, depending on the Arctic route that is considered.

Finally, the bilateral trade statistics for 2015 are extracted from the COMTRADE dataset (United Nations, 2017). Each observation is reported in current U.S. Dollars and corresponds to a directional bilateral trade flow.[10]

Table 1 – Bilateral distance reductions: Descriptive statistics

	Mean	s.d.	Bilateral trade-weighted mean	Share of impacted routes
Northwest Passage	-12.4%	8.6pp.	-1.4%	1.8%
Northern Sea Route	-15.1%	11.9pp.	-1.3%	2.2%
Transpolar Route	-16.5%	12.8pp.	-2.0%	2.8%

[7] Shortest sea distances without taking into account Arctic routes are taken from Hugot and Umana Dajud (2016).
[8] Our data reveals that in 2015, 25% of world trade was carried out by countries less than 2,100 km away, and 50% by countries separated by less than 6,000 km.
[9] The cutoff for the Transpolar Route corresponds to the Italia-Japan pair: with a bilateral distance of 18,024 km through the Suez Canal and 18,021 km via the Transpolar Route.
[10] e.g. British exports to France are reconciled with French imports from the U.K. and constitute one observation for each year. The flow in the opposite direction constitutes a separate observation. The data therefore reports two observations for each country pair and each year.

Figure 2 – Ports for which bilateral Arctic shipping distances are computed

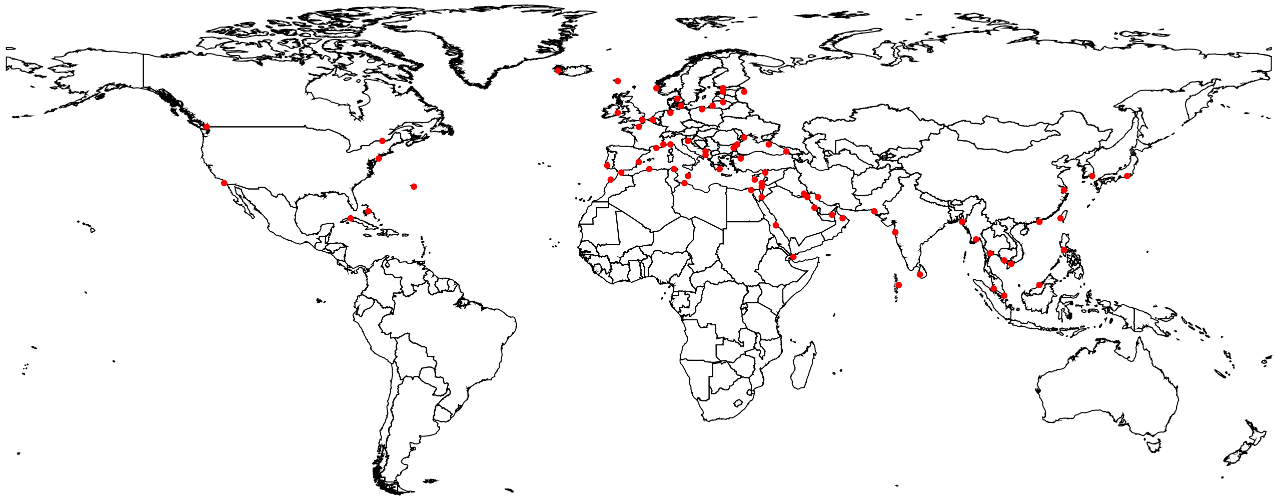


Table 2 – Largest percentage distance reductions

Country 1	Country 2	Transpolar Route	Northern Sea Route	Northwest Passage
ISL	JPN	-45.8	-37.6	-36.2
JPN	NOR	-43.2	-38.4	-27.6
ISL	KOR	-41.8	-33.8	-31.7
JPN	SWE	-40.5	-35.7	-25.0
DNK	JPN	-39.0	-34.2	-23.6
KOR	NOR	-38.8	-34.0	-22.7
DEU	JPN	-37.9	-33.1	-22.3
JPN	LTU	-37.7	-33.0	-22.6
EST	JPN	-37.6	-33.0	-22.6
FIN	JPN	-37.3	-32.7	-22.4
JPN	LVA	-37.0	-32.4	-21.3
IRL	JPN	-36.6	-29.8	-25.3
KOR	SWE	-36.1	-31.5	-20.0
GBR	JPN	-35.9	-30.2	-23.0
BEL	JPN	-35.8	-30.8	-21.6

Note: This table reports the 15 largest relative distance reductions associated with each Arctic route.

3. Counterfactual trade flows, incomes and welfare

This section presents the theory that we use to perform the counterfactual exercise of opening Arctic routes to commercial traffic, and to compute the corresponding welfare effects.

3.1. Partial Equilibrium

It has been shown that a broad range of trade models yields structural gravity equations (Head and Mayer, 2014). In order to take advantage of its robustness across trade theories, we will therefore use a structural gravity equation to assess the impact of the three Arctic routes:

$$X_{ni} = \frac{Y_i}{Pi}\frac{X_n}{P_n}\phi_{ni}, \tag{1}$$

where X_{ni} are the exports from n to i, ϕ_{ni} are trade costs (including the trade elasticity), Y_i is income in i, X_n represents expenditure in n, and P_n and P_i are the outward and inward price terms or "multilateral resistance terms".

