Melting Ice Caps: Implications for Asia-North America Linkages and the Panama Canal

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Abstract

Arctic ice caps have been melting at an increased pace and projections imply that the extent of the ice cover will be greatly reduced in the near future. Such a climatic phenomenon has important socio-economic implications, as it would open up shipping routes in the Arctic. In this regard, media attention and research has largely centered on the use of the Northern Sea Route (NSR) connecting Northeast Asia with Northwestern Europe and its effect on traffic through the Suez Canal. However, melting Arctic ice caps would also make the North West Route (NWR) a feasible trade route for high volume commercial traffic, reducing the shipping distances between Northeast Asia and the East Coast of the United States. In this paper we analyze the commercial feasibility of the NWR and the economic impact of reducing the trade distances between Asia and the United States East Coast. In particular, we examine the extent to which the NWR would compete with the Panama Canal for certain trade routes. Such competition has significant geopolitical implications linked to both a drop in traffic through the Panama Canal as well as changes in the global supply chains that currently link East Asia and the United States.

Keywords: Arctic shipping routes, transportation costs, trade forecasting, gravity model, CGE models, trade and emissions
JEL Classification: R41, F17, C21, C68, D58, F18

1 Introduction

The steady reduction of Arctic sea ice has been well documented (Rodrigues, 2008; Kinnard et al., 2011; Comiso, 2012). There is broad agreement on continued reduction through the remainder of the century (Wang and Overland, 2009; Vavrus

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et al., 2012), and recent studies even suggest that the melting rate could accelerate (Kattsov et al., 2010; Rampal et al., 2011; Shepherd *et al.*, 2012; Kerr, 2012; Stroeve et al., 2012; Slezak, 2013). Wang and Overland (2012) for example point to ice free access to Arctic routes by the mid 2030s, while in a meta-analysis of model results Rogers et al. (2015) identify a median prediction of 2034 for an ice free Arctic in September. Stammerjohn et al. (2012) note that already, some Arctic routes are ice free now more than predicted my climate models for 2030. This implies that even in the near future, the extension of ice cover will be greatly reduced. Indeed a substantial share of the Arctic may soon be completely ice-free for much of the year.

Besides the environmental effects, another consequence of this climatic phenomenon would be the viability of shipping routes in the Arctic. In this paper, we examine the economic effects of the viability of the North West Route (NWR) between Asia and North America for high volume commercial traffic. This route will reduce the shipping distances and time between Northeast Asia (i.e. China, Korea, Japan) and the East Coast of the United States and Canada (see Figure 1).

In this paper, we analyze the economic impact of the commercial feasibility of the NWR and realized reductions in the trade distances between Asia and North America. With reduced ice cover the NWR becomes a direct competitor with the Panama Canal for certain trade routes. Such a change has significant geopolitical implications linked to both a drop in traffic through the Panama Canal as well as changes in the global supply chains that currently link East Asia and North America.[1]

Until 2011, there was still controversy about the feasibility of the commercial use of Arctic routes. However, the ever-quicker melting pace found in several studies has broadened the consensus in favor of its likely commercial use in the near future. A growing number of papers find that both Arctic routes (i.e. the NSR and NWR) could be fully operational for several months or even all-year round in the near future (cf. Verny and Grigentin, 2009; Liu and Kronbak, 2010; Khon et al., 2010; Stephenson et al., 2013; Wang and Overland, 2012; Rogers et al., 2015; Stammerjohn et al., 2012).[2]

Given current uncertainties regarding the relation between the icecap melting pace and the transport logistic barriers associated with the NSR and the NWR, it is hard to predict the year when these new shipping routes will become fully operational. Throughout this paper we use a what-if approach where we assume that by the year 2030 the icecaps have melted far enough and logistics issues related to navigating the Arctic have been resolved, so both the NSR and the NWR are

[1] In this way, this paper is a companion to Francois and Rojas-Romagosa (2015), with a focus on the NSR. While we are concerned with the NWR here, throughout we assume that melting icecaps will allow the use of both the NSR and the NWR. The search for the NWR led to a great deal of tragedy, while motivating early exploration of much of the American interior and coasts. See for example Berton (1988) on historic relevance, and Oestreng (1997) on geopolitical significance.

[2] The differences on the approximate year and the yearly extent for which the Arctic routes will be fully operational varies much between papers, depending on different assumptions and estimations regarding the pace of the ice caps melting and developments in the shipping industry with respect to the new route. More recent evidence points to accelerated loss of ice cover.

Figure 1: The North Western Route (NWR) and the Panama Canal shipping routes

fully operationally all year round.[3] In practical terms, this also implies that we use an "upper bound" scenario that assumes that the NWR becomes a perfect substitute for the Panama Canal, and as such, all commercial shipping between Northeast Asia and the East coast of North America will use the shorter, faster, and cheaper NWR instead of the Panama Canal route.[4]

Our economic analysis follows a three-step process. In the first step we estimate changes in physical distances between East Asia and the US along major and prospective shipping routes using both the NWR (new routes) and the Panama Canal (current routes). The second step employs a regression-based gravity model of trade to map the new distance calculations –for both the NWR and the Panama Canal route– into estimates of the bilateral trade cost reductions between trading partners at the industry level. While part of this reduction in costs follows from physical shipping costs, other trade costs also follow from time and distance barri-

[3]The use of 2030 as our benchmark year is mainly for illustration purposes and the use of another year does not affect our main economic results.

[4]Additionally, as in Francois and Rojas-Romagosa (2015) we assume that the NSR is a perfect substitute for the South Sea Route through the Suez Canal.

ers, as benchmarked in the gravity exercise. In the third step we integrate our trade cost reduction estimates into a computable general equilibrium (CGE) model of the global economy to simulate the effect of the commercial opening of both the NSR and NWR on bilateral trade flows, macroeconomic outcomes and the total amount of CO_2 emissions.[5] It is important to note that since the opening of the Arctic shipping routes will be a gradual process that will take a number of years, the economic adjustment pattern we describe in our analysis will also be gradual.