Obtaining partial equilibrium counterfactuals is straightforward and does not depend on the particular form taken by the model. In partial equilibrium, we set income and price terms to their original level. Counterfactual bilateral trade is therefore given by:

$$X'_{ni} = \frac{Y_i}{P_i}\frac{X_n}{P_n}\phi'_{ni}, \tag{2}$$

where $'$ denotes counterfactual values. The ratio of bilateral exports before and after the opening of a given route is thus simply equal to the ratio of trade costs:

$$\frac{X'_{ni}}{X_{ni}} = \frac{\phi'_{ni}}{\phi_{ni}}. \tag{3}$$

Let's assume that trade costs have two components: distance and an unobserved component:[11]

$$\phi_{ni} = \exp(\zeta dist_{ni}) \times \upsilon \quad \text{and} \quad \phi'_{ni} = \exp(\zeta dist^{AR}_{ni}) \times \upsilon, \tag{4}$$

where $dist_{ni}$ and $dist^{AR}_{ni}$ are bilateral distances before and after the opening of a given Arctic route AR. ζ is the maritime distance elasticity of trade, and υ are unobserved trade costs. Counterfactual bilateral trade flows are given by:

$$X'_{ni} = \exp\left[\zeta(dist^{AR}_{ni} - dist_{ni})\right] \times X_{ni}. \tag{5}$$

Note that to compute partial equilibrium counterfactuals we only need the current trade flow, the distance elasticity and maritime distances before and after the opening of Arctic routes.

[11] Unobserved components include trade costs that are in fact both observable (e.g. tariffs) and unobservable (e.g. cultural proximity).

3.2. Trade elasticity

Sensible estimates of ζ are obtained from Hugot and Umana Dajud (2016). In this previous work, we estimate ζ controlling for the unobserved characteristics that affect bilateral trade flows but do not vary over time. For this purpose, we exploit – as in Feyrer (2011) – the variation in shipping distances due to the closure and reopening of the Suez Canal following the Six-Day War.[12] This historical episode brought about changes in bilateral distances over time, that only affected certain pairs of countries. In turn, this feature allows us to include pair fixed effects in our gravity estimations. On top of the origin-year and destination-year effects – that control for multilateral resistance – we thus also include country pair directional effects to control for the cross-sectional component of the correlation between bilateral trade and maritime distance.

Following this procedure, we obtain two relevant estimates of ζ for the present paper. The first one (-0.03) is the lowest absolute elasticity obtained in Hugot and Umana Dajud (2016), when ζ is estimated on an unbalanced sample that covers 1958-1970 and therefore includes the closing of the Suez Canal in 1967. The second (-0.23) is the largest absolute elasticity obtained in Hugot and Umana Dajud (2016), when ζ is estimated on an unbalanced sample that covers 1970-1984 and therefore includes the re-opening of the Suez Canal in 1975.[13] For comparison purposes, we also provide results where ζ is set to -1.1, which is the average structural estimate of the distance elasticity, when estimated using cross-sectional variation across country pairs.[14] All results are presented for these three values of the distance elasticity.

3.3. General Equilibrium and Welfare

In the previous section we held both income and multilateral resistance terms constant. Yet, in order to provide general equilibrium counterfactuals, changes in bilateral trade costs must be allowed to affect these terms. An important point is that in all the models that yield a structural gravity equation, multilateral resistance terms are a function of trade costs.[15] For example, in the seminal paper of Anderson and van Wincoop (2003) they take the following form:

$$P_i = \left(\sum_n (\tau_{ni}/P_n)^{\sigma-1} \frac{Y_n}{Y_W} \right)^{\frac{1}{1-\sigma}}, \tag{6}$$

and:

$$P_n = \left(\sum_n (\tau_{ni}/P_i)^{\sigma-1} \frac{Y_i}{Y_W} \right)^{\frac{1}{1-\sigma}}, \tag{7}$$

where τ_{ni} are bilateral trade costs.

[12] Feyrer (2011) focuses on the impact of trade on income, while we concentrate on the precise estimation of ζ.
[13] The estimates can respectively be found in column 3 and 1 of table 3 in Hugot and Umana Dajud (2016).
[14] This value is extracted from table 3.4, p.160 of the meta-analysis of Head and Mayer (2014).
[15] Table 3.1 in Head and Mayer (2014) summarizes the different forms taken by P_n and P_i.

Any general equilibrium prediction therefore requires to take into account the changes in multilateral resistance terms that arise from bilateral trade costs reductions.

In order to compute general equilibrium counterfactual trade flows, we use the methodology developed in Dekle et al. (2007, 2008).[16] In this setting, multilateral resistance terms and countries' incomes and expenditures adjust to changes in bilateral trade costs. As a result, countries can be affected by the opening of Arctic routes, even if none of the distances between them and foreign markets is modified. Another considerable advantage of this method is its low data requirements. Two endogenous but observable parameters – income and trade shares – perfectly identify unobserved trade costs and multilateral resistance terms. As explained below and similarly to what happens in partial equilibrium, expressing the system in variations allows to eliminate the unobserved components of trade costs.

Assuming that labor is the only source of income and constant markups, Arkolakis et al. (2012) show that in most of the models that yield a gravity equation, trade shares write:

$$\pi_{ni} = \frac{\chi_{ni} N_i (w_i \tau_{ni})^{\epsilon}}{\sum\limits_{l} \chi_{nl} N_l (w_l \tau_{nl})^{\epsilon}}, \tag{8}$$

where χ_{ni} can be a particular parameter of a structural gravity equation, and N_i is the number of goods produced in i. w_i are wages and τ_{nl} are the trade costs between n and third countries $l \neq i$. Counterfactual trade shares are in turn expressed as:

$$\pi'_{ni} = \frac{\chi_{ni} N'_i (w'_i \tau'_{ni})^{\epsilon}}{\sum\limits_{l} \chi_{nl} N'_l (w'_l \tau'_{nl})^{\epsilon}}. \tag{9}$$

Dekle et al. (2007, 2008) first showed that under the assumption of a constant number of goods produced in i (N_i), dividing actual by counterfactual expenditure shares yields changes in the share of country i in country n's spending:[17]

$$\hat{\pi}_{ni} = \frac{\left(\hat{Y}_i \hat{\tau}_{ni}\right)^{\epsilon}}{\sum\limits_{l} \pi_{nl} \left(\hat{Y}_i \hat{\tau}_{ni}\right)^{\epsilon}}, \tag{10}$$

where $\hat{Y}_i$ denotes changes in country i's income and $\hat{\tau}_{ni}$ changes in bilateral trade costs.

We use the resulting changes in income to assess the welfare impact of the opening of Arctic routes. Arkolakis et al. (2012) show that a large class of trade models – including Anderson and van Wincoop (2003), Eaton and Kortum (2002) and Chaney (2008) – lead to a common measure of welfare changes associated with changes in trade flows. However, it should be

[16] The counterfactual exercise is facilitated by the existence of a unique equilibrium (Alvarez and Lucas, 2007).
[17] Further explanations can be found in Head and Mayer (2014).

noted that despite sharing a common sufficient statistic for welfare changes, differences in the structure of the underlying models can lead to different general equilibrium counterfactual trade flows and, ultimately, to different welfare effects. In practice, once we have obtained general equilibrium changes in trade flows using the approach of Dekle et al. (2007), changes in the import openness and the trade elasticity are sufficient to compute welfare effects as:

$$\widehat{W_j} = \widehat{\pi_{jj}}^{1/\epsilon}, \tag{11}$$

where $\widehat{W_j}$ is the change in real income, $\widehat{\pi_{jj}}$ is the change in the share of domestic expenditure, and $\epsilon < 0$ is the trade elasticity.

We obtain income changes using equation (10) and the market clearing condition. Thanks to the existence of a unique equilibrium we solve for counterfactual multilateral resistance terms, incomes, and trade flows using the iterative procedure proposed in Head and Mayer (2014). Finally, we set the trade elasticity to -3.78, which is the median elasticity for structural gravity estimations from the meta-analysis of Head and Mayer (2014).

4. Partial Equilibrium results

This section presents our partial equilibrium trade predictions for each Arctic route, obtained by applying equation 5 to the distances computed in section 2.

Table 3 presents the ten largest expected percentage increases in bilateral trade associated with the opening of the Transpolar Route. All results are presented for three different values of the distance elasticity: -0.03, -0.23 and -1.1.[18] From this table, it is clear that Japan is among the countries that would gain the most from the opening of the Arctic routes. In fact, eight of the ten largest changes in trade flows involve Japan.

Another important point is the sensitivity of the results to the distance elasticity. When ζ is set to -0.03, trade between Iceland and Japan increases by 1.85%. The increase in trade reaches about 15% if ζ is set to -0.23. The last column reports predicted effects with a much higher distance elasticity of -1.1, which is a standard estimate of the distance elasticity in settings where distances do not vary in the time dimension. In that case, trade between Iceland and Japan would surge 96%. In the end, assuming a distance elasticity in the range of -0.03 to -0.23, bilateral trade is predicted to rise by 0.60 to 4.76% for the country pairs that are affected by distance reductions.

Table 4 presents the ten largest percentage increases in aggregate exports. Consistently with table 3, Japan is predicted to be the most affected country: with our preferred distance elastic-

[18] Section 3.2 provides an explanation.

Table 3 – Largest percentage bilateral trade increases: Transpolar Route

Country 1	Country 2	ζ=-.03	ζ=-.23	ζ=-1.1
ISL	JPN	1.85	15.13	96.19
JPN	NOR	1.71	13.90	86.36
ISL	KOR	1.64	13.24	81.25
JPN	SWE	1.57	12.66	76.88
DNK	JPN	1.49	12.04	72.26
KOR	NOR	1.48	11.95	71.60
DEU	JPN	1.44	11.58	68.86
JPN	LTU	1.43	11.50	68.30
JPN	POL	1.43	11.49	68.22
FIN	JPN	1.41	11.33	67.05
Average		**0.60**	**4.76**	**26.59**

Note: This table reports the ten largest predicted partial equilibrium percentage bilateral trade increases. By construction, the effects are symmetric for each country pair, so countries are simply ordered alphabetically in columns "Country 1" and "Country 2". The average value is the mean across all positive bilateral trade changes.

ities, total exports for Japan are expected to rise between 0.17 and 1.39%. Finally, the average increase in aggregate exports across all affected countries ranges between 0.07 and 0.52%.

Similarly to table 4, tables A.1 and A.2 – reported in the appendix – show predicted aggregate exports for the Northern Sea Route and the Northwest Passage. Because they imply smaller distance reductions, the predicted trade effects for these routes are lower, by 25% for the Northern Sea Route and 45% for the Northwest Passage. As a result, assuming that the real shipping distance elasticity is -0.23, our predicted average effect on the exports of affected countries is 0.30% for the Northwest Passage, 0.39% for the Northern Sea Route and 0.52% for the Transpolar Route.

Table 4 – Largest percentage total exports increase: Transpolar Route

Country	ζ=-.03	ζ=-.23	ζ=-1.1
JPN	0.17	1.39	7.95
DEU	0.15	1.15	6.43
CHN	0.15	1.20	6.36
NOR	0.12	0.99	5.79
FIN	0.12	0.92	5.17
DNK	0.11	0.90	5.10
ISL	0.10	0.81	4.98
IRL	0.11	0.85	4.84
SWE	0.10	0.83	4.69
KOR	0.11	0.84	4.64
Average	**0.07**	**0.52**	**2.88**

Note: This table reports the ten largest predicted partial equilibrium percentage total exports increases. The average value corresponds to the mean across all positive total exports changes.