The paper is organized as follows. In Section 2 we analyze logistic issues and projections for commercially using Arctic routes, including the NSR and NWR, in the future. We then explain how we estimate the new water-transportation distances in Section 3 and then use these new distance measures to estimate the gravity model of trade in Section 4. The CGE simulations and macroeconomic results are presented in Section 5. We then compare our simulations results (using both the NSR and NWR) with the results found in Francois and Rojas-Romagosa (2015) where only the NSR was assumed to be used. Section 7 concludes by summarizing our main results.

2 Commercial feasibility of the Arctic shipping routes

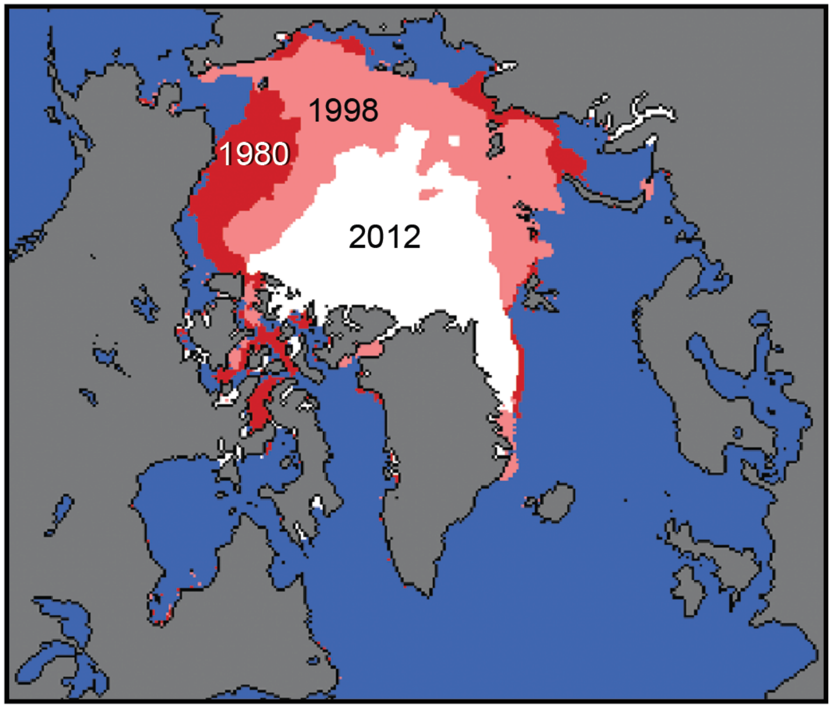
There are two elements that condition the feasibility of Arctic routes (see Figure 1) to become fully viable commercial substitutes of the current routes (SSR and Panama Canal). The first is the ice levels in the Arctic, which is the main barrier to the commercial use of the NSR and NWR. A quicker melting pace will make the commercial use of the NWR more likely in the near future. Figure 2 further illustrates the current degree of ice cap melting (until 2012).

The second barrier to the Arctic routes is the transport logistic issues associated with the opening of new commercial shipping routes in regions without transport infrastructure and extreme weather conditions. Even though a number of ships have already used the NSR and the NWR during summer months, significant logistical obstacles remain. These include slower speeds, limited commercial weather forecasts, patchy search and rescue capabilities, scarcity of relief ports along the route and the need to use icebreakers and/or ice-capable vessels (Liu and Kronbak, 2010; Schøyen and Bråthen, 2011). These conditions not only affect the insurance premia currently charged to use the Arctic routes, but also limit the commercial viability of shipping operations, which are dependent on predictability, punctuality and economies of scale (Humpert and Raspotnik, 2012).

Moreover, Stephenson et al. (2013) estimate that the NWR has a substantial lower prospect of full-year navigation than the NSR. Khon et al. (2010) find that: "The models predict prolongation of the season with a free passage from 3 to 6

[5] In practical terms, we build on the results of Francois and Rojas-Romagosa (2015), mapping these into transport and trade cost reductions associated along the SSR through the Panama canal and the NWR and focusing in the impact on trade-related linkages between North America and Asia.

Figure 2: Extent of the summer Arctic Sea ice loss



Notes: Summer Arctic Sea ice has declined dramatically since satellites began measuring it in 1979. The extent of sea ice in September 2012, shown in white in figure, was more than 40% below the median for 1979-2000. Source: Melillo et al. (2014).

months for the NSR and from 2 to 4 months for the NWR by the end of twenty-first century according to A1B scenario of the IPCC". So the NWR may be one-third less navigable during the year than the NSR. Yet, actual loss of ice cover is running far faster than predicted (again see Figure 2, and Stammerjohn et al. (2012).)

The literature generates a wide range of estimates regarding the precise date when the Arctic routes will be fully operational. This relates to the uncertainties regarding the pace and extent of ice cap melting, in conjunction with the logistical build-up needed. The uncertainties regarding both elements are directly related and also reinforce each other. In particular, a quicker pace of melting will also make it easier to overcome the transport logistical obstacles. Therefore, the assessments of the feasibility of Arctic routes range from studies that see limited use for many years to come (cf. Lasserre and Pelletier (2011) and papers referred therein) and more optimistic papers that foresee the full use of the routes within 10 years (Verny and Grigentin, 2009).

In this paper, we follow the approach taken in Francois and Rojas-Romagosa (2015) and use 2030 as our benchmark year, for which we assume that arctic routes will be fully operational all-year round.[6] This implies that we use an "upper bound" scenario that estimates the largest expected trade and economic impact from the Arctic routes. For instance, if the routes are not operational during winter and/or other logistic issues related to the extreme weather of the Arctic are not fully resolved, then it can be expected that shipping companies pursue a diversification strategy, using both routes conditional on which offers the lowest costs at certain seasons the year.[7]

3 Estimating US trade distance reductions using the North Western Route

As the first step of our analysis, we estimate the precise distance reductions for bilateral trade flows associated with the NWR. To do so we include shipping routes in the estimation of the distance between two trading partners in the gravity equation.[8] Sea transport is the most important transport mode for global trade: 90 percent of world trade is carried by ship (OECD, 2011). The rest moves primarily by land.[9] For the country pairs and trade flows we focus on in this research, water transportation, or multi-modal transport (water and land) accounts for essentially all trade.