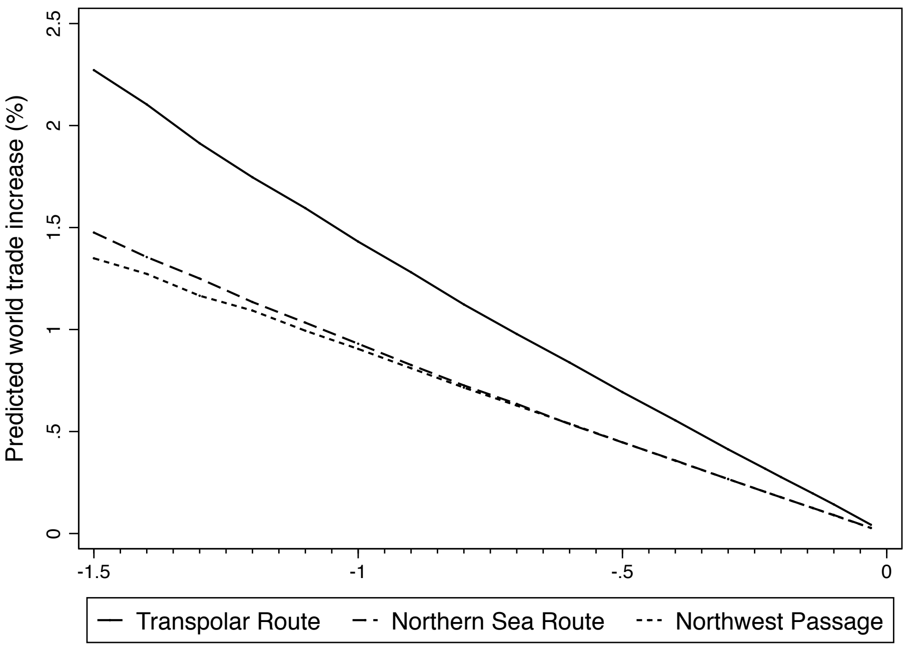
5. General Equilibrium results

This section presents our general equilibrium predictions, obtained using the method described in section 3.3.

The predicted increase in world exports associated with the opening of the Transpolar Route reaches 0.32% with our preferred distance elasticity ($\zeta = -0.23$). In 2016, this corresponds to an increase of world exports by 48 billion U.S. dollars, equivalent to the exports of Ukraine. This increase in trade translates into a 0.02% increase in global welfare. Taking GDP as an approximation of welfare, this represents an addition to world welfare in the order of magnitude of the GDP of Iceland. Figures 3 and 4 show that the effects of the Northern Sea Route and the Northwest Passage are about two thirds that of the Transpolar Route.

Figures 3 and 4 illustrate the sensitivity of our predictions to the shipping distance elasticity. They demonstrate the crucial importance of setting the distance elasticity as close as possible to its true value to accurately capture the effects of changes in maritime distance. Indeed, the predicted global trade effect reaches 1.6% with an elasticity close to -1.1 – the typical estimate in gravity settings where distances do not vary over time. On the other hand, with a more realistic elasticity of -0.23, estimated in the time dimension, the predicted global trade effect of the Transpolar Route falls to 0.32%. Similarly, figure 4 shows that the global welfare impact falls from 0.13 to 0.02% when the distance elasticity moves from -1.1 to -0.23.

Figure 3 – Sensitivity of the trade effects to the distance elasticity



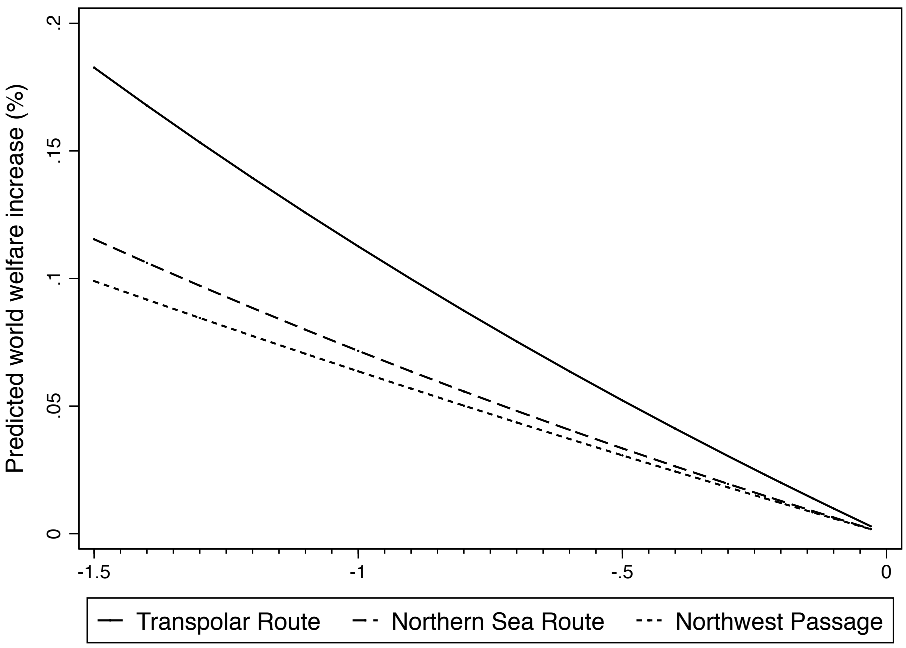
This aggregate picture, however, conceals a large heterogeneity across countries. In fact, tables 5 and 6 show that the slightly positive global trade effect of the Transpolar Route arises from about 25% of the countries in our sample, for which trade creation over-compensates the export reductions of the remaining 75%. In turn, despite our preferred prediction of the global trade effect lying around 0.3%, the average effect for the countries that are positively affected reaches 0.44%, against −0.11% for the countries that are negatively affected.[19]

Table 5 reports the largest predicted positive effects on countries' exports for the Transpolar Route. As in partial equilibrium, Northeast Asian and Northern European countries are predicted to see their trade increase the most. Japan's exports are predicted to increase by between 0.14 and 1.11%, followed by Norway, and the U.K. Table 7 reports the corresponding welfare effects: Korea and Ireland are predicted to be benefit the most the Arctic routes – with welfare gains between 0.01 and 0.11% –, followed by the Netherlands and Norway.

Table 6 reports the largest predicted negative effects on countries' exports for the Transpolar Route. Indeed, our general equilibrium predictions allow countries to be affected via two channels: i) directly, through bilateral distance reductions, and ii) indirectly, through adjustments in multilateral resistance terms. As a result, aggregate trade is now predicted to decrease for some countries, if i) they don't benefit from substantial distance reductions and ii) the new routes deteriorate their access to/from world markets relative to third countries. The countries that are the most adversely affected cluster around the Tropic of Cancer: in the Caribbean, the

[19] These figures are for $\zeta = -0.23$. See column 2 of tables 5 and 6.

Figure 4 – Sensitivity of the trade effects to the distance elasticity



Mediterranean, the Indian Ocean and in Western Africa. The largest trade reduction affects Jamaica (−0.02 to −0.21%), followed by Turkey and Pakistan. The resulting adverse welfare effects are more limited, with a maximum effect of −0.06%, for Malaysia. These results are consistent with the intuition behind the multilateral resistance terms of the gravity equation. Indeed, these countries are all located close to those that will benefit the most from the new routes, but they will not benefit from distance reductions themselves. In turn, they will become *relatively* less accessible to/from world markets.

All Arctic route have similar overall effects, but some particularities are worth mentioning. First, being the shortest, the Transpolar Route has the largest predicted effects, followed by the Northern Sea Route and the Northwest Passage. Comparing tables 5, B.3 and B.7, however, reveals that the ordering of the countries which trade will be the most affected varies across Arctic routes. Specifically, the Northern Sea Route will bring larger positive effects in Northern Europe, while the Northwest Passage will affect Korea more. Finally, the largest positive welfare effects will be more concentrated in Northern Europe for the Northern Sea Route, and in East Asia for the Northwest Passage (tables B.5 and B.9).

Table 5 – Largest percentage total exports increases: Transpolar Route

Country	ζ=-.03	ζ=-.23	ζ=-1.1
JPN	0.14	1.11	6.16
NOR	0.11	0.86	4.88
GBR	0.11	0.88	4.64
DEU	0.11	0.85	4.57
ISL	0.09	0.70	4.18
KOR	0.09	0.72	3.79
CHN	0.10	0.73	3.67
DNK	0.08	0.64	3.46
FIN	0.08	0.60	3.20
SWE	0.07	0.51	2.77
Average	**0.06**	**0.44**	**2.54**
Share of positive changes	**26.09**	**25.00**	**22.83**

Note: This table reports the ten largest predicted general equilibrium export increases. Average values are computed across all positive export changes. "Share of positive changes" is the share of countries which exports are predicted to increase.

6. Sensitivity analysis

This section explores the sensitivity of our results to changes in the trade elasticity (ϵ) and the relative cost assigned to the Arctic portions of each shipping route.[20] For each exercise, third parameters are set to their baseline values: Arctic relative shipping costs are set to unity, $\zeta = -0.23$ and $\epsilon = -3.78$.

6.1. Sensitivity to the trade elasticity

Figures 5 and 6 illustrate the sensitivity of our trade and welfare predictions to changes in the elasticity of trade to trade costs (ϵ). For reasonable values of the trade elasticity – in the range of -2.5 to -4.5 –, the magnitude of our results is not much affected. Still, the sensitivity of welfare changes to the trade elasticity reflects the intuition of all underlying trade models. Indeed, figure 6 shows that welfare effects are higher when the key parameter of the model reveals a large heterogeneity, whether across varieties (Anderson and van Wincoop, 2003), industry productivity (Eaton and Kortum, 2002), or firm productivity (Chaney, 2008).

[20] The sensitivity of the results to the maritime distance elasticity of trade (ζ) is explored in the previous section.

Table 6 – Largest percentage total exports reductions: Transpolar Route

Country	ζ=-.03	ζ=-.23	ζ=-1.1
JAM	-0.02	-0.21	-1.22
TUR	-0.02	-0.19	-1.12
PAK	-0.02	-0.19	-1.11
BLZ	-0.02	-0.19	-1.11
LKA	-0.02	-0.19	-1.11
MUS	-0.02	-0.18	-1.05
NAM	-0.02	-0.17	-0.99
CIV	-0.02	-0.16	-0.97
GUY	-0.02	-0.17	-0.97
EGY	-0.02	-0.15	-0.93
Average	**-0.01**	**-0.11**	**-0.68**
Share of negative changes	**73.91**	**75.00**	**77.17**

Note: This table reports the ten largest predicted general equilibrium percentage total exports reductions. The average value corresponds to the mean across all negative total exports changes. "Share of negative changes" refers to the percentage of countries which total exports are predicted to decrease.

6.2. Sensitivity to transport costs in the Arctic Ocean

In figures 7 and 8, it is now the relative cost assigned to the Arctic fraction of each route that varies along the horizontal axis. In fact, there are reasons to believe that Arctic shipping will remain relatively more costly. First, even after the melting of the permanent ice cap, icebergs will remain common in the Arctic Ocean. Second, refueling and supplying will also remain more costly because of difficult access to the coasts of the Arctic Ocean, the lack of infrastructures – including deep-water ports –, and the resulting lack of competition. For the same reason, search and rescue missions are particularly costly in the Arctic Ocean, driving insurance costs up. Finally, Canada and Russia might be tempted to charge a fee for traveling along the portions of the Northwest Passage and the Northern Sea Route that cross their territorial waters.

In the end, figures 7 and 8 illustrate that whether the opening of Arctic routes will yield trade and welfare gains depends on the cost of using them. All positive effects vanish if navigation in the Arctic is more than 2.5 times more costly than elsewhere. Trade and welfare gains decrease faster for the Northwest Passage with the increase of the relative cost factor, eliminating any significant effect above 1.5. This is because the Northwest Passage is the route that crosses through the longest Arctic portion.[21]

[21] The length of the Transpolar Route through the current Arctic ice cap is 5,865 km, against 6,646 km for the Northern Sea Route and 7,129 km for the Northwest Passage.

Table 7 – Largest percentage welfare increases: Transpolar Route

Country	ζ=-.03	ζ=-.23	ζ=-1.1
KOR	0.01	0.11	0.62
IRL	0.01	0.10	0.57
NLD	0.01	0.10	0.56
NOR	0.01	0.10	0.56
DEU	0.01	0.10	0.56
BEL	0.01	0.09	0.52
ISL	0.01	0.08	0.49
POL	0.01	0.08	0.42
DNK	0.01	0.06	0.36
FIN	0.01	0.06	0.33
Average	**0.01**	**0.05**	**0.27**
Share of positive changes	**30.43**	**30.43**	**28.26**

Note: This table reports the ten largest predicted general equilibrium percentage welfare increases. The average value corresponds to the mean across all positive welfare changes. "Share of positive changes" refers to the percentage of countries which welfare is predicted to increase.