Therefore, we use the actual shipping distances collected in Francois and Rojas-Romagosa (2015).[10] The more challenging issue is to assess the impact of the NWR on US international trade. As a large country with major ports in both the Atlantic and Pacific oceans, the US has a variety of trade routes that link it with Northeast Asia (i.e. China, Japan and Korea). From the data collected in Francois and Rojas-Romagosa (2015) we have shipping distances for three US ports: Newark (New Jersey), New Orleans (Louisiana) and Long Beach (California).

[6] However, our economic estimations are not dependent on this occurring precisely in 2030. We chose a benchmark year mainly for reporting reasons, since we expect to have quantitatively similar results if we used another benchmark year, either an earlier one (2015) or later one (2040). From Francois and Rojas-Romagosa (2015) we know that the use of different benchmark years affects the size of some of the results, but the main qualitative results and patterns for 2030 remain robust to the use of different years.

[7] Another potential limitation is the increased pressure on current transportation infrastructure. In particular, current shipping hubs may need to expand. However, since the opening of the NSR and NWR will be a gradual process, we expect that any additional infrastructure needs can be developed while the Arctic routes become fully operational.

[8] Currently, the econometric literature on the gravity model of bilateral trade relies on measures of physical distances between national capitals as a measure of distance, known as the CEPII database (Mayer and Zignago, 2011). However, these measures use the shortest physical distance and thus, are not appropriate for our work, since shipping routes are usually longer than the shortest physical distance, and melting sea ice, for example, will not change the physical distance between Tokyo and New York.

[9] Very few exceptions use air transportation, which mainly applies for high-value commodities that need to reach the final destination in a short time (e.g. fish and flowers).

[10] This paper provides a detailed explanation on how the shipping distances are constructed. In essence, the distances are constructed using shipping industry data on the physical distance between ports. For landlocked countries, we combine the port-to-port distances with land-transport distances from the CEPII's database.

We employ US import value data to assign total US trade by region of origin for each of the three ports for which we have available shipping data.[11] We then estimate the total trade shares by port and find that of the total US trade from East Asia, 31% goes to Newark (NJ), 33% to New Orleans (LO) and 36% to Long Beach (CA). This means that around two-thirds of total US trade with Northeast Asia goes through the Panama Canal before arriving in New Orleans or Newark. These estimations are confirmed by Panama Canal traffic data. Around 35% of the total transit volume using the canal are servicing the route between the east coast of the US and East Asia. This is the largest share of all Panama Canal traffic, with the second route representing only 9% of the total (i.e the route between the US East Coast and South America's West Coast) and a variety of less important routes representing more than half of the total traffic.[12]

Using the point of entry trade value shares, we estimate the US shipping distance with East Asian countries as a weighted shipping distance. The estimated distance is then the average of the three US port distances weighted by their trade value shares with East Asia.

Table 1 presents the different distance measures. First, the great-circle formula is the standard distance measure estimated by CEPII. Then we present the shipping distances constructed in Francois and Rojas-Romagosa (2015). As expected, the shipping distances are larger than the shortest physical distances. We then use the data compiled in Christensen (2009) to obtain the new shipping distances through the NWR.[13] We observe that the NWR shipping distance is around 25% shorter than the Panama Canal for the routes between Northeast Asia and Newark, while the distance reduction is just about 5% for the route to Louisiana. Finally, when we use the weighted US distance to China, Korea and Japan we observe that the NWR reduces the total shipping distance by around 10%. Although these distance reductions are approximately one-third less than those related to the NSR linking Northeast Asia and Northwestern Europe (see Table 10 in Appendix C), the reduction associated with the NWR is still significant and will have an impact on global trade and production patterns.

4 Gravity model of trade: Estimated linkage between shorter shipping distances and trade cost reductions

The second step in our analysis is to use the gravity model of trade to estimate the trade cost reductions associated with shorter shipping distances. We follow the gravity model estimated in Francois and Rojas-Romagosa (2015). Appendix A

[11] We employ US import data by customs district and country of origin from US Customs, provided to us by USITC.

[12] Taken from the Panama Canal Authority Transit Statistics at pancanal.com.

[13] The exact distances are slightly adjusted so that the current shipping distances presented in Christensen (2009) are consistent with our own shipping distances.

Table 1: USA distance estimates to main East Asia countries using different routes

	From:		
Distances to the USA	**China**	**Korea**	**Japan**
Great-circle formula (km)	10,993.7	11,065.7	10,855.6
Shipping distance to California	10,667.6	9,780.2	9,309.6
Using Panama Canal:			
to Newark (NJ)	19,743.1	18,855.8	18,343.8
to Lousiana	18,779.1	17,891.8	17,379.8
Using Arctic NWR			
to Newark (NJ)	16,102.8	15,190.2	14,387.5
to Lousiana	17,818.0	16,905.4	16,102.7
Distance reductions using NWR			
to Newark (NJ)	22.6%	24.1%	27.5%
to Lousiana	5.4%	5.8%	7.9%
Weighted shipping distance	16,157.8	15,270.4	14,773.3
Distances using NWR	14,712.1	13,808.6	13,125.5
Distance reductions using NWR	**-8.9%**	**-9.6%**	**-11.2%**

Source: Great-circle distances taken from the GeoDist database from CEPII. Shipping distances are own estimations based on data from AtoBviaC and Christensen (2009).

provides detailed information on the specific gravity equations used and the main results.[14]

Controlling for country-specific structural features of the gravity model, estimates of pairwise coefficients provide measures of the impact that distance between two trading partners has in terms of *trade costs* between the two countries. In the present context, when we substitute the current shipping distances using the Panama Canal and the SSR routes with the new Arctic route distances (NSR and NWR), we obtain a measure of how much current trade costs will be reduced by the shorter physical shipping distances associated with the Arctic routes.