7. Conclusion

In this paper we gauged the impact of the year-long opening of Arctic shipping routes by combining recent advances in the structural trade literature with precise estimates of the elasticity of trade to changes in maritime distance. This novel approach yields predictions of the resulting increase in world trade that lie between 0.04 and 0.32%, roughly halfway between the previous predictions by Bensassi et al. (2016) and Francois and Rojas-Romagosa (2014).

Our results show that the opening of Arctic shipping routes would reduce bilateral distance for the average trade flow by 1.4 to 2% on average. Distance reductions would affect 1.8 to 2.8% of the country pairs that we consider. At the extreme, the maritime distance between Iceland and Japan would fall by 46%. As a result, Arctic routes would considerably increase trade between Northeast Asia and Northern Europe. Our preferred estimate suggests that world trade could increase by 0.32%, while world welfare could progress by 0.02%.

The largest welfare gains would logically concentrate in Northern Europe and in Northeast Asia. Korea would be the country that reaps the largest benefits: aggregate exports would rise by 0.72% and welfare by about 0.11%. Our general equilibrium framework also yields negative effect for some countries, particularly in the Caribbean, West Africa, the Mediterranean and the Indian Ocean. Malaysia would suffer from the largest loss, with a welfare reduction of 0.06%.

Table 8 – Largest percentage welfare reductions: Transpolar Route

Country	ζ=-.03	ζ=-.23	ζ=-1.1
MYS	-0.01	-0.06	-0.30
EST	-0.00	-0.02	-0.09
GUY	-0.00	-0.01	-0.07
THA	-0.00	-0.01	-0.05
SGP	-0.00	-0.01	-0.05
BLZ	-0.00	-0.01	-0.04
BGR	-0.00	-0.01	-0.04
SYC	-0.00	-0.01	-0.04
CIV	-0.00	-0.01	-0.04
NIC	-0.00	-0.01	-0.04
Average	**-0.00**	**-0.00**	**-0.02**
Share of negative changes	**69.57**	**69.57**	**71.74**

Note: This table reports the ten largest predicted general equilibrium percentage welfare reductions. The average value corresponds to the mean across all negative welfare changes. "Share of negative changes" refers to the percentage of countries which welfare is predicted to decrease.

Our results are however sensitive to the maritime distance elasticity of trade, which should therefore be chosen with great care. For this reason, we use a distance elasticity that is estimated using historical changes in maritime distance. This approach yields an elasticity that is purged from all cross-sectional unobservable factors that are correlated with distance and hamper trade, but that are unlikely to be affected by the opening of Arctic routes (e.g. cultural proximity).

Our results are also sensitive to the relative cost of Arctic navigation: we show that setting the navigating cost 20% higher in the Arctic portion of the routes reduces welfare gains by 35 to 75%, depending on the route. In other words, the already-limited predicted effects of Arctic routes would be further reduced by any remaining Arctic navigation cost premium.

Figure 5 – Sensitivity of the aggregate trade effect to the trade elasticity

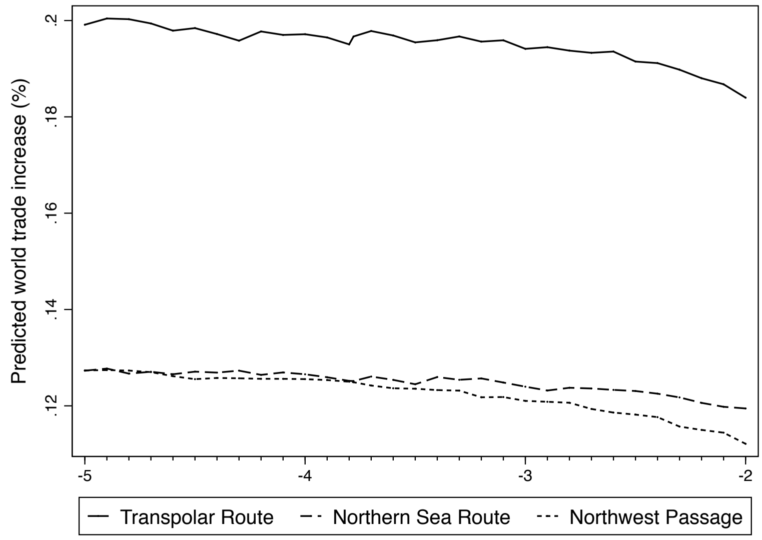


Figure 6 – Sensitivity of the aggregate welfare effect to the trade elasticity

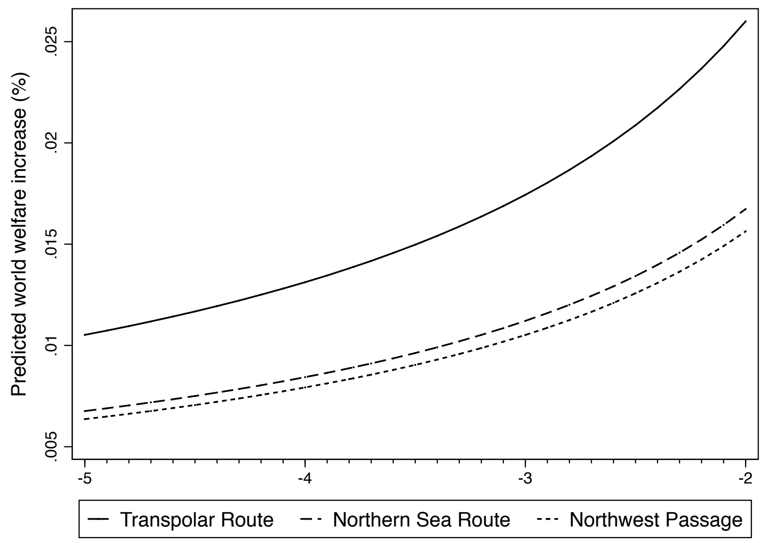


Figure 7 – Sensitivity of the aggregate trade effect to relative Arctic transport costs