4.1 Total trade cost reductions

Working from our data on shipping distance changes –as discussed above– combined with the distance and tariff elasticities in Table 9 in Appendix A, we can assess how much the decrease in shipping distance translates into effective trade cost reductions. The basic calculation is the following:

$$\Delta \text{cost}_{jsd} = \frac{\beta_{j,\text{distance}}}{\beta_{j,\text{tariff}}} \Delta \ln(\text{distance}_{sd}) \tag{1}$$

where Δcost_{jsd} is the change in the total cost of goods sold as a share of the value of trade. They are defined for each sector j and for bilateral trade flowing from country s to country d. Table 2 summarizes our estimates of Δcost_{jsd} for

[14]Since we use the new shipping distances from the USA to East Asia, the results of the gravity model are slightly different than in Francois and Rojas-Romagosa (2015), but qualitatively the same.

both the NWR (above) and the NSR (below). Note that these total trade costs are sector-specific and are not symmetric for country pairs. For instance, the trade costs from USA to Korea are slightly different than from Korea to the USA. As expected, since the distance changes associated with the NWR are one-third lower than the NSR changes, the related trade cost reductions are also smaller for the NWR.

Table 2: Total trade cost reductions for the Arctic routes between 20 non-services sectors for selected countries, percentage changes.

		trade cost reductions					trade cost reductions		
From:	To:	average	max	min	From:	To:	average	max	min
NWR route:									
USA	CHN	1.03	3.15	0.08	CHN	USA	1.03	3.15	0.08
USA	JPN	1.30	3.97	0.11	JPN	USA	1.30	3.96	0.11
USA	KOR	1.11	3.39	0.09	KOR	USA	1.10	3.38	0.09
USA	TWN	0.77	2.36	0.06	TWN	USA	0.77	2.36	0.06
NSR route:									
DEU	CHN	3.51	10.39	0.30	CHN	DEU	3.50	10.35	0.30
DEU	JPN	5.24	15.33	0.46	JPN	DEU	5.22	15.28	0.46
DEU	KOR	4.22	12.45	0.37	KOR	DEU	4.21	12.41	0.37
DEU	TWN	2.39	7.13	0.21	TWN	DEU	2.38	7.11	0.20

Notes: Average is the mean trade cost reductions between all 20 sectors, while max and min are the maximum and minimum trade cost reductions, respectively. Source: Own estimations.

4.2 Cost allocation between transport services and other trade costs

To link our gravity estimations with the CGE model, we allocate these total trade cost reductions from Equation (1) over actual international transport services costs ("atall" in the GTAP code) and the remainder as iceberg trade cost reductions ("ams" in the GTAP code).

We first estimate the shipping services costs reduction as the percentage distance reduction associated with the Arctic routes:

$$\mathrm{atall}_{sd} = -\left(\frac{\mathrm{NSR/NWRdistance}_{sd}}{\mathrm{distance}_{sd}} - 1\right) \tag{2}$$

This reduction is applied directly to the international transport margin (ITM_{sd}), which is the wedge between the *fob* and *cif* trade values in the GTAP database. These are country specific margins: by country of origin (s) to country of destination (d). The results are presented in Table 3.

Table 3: Shipping services ("atall") cost reductions for selected countries

From:	To:	% reduction
USA	CHN	8.9
USA	JPN	11.2
USA	KOR	9.6
USA	TWN	6.8
DEU	CHN	28.1
DEU	JPN	39.4
DEU	KOR	33.0
DEU	TWN	19.9

Source: Own estimations.

The iceberg trade costs are then calculated as the difference between the total trade costs in Equation (1) and the shipping service cost reductions from Table 3. In particular, the reduction in the GTAP iceberg costs ("ams") are calculated as:

$$\text{ams}_{jsd} = \begin{cases} \Delta\text{cost}_{jsd} - (\text{atall}_{sd} * \text{ITM}_{sd}) & \text{, if positive} \\ 0 & \text{, otherwise} \end{cases} \tag{3}$$

The estimated iceberg trade cost reductions are presented in Table 4. These iceberg trade costs account for several costs that hinder international trade, such as time, coordination, and other non-shipping service costs (cf. Hummels and Schaur, 2012).

Table 4: Iceberg trade cost ("ams") reductions for the Arctic routes between 20 non-services sectors for selected countries, percentage changes.

		iceberg cost reductions					iceberg cost reductions		
From:	To:	average	max	min	From:	To:	average	max	min
NWR route									
USA	CHN	0.51	2.47	0.00	CHN	USA	0.49	2.43	0.00
USA	JPN	0.45	2.91	0.00	JPN	USA	0.75	3.05	0.00
USA	KOR	0.44	2.52	0.00	KOR	USA	0.55	2.47	0.00
USA	TWN	0.30	1.60	0.00	TWN	USA	0.35	1.84	0.00
NSR route									
DEU	CHN	1.87	7.54	0.00	CHN	DEU	2.00	7.56	0.00
DEU	JPN	3.07	11.52	0.00	JPN	DEU	2.63	10.73	0.00
DEU	KOR	2.17	8.30	0.00	KOR	DEU	2.76	9.98	0.00
DEU	TWN	1.36	4.90	0.00	TWN	DEU	1.38	6.02	0.00

Notes: Average is the mean trade cost reductions between all 20 sectors, while max and min are the maximum and minimum trade cost reductions, respectively. Source: Own estimations.

5 CGE analysis of trade and macroeconomic outcomes

The trade cost estimates described previously are integrated into a computable general equilibrium (CGE) model of the global economy in our third and final step. The opening and future use of the NWR and the NSR will have a simultaneous effect on multiple countries and will influence how different trading partners interact with one another. The use of the Arctic routes will have several impacts, including trade facilitation that will affect bilateral trade, as well as sectoral production and consumption patterns, relative domestic and international prices, and how the region and sector-specific factors of production (i.e. labor and capital) are used. Accordingly, we employ a CGE modeling framework that is widely used and accepted for the study of global economic shocks to the international trading system and well suited for this analysis.[15] The primary advantages of the CGE modeling framework include the analysis of how key variables will respond to changes in trade costs that we estimate, given the future use of the NWR. The CGE framework begins by creating a baseline scenario of the global economy in the year 2030 based on macroeconomic projections and comparing how the projected 2030 economy would respond to changes in trade costs. This allows for the quantification of resulting changes in bilateral trade flows, relative prices and corresponding changes in production and consumption throughout the global economy, as well as changes in CO_2 emissions that may arise given global economic adjustments to the opening of the Arctic routes. The opening of the NSR and NWR, therefore, fits within the analytical scope of CGE models since it implies a very seizable shock to the world trade system that will affect a large set of countries simultaneously.[16]

The particular CGE model we use is a modified version of a standard GTAP class CGE model. The model characteristics are detailed in Appendix B.[17] One key specification that is pertinent to our analysis of the NWR is the calculation of changes in CO_2 emissions by region and sector, given the emergence of new trade routes and corresponding changes in production. The inclusion of CO_2 data and the model-predicted changes in CO_2 emissions allow for the analysis of environmental impacts that are expected, given the future use of the NWR. We use the GTAP global database that describes the initial equilibrium of the economy, includes complete bilateral trade information, as well as transport and protection linkages, and

[15] See for instance, Schmalensee et al. (1998), Elliott et al. (2010), Peng (2011); Beckman et al. (2011); Boehringer et al. (2011); Böhringer et al. (2012); Auffhammer and Steinhauser (2012); Dixon and Jorgenson (2013).

[16] We recognize the importance of recent quantitative trade models –summarized by Costinot and Rodríguez-Clare (2013)– yet these models are not able to account for the economic shocks resulting from the opening of the Arctic routes. Further discussion is provided in Appendix B.

[17] The main distinction between our model and the standard GTAP model is that we use a monopolistic competition framework with increasing returns to scale (*à la* Krugman, 1980), and CO_2 emissions are directly linked to production, consumption and trade. The model is implemented in GEMPACK under OSX and the model code is available upon request, as well as an executable version of the model.

parameters that define elasticities for supply and demand.[18] The current version of the database includes data for 129 regions and 57 sectors for the year 2007 that we thoughtfully aggregated to describe the 39 regions and 23 sectors of most importance for this research (see Table 11 and Table 12 in Appendix C). To assess the global general equilibrium effects of the commercial use of the NWR, we project the database along the medium or SSP2 (Shared Socioeconomic Pathway) from the most recent SSPs and related Integrated Assessment scenarios (IIASA, 2012; O'Neill et al., 2012). Our work focuses on the year 2030 from this baseline.[19] Our modeling framework allows us to assess both the trade and macroeconomic implications associated with the NWR, as well as changes in CO_2 emissions from production and international transport.

Working from the 2030 projection along the baseline SSP, we report our main CGE results as the differences between the baseline values in 2030 (i.e. the baseline scenario with no Arctic shipping lanes) compared to the counterfactual scenario where bilateral trade is permitted to move through the NSR and NWR. The NWR scenario incorporates both the transportation and trade cost reductions that we estimate into our CGE model to assess the impacts of the Arctic routes on bilateral trade flows, sectoral output, and other macroeconomic variables.[20] Our work explicitly accounts for the input-output relationships within countries and sectors embodied in global value chains (GVC). This allows for the assessment of how GVC may adjust to the NWR that creates new shipping distances and corresponding cost reductions. Furthermore, we quantify impacts of the NWR on welfare and employment/wage changes. Finally, we quantify the effects of the NWR on transportation related pollution levels that considers both distance reductions as well as the potential for larger trade volumes.

5.1 Trade effects

The global and bilateral trade changes resulting from the NWR scenario that allows for the NSR and NWR to be fully operational are relative to the baseline 2030 scenario that is in absence of the Arctic shipping lanes as a viable trade route. Our results show that utilization of the Arctic routes will reduce international shipping, volume by distance, by 0.71%, and that the corresponding volume of global trade increases by 0.76%. While values for global trade volumes are relatively modest, it is important to note that concentration of trade that is affected is primarily centered on trade changes between Northeast Asia (i.e. China, Japan and South Korea), Europe, and the east coast of the United States. Our estimates for the share of

[18] GTAP is the standard basic dataset used in most CGE models. See Narayanan et al. (2012) for documentation on the GTAPv8 database and Hertel (2013) for the full database project.

[19] Robustness checks that assess impacts given other years for which the NWR is fully operational, indicate that while magnitudes of the relative trade effects (which depend on projected GDP growth) differ, the main results found for 2030 are not significantly different.

[20] As explained in Section 4, we accomplish this by implementing technical efficiency gains in shipping and iceberg trade costs that are equivalent to the estimated reductions in total trade costs.

world trade that will now flow through the Arctic routes, rather than traditional routes, is equal to 13.5%.

In this "upper bound" scenario, where the NWR is a perfect substitute for the Panama Canal, the increase in the trade between the US East Coast and Northeast Asia implies that both the current Panama Canal traffic that serves both regions (around 35% of the total canal traffic, see Section 3), but also the increased trade will be using the NWR. Employing current data from the Panama Canal Authority on the number of vessels that use the canal, we estimate that approximately between 4000 to 4500 vessels will be using the NWR (instead of the Panama Canal) when it is fully operational all-year round.[21]

Table 5 illustrates the bilateral trade changes in trade values for goods and services for China, Japan and South Korea, the largest Northeast Asian exporters who will be affected with the opening of the Arctic routes.