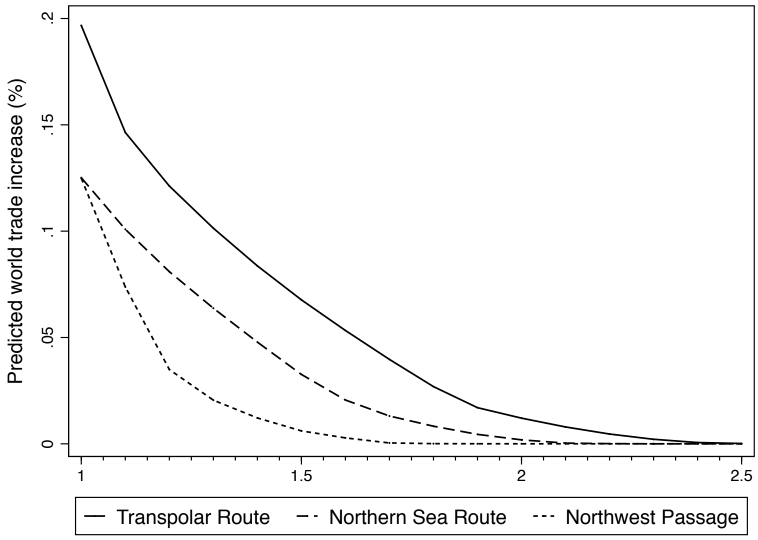
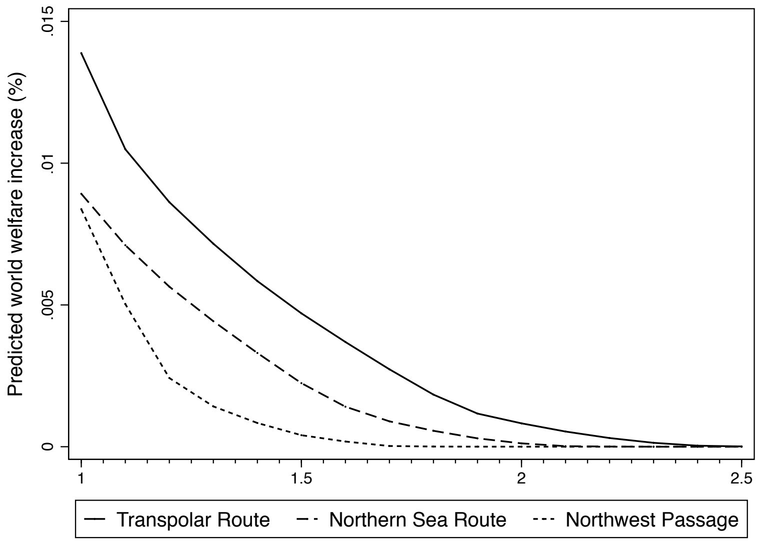


Figure 8 – Sensitivity of the aggregate welfare effect to relative Arctic transport costs



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Appendix

A. Partial Equilibrium results

Table A.1 – Largest percentage total exports increase: Northern Sea Route

Country	ζ=-.03	ζ=-.23	ζ=-1.1
JPN	0.12	0.99	5.59
DEU	0.11	0.86	4.69
NOR	0.10	0.77	4.38
FIN	0.09	0.70	3.86
DNK	0.09	0.69	3.78
CHN	0.09	0.71	3.74
SWE	0.08	0.62	3.45
IRL	0.08	0.61	3.33
ISL	0.07	0.57	3.32
GBR	0.07	0.55	2.96
Average	**0.05**	**0.39**	**2.12**

Note: This table reports partial equilibrium percentage increases in total exports. The average value corresponds to the mean across all positive total exports changes.

Table A.2 – Largest percentage total exports increase: Northwest Passage

Country	ζ=-.03	ζ=-.23	ζ=-1.1
JPN	0.13	1.03	5.36
CHN	0.10	0.80	4.01
KOR	0.08	0.65	3.33
ISL	0.07	0.55	3.17
IRL	0.06	0.48	2.56
CAN	0.06	0.47	2.42
NOR	0.06	0.44	2.36
DEU	0.05	0.41	2.12
FIN	0.05	0.36	1.89
USA	0.05	0.37	1.82
Average	**0.04**	**0.30**	**1.59**

Note: This table reports partial equilibrium percentage increases in total exports. The average value corresponds to the mean across all positive total exports changes.

B. General Equilibrium results

Table B.3 – Largest percentage total exports increases: Northern Sea Route

Country	ζ=-.03	ζ=-.23	ζ=-1.1
JPN	0.10	0.81	4.47
NOR	0.09	0.69	3.85
DEU	0.09	0.66	3.49
GBR	0.08	0.62	3.22
ISL	0.06	0.49	2.76
DNK	0.07	0.51	2.71
KOR	0.06	0.49	2.57
FIN	0.06	0.47	2.50
CHN	0.06	0.45	2.29
SWE	0.05	0.40	2.16
Average	**0.04**	**0.34**	**1.88**
Share of positive changes	**23.91**	**22.83**	**21.74**

Note: This table reports the ten largest predicted general equilibrium percentage total exports increases. The average value corresponds to the mean across all positive total exports changes. "Share of positive changes" refers to the percentage of countries which total exports are predicted to increase.