Table 5: Northeast Asia, changes in trade values for goods and services, percentage changes

	China		Japan		South Korea	
	exports	imports	exports	imports	exports	imports
Germany	10.36	19.33	14.50	20.50	9.14	19.71
United Kingdom	11.90	17.28	10.54	14.45	5.67	16.76
France	3.09	7.04	10.71	14.69	7.36	8.74
Italy	-1.91	1.21	6.85	8.38	2.18	4.31
Spain	2.41	4.83	10.29	8.17	5.27	4.77
Netherlands	9.55	16.98	14.42	19.16	15.84	18.70
EU27	7.88	14.39	11.79	17.24	7.86	14.70
USA	4.62	13.48	3.07	4.80	3.28	4.49

Source: Own estimations using the GTAP database.

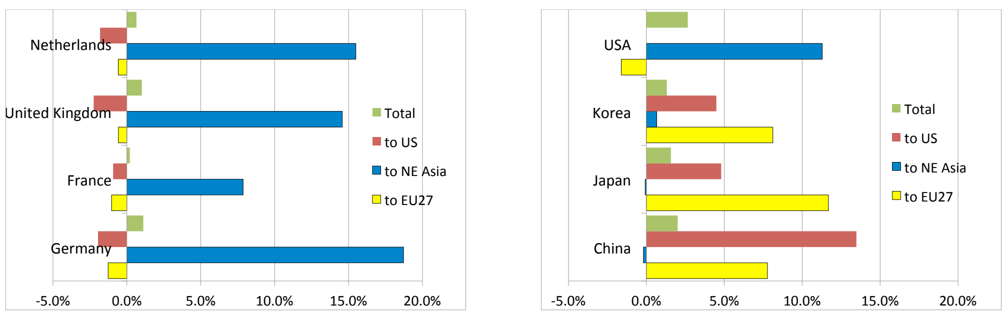
The largest changes in export and import values are observed for the three main Asian countries that benefit from the NWR: China, Japan, and South Korea. In general, total trade between China, Japan and South Korea increases by more for European markets (EU27) than for the US. The increases in total exports from the three key East-Asian exporters range from 7.86% for Chinese and South Korean exports to the EU27 to 11.8% for Japanese exports to the EU. Imports from the EU and US are greater than the increase in exports from East-Asia to both markets. Imports from the EU into the three East-Asian markets range from an increase of 14.4% (China) to 17.2% (Japan). Increases in exports from East-Asia to the US range from 3.1% (Japan) to 4.6% (China) while imports from the US increase by less than 5% for Japan and South Korea, but increase by 13.5% for imports into

[21] As explained in Section 2, however, the transition from the Panama Canal to the NWR will be a very gradual process conditional on the pace of icecap melting and the build-up of the necessary transportation logistics to make the NWR a feasible commercial shipping route.

China. Table 13 in Appendix C includes the corresponding data for merchandise trade in volumes, which exhibits a similar pattern to the changes in trade values described above.

The substantial increases in bilateral trade between the East-Asia and the US, as well as East-Asia and the EU results in trade diversion effects where increases in trade between these large economic zones arises at the expense of decreasing trade with other regions. Figure 3 shows these trade diversion patterns.[22] Primarily, there is a noteworthy decrease in the US-EU trade flows. In addition, intra-European trade also decreases but less than when only the NSR is available (see Francois and Rojas-Romagosa, 2015).

Figure 3: Trade flows after opening both the NSR and NWR: percentage changes in exports by selected countries



Source: Own estimations using the GTAP database.

Table 6 illustrates the trade diversion that is expected to occur. The United States reduces its trade withe the EU, but the changes are different between EU subregions. Trade with South and East EU countries is reduced, while US trade flows increase to Northwestern EU countries. However, the initial trade share is higher for the former regions and this implies an overall decrease in trade from the US to the EU. US trade with Northeast Asia increases substantially, while it increases slightly with other regions (RoW). For the three Northeast Asia countries –China, Japan and Korea– we observe that trade increases with all regions, where only Japan has a very small decrease in trade with the other two Northeast Asian countries.

It is important to note that these total trade patterns sometimes arise from different changes in exports and imports. For instance, the US exports to the EU decrease while imports are increasing. The magnitude of these changes are of different magnitudes between EU regions, which implies that bilateral trade balances are bound to experience changes as well.

[22]The specific changes by country in Figure 3 and additional countries are presented in Table 14 in Appendix C.

Table 6: Changes in trade values by region for selected countries, percentage changes

	USA			China			Japan			Korea		
	exports	imports	trade	exports	imports	trade	exports	imports	trade	exports	imports	trade
Total EU	-1.6	0.3	-0.6	7.8	14.0	9.0	11.7	16.9	13.6	8.1	14.7	10.4
South EU	-0.8	-0.1	-0.4	-0.2	3.1	0.5	6.8	7.5	7.1	3.1	3.9	3.4
East EU	-2.9	0.4	-1.2	9.5	18.3	11.3	10.7	17.9	12.3	7.8	16.3	8.7
NW EU	6.1	2.8	4.2	8.4	14.7	9.6	4.7	3.4	4.0	2.8	2.4	2.6
NE Asia	11.3	4.1	7.0	-0.2	0.7	0.2	-0.1	-0.1	-0.1	0.7	-0.2	0.2
USA	0.0	0.0	0.0	4.6	13.5	8.1	3.1	4.8	3.7	3.3	4.5	3.9
RoW	-0.5	1.4	0.5	0.9	2.0	1.4	0.5	0.7	0.6	0.3	0.8	0.6
TOTAL	**2.7**	**2.2**	**2.4**	**2.0**	**2.5**	**2.2**	**1.6**	**1.4**	**1.5**	**1.3**	**1.2**	**1.3**

Notes: South EU is: Cyprus, Greece, Italy, Malta, Portugal and Spain. East EU is: Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia and Slovenia. Northwestern (NW) EU is: Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Luxembourg, the Netherlands, Sweden and the United Kingdom. Northeast (NE) Asia is: China, Japan, South Korea, Hong Kong and Taiwan. RoW is Rest of the World.
Source: Own estimations using the GTAP database.

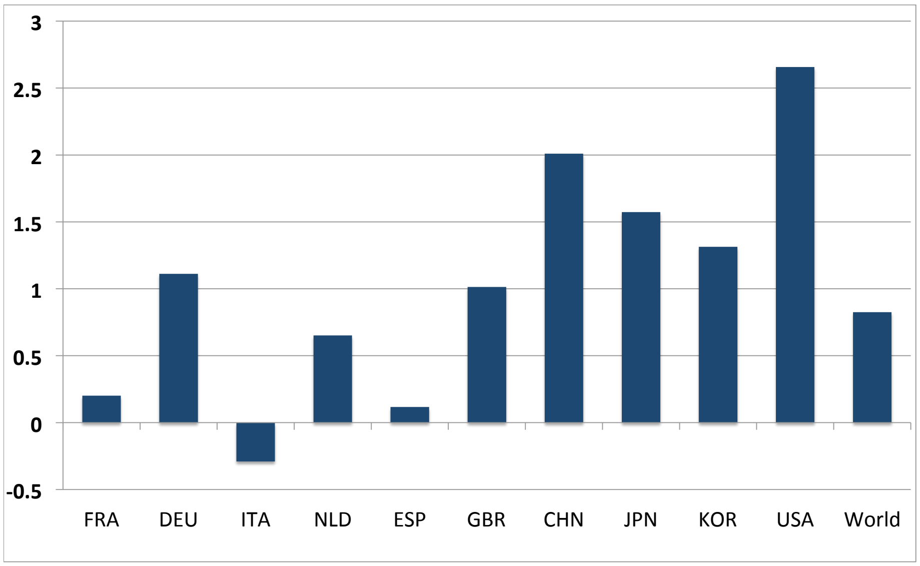
Similar trade diversion patterns persist when considering expected exports at the sectoral level. Tables 15 and 16 in Appendix C illustrate changes in exports to the US and China by sector. Changes in sectoral exports are evenly spread among all manufacturing sectors with few exceptions (mainly the service sectors). Table 15 illustrates the percentage changes in export sales to the US. Results indicate that China, Japan and South Korea significantly increase their exports to the US in almost all sectors but services (Japanese exports of wood products and transport services may decreases as well). However, European countries decrease their exports to the US for the majority of sectors, with exceptions in four sectors being potential increases in exports of agricultural products, plant products, petrochemicals and gas, and mining and extraction.

Given substantial trade diversion for key economic players in the global market, the expected changes in aggregate exports are minor, with the largest increase expected for the US at 2.7% (see Figure 4). After the US, China experiences the largest overall export increase at 2%, followed by Japan and Korea. Within the EU, the Northwestern countries increase exports (Germany, United Kingdom and the Netherlands), with a slight increase in France and Spain, and an export decrease in Italy. Total World exports increase at 0.76%.

5.2 Macroeconomic outcomes

Resulting macroeconomic effects given changes in trade flows show countries that benefit from the opening of Arctic routes as well as countries that are worse off from a macroeconomic standpoint (see Figure 5). GDP and welfare, measured as the percentage changes in per capita utility, are expected to increases slightly (less than 0.25%) for some Northwestern European countries (Germany, United Kingdom, the Netherlands) as well as minor increases in Japan (0.25%) and the largest gains ex-

Figure 4: Changes in export values by selected countries, percentage changes



Source: Own estimations using the GTAP database.

pected for China and South Korea (1% and 0.75%, respectively).[23] Welfare and GDP gains are negligible for the US and relatively minor (less than -0.25%, in general) for France and Spain, while Italy has the largest welfare losses at -0.36%. These welfare losses are attributable to the disruption in intra-EU trade and regional production value chains resulting from the opening of the Arctic routes. While the macroeconomic effects of trade diversion may seem relatively minor, the GDP changes expected from the opening of the Arctic routes is comparable to estimates of GDP changes for key global trade liberalization from a potential Doha agreement within the WTO, or a potential bilateral Transatlantic Trade and Investment Partnership agreement between the US and EU.[24]

Figure 6 illustrates that there is a direct relationship between the expected real income changes and the corresponding country-specific changes in exports (and overall trade volumes). In general, countries that increase their exports are those that also benefit from the opening of the Arctic routes.

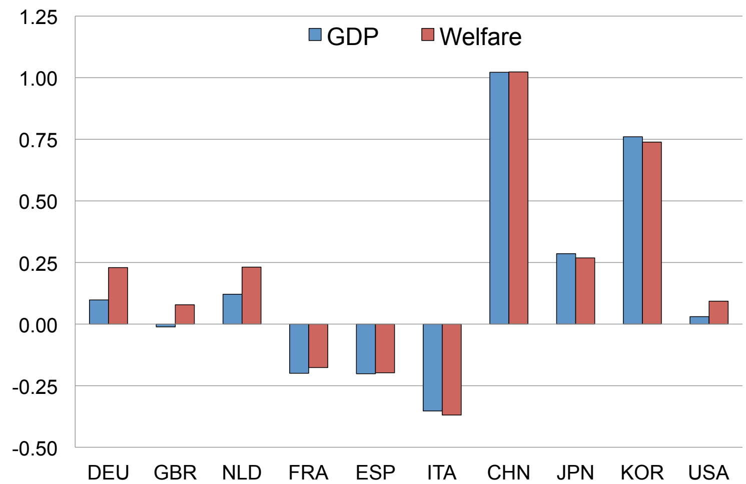
5.3 Labor market effects

We investigate the effects on labor by employing two different CGE model closures. The baseline scenario for which we have presented results thus far, assumes a flex-

[23]See also Table 17 in Appendix C for the GDP and real income changes for all countries. We also include two measures of changes in welfare: per capita utility and equivalent variation (EV) in US$ million. Both welfare measures follow roughly the same pattern as GDP and real income changes.