Table B.4 – Largest percentage total exports reductions: Northern Sea Route

Country	ζ=-.03	ζ=-.23	ζ=-1.1
JAM	-0.02	-0.13	-0.74
BLZ	-0.02	-0.13	-0.73
TUR	-0.01	-0.12	-0.71
PAK	-0.01	-0.12	-0.66
NAM	-0.01	-0.11	-0.62
LKA	-0.01	-0.11	-0.62
MUS	-0.01	-0.11	-0.61
CIV	-0.01	-0.11	-0.61
ROM	-0.01	-0.10	-0.57
HRV	-0.01	-0.10	-0.57
Average	**-0.01**	**-0.07**	**-0.40**
Share of negative changes	**76.09**	**77.17**	**78.26**

Note: This table reports the ten largest predicted general equilibrium percentage total exports reductions. The average value corresponds to the mean across all negative total exports changes. "Share of negative changes" refers to the percentage of countries which total exports are predicted to decrease.

Table B.5 – Largest percentage welfare increases: Northern Sea Route

Country	ζ=-.03	ζ=-.23	ζ=-1.1
NOR	0.01	0.08	0.43
KOR	0.01	0.08	0.42
DEU	0.01	0.08	0.42
NLD	0.01	0.08	0.42
IRL	0.01	0.07	0.39
BEL	0.01	0.07	0.38
POL	0.01	0.06	0.33
ISL	0.01	0.06	0.32
DNK	0.01	0.05	0.28
FIN	0.01	0.05	0.25
Average	**0.00**	**0.04**	**0.22**
Share of positive changes	**25.00**	**25.00**	**23.91**

Note: This table reports the ten largest predicted general equilibrium percentage welfare increases. The average value corresponds to the mean across all positive welfare changes. "Share of positive changes" refers to the percentage of countries which welfare is predicted to increase.

Table B.6 – Largest percentage welfare reductions: Northern Sea Route

Country	ζ=-.03	ζ=-.23	ζ=-1.1
MYS	-0.00	-0.03	-0.16
EST	-0.00	-0.01	-0.06
VNM	-0.00	-0.01	-0.05
GUY	-0.00	-0.01	-0.03
BLZ	-0.00	-0.01	-0.03
SGP	-0.00	-0.01	-0.03
THA	-0.00	-0.01	-0.03
CIV	-0.00	-0.01	-0.03
BGR	-0.00	-0.01	-0.03
SYC	-0.00	-0.01	-0.03
Average	**-0.00**	**-0.00**	**-0.01**
Share of negative changes	**73.91**	**75.00**	**76.09**

Note: This table reports the ten largest predicted general equilibrium percentage welfare reductions. The average value corresponds to the mean across all negative welfare changes. "Share of negative changes" refers to the percentage of countries which welfare is predicted to decrease.

Table B.7 – Largest percentage total exports increases: Northwest Passage

Country	ζ=-.03	ζ=-.23	ζ=-1.1
JPN	0.10	0.78	4.02
ISL	0.07	0.53	2.95
KOR	0.07	0.51	2.52
CAN	0.06	0.44	2.22
CHN	0.06	0.45	2.21
USA	0.06	0.44	2.12
NOR	0.05	0.39	2.01
GBR	0.04	0.34	1.72
DEU	0.04	0.29	1.45
DNK	0.03	0.23	1.17
Average	**0.03**	**0.24**	**1.31**
Share of positive changes	**28.26**	**25.00**	**22.83**

Note: This table reports the ten largest predicted general equilibrium percentage total exports increases. The average value corresponds to the mean across all positive total exports changes. "Share of positive changes" refers to the percentage of countries which total exports are predicted to increase.

Table B.8 – Largest percentage total exports reductions: Northwest Passage

Country	ζ=-.03	ζ=-.23	ζ=-1.1
GUY	-0.02	-0.15	-0.76
JAM	-0.02	-0.14	-0.73
LKA	-0.02	-0.14	-0.73
DOM	-0.02	-0.12	-0.64
PAK	-0.01	-0.12	-0.63
MEX	-0.01	-0.11	-0.60
NIC	-0.01	-0.11	-0.57
MUS	-0.01	-0.11	-0.57
CUB	-0.01	-0.10	-0.55
GTM	-0.01	-0.10	-0.52
Average	**-0.01**	**-0.06**	**-0.33**
Share of negative changes	**71.74**	**75.00**	**77.17**

Note: This table reports the ten largest predicted general equilibrium percentage total exports reductions. The average value corresponds to the mean across all negative total exports changes. "Share of negative changes" refers to the percentage of countries which total exports are predicted to decrease.

Table B.9 – Largest percentage welfare increases: Northwest Passage

Country	ζ=-.03	ζ=-.23	ζ=-1.1
KOR	0.01	0.07	0.38
ISL	0.01	0.06	0.32
VNM	0.01	0.06	0.29
IRL	0.01	0.05	0.28
CAN	0.01	0.05	0.24
NOR	0.01	0.04	0.23
NLD	0.00	0.04	0.19
BEL	0.00	0.04	0.19
DEU	0.00	0.03	0.18
JPN	0.00	0.03	0.18
Average	**0.00**	**0.03**	**0.13**
Share of positive changes	**27.17**	**27.17**	**27.17**

Note: This table reports the ten largest predicted general equilibrium percentage welfare increases. The average value corresponds to the mean across all positive welfare changes. "Share of positive changes" refers to the percentage of countries which welfare is predicted to increase.

Table B.10 – Largest percentage welfare reductions: Northwest Passage

Country	ζ=-.03	ζ=-.23	ζ=-1.1
MYS	-0.01	-0.05	-0.25
GUY	-0.00	-0.02	-0.07
NIC	-0.00	-0.01	-0.05
MEX	-0.00	-0.01	-0.04
THA	-0.00	-0.01	-0.04
EST	-0.00	-0.01	-0.04
MUS	-0.00	-0.01	-0.03
CIV	-0.00	-0.00	-0.02
MDG	-0.00	-0.00	-0.02
SGP	-0.00	-0.00	-0.02
Average	**-0.00**	**-0.00**	**-0.02**
Share of negative changes	**72.83**	**72.83**	**72.83**

Note: This table reports the ten largest predicted general equilibrium percentage welfare reductions. The average value corresponds to the mean across all negative welfare changes. "Share of negative changes" refers to the percentage of countries which welfare is predicted to decrease.