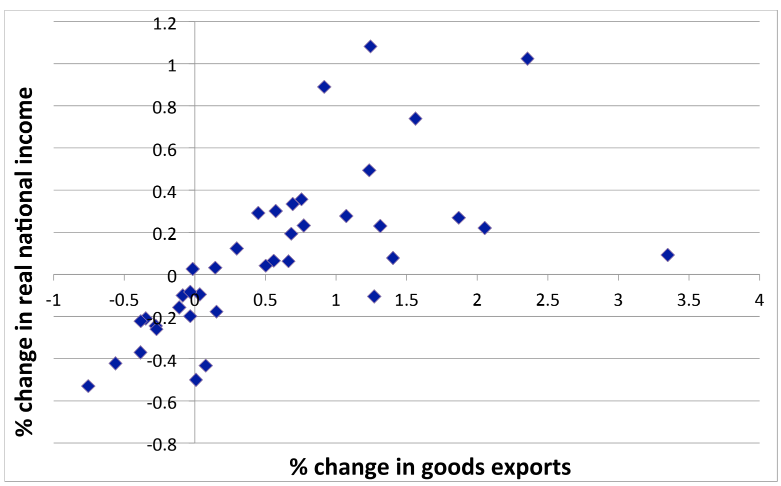
[24]See for example Francois (2000), Francois et al. (2005), and Francois et al. (2013b)).

Figure 5: GDP and welfare changes associated with the opening of both the NSR and NWR, percentage changes



Note: Welfare is measured as per capita utility. Source: Own estimations using the GTAP database.

Figure 6: Total export values and real income percentage changes



Source: Own estimations using the GTAP database.

ible labor supply, sticky wages, and labor market clearing conditions that adjust employment levels to reach the new equilibrium.[25] The second closure assumes that the labour supply is fixed and changes in wages alone are what clear the market.

Table 18 in Appendix C includes the changes in real wages and employment for both model closures. The changes in real wages are similar in sign and magni-

[25]The wage curve we use has an elasticity of 0.2.

tude for both closures that we employ. Furthermore, the expected changes in real wages follow a similar pattern as the real income changes. In general, the countries with expected declines in real incomes also have expected decreases in real wages. Furthermore, this pattern extends to the results for both skilled and unskilled labor, indicating that the expected changes in the relative demand for skilled and unskilled workers are minimal.[26] For instance, the US experiences changes in wages and employment that are very close to zero: between -0.05% and -0.01%.

The changes in total employment are negligible, as illustrated by Table 18 in Appendix C being less than a tenth of a percentage point. For most countries, the changes in real wages are not large enough to affect the overall labor supply. Under the assumption of a fixed labor supply, no changes are expected in employment by construction, as wages adjust to maintain full employment levels.

Results for the changes in employment do vary by sector, as shown in Table 19 in Appendix C. We create a labor displacement indicator to further describe the sectoral changes in employment, which is equal to the weighted standard deviation of the changes in employment by sector. This allows for a standardized measure of the employment changes by country. While there is variation by country for the labor that is displaced to another sector, these changes are around 1% on average for the labor force in a given country. The US, for example, has a labor displacement value of just around 0.35 for unskilled labor and 0.25 for skilled labor.

Furthermore, Table 19 also shows the country-specific percentage changes for unskilled workers in four selected sectors. The changes in employment of unskilled workers vary by country and sector and can be relatively high, especially in some European countries, reaching more than a 14% decrease in employment in the other manufactures sector for four countries in Europe. While the expected changes in labor displacement can be quite substantial in certain sectors, the adjustments in production and employment are expected to occur gradually over time in response to the speed by which the Arctic routes replace traditional transportation routes.

5.4 Changes in CO_2 emissions

Changes in trade flows given the emergence of Arctic shipping routes may lead to the assumption that fuel costs and CO_2 emissions would decrease for the water transportation sector, given shorter shipping distances between trading partners. However, the increases in trade volumes resulting from the decreased shipping distances between Northeastern Asia and Europe and the east coast of North America causes increased demand for shipping services. Consequently, the decreased distance is largely offset by the increased demand for shipping for regions that benefit most from the opening of the Arctic routes. Results show minimal decreases in CO_2 emissions for most countries, yet slight increases in emissions for Northeast

[26] These results are as expected, given the relatively small changes in sectoral output. The demand for skill levels differ by sector; however, if output shares by sector do not vary significantly, the corresponding demand for workers of different skill levels and the skill premium (the difference between skilled and unskilled wages) will remain steady.

Asian countries. Overall, there is a minor increase in estimated global CO_2 emissions equal to 12.46 million MT which is an increase of 0.02% relative to baseline emission levels (see Table 20 in Appendix C).[27] It is important to recognize that we assume constant emission levels by sector and country, meaning that there are no technological advancements or new policy changes altering emission levels (i.e. carbon taxes, emission permits) by country and sector for both the baseline and Arctic routes counter-factual.

6 Comparing results when different Arctic routes are available

In this final section we compare the main results of our simulations using both Arctic routes –NSR and NWR– with the simulation results in Francois and Rojas-Romagosa (2015) where only the NSR is assumed to be commercially feasible.[28] From Table 7 we observe that the trade between East Asia and Europe does not change much when the NWR is also used in conjunction with the NSR. However, trade between East Asia and the US increases significantly, especially with China, from less than 1% when only the NSR is available to more than 13% when both Arctic routes are used.

Table 7: Exports from East Asia to selected countries with different Arctic routes

	only NSR			both NSR & NWR		
	China	Japan	Korea	China	Japan	Korea
Germany	18.94	20.56	20.01	19.33	20.50	19.71
United Kingdom	17.20	14.48	17.09	17.28	14.45	16.76
France	6.58	14.79	9.09	7.04	14.69	8.74
Italy	1.24	8.33	4.47	1.21	8.38	4.31
Spain	5.37	8.20	4.98	4.83	8.17	4.77
Netherlands	16.73	19.39	19.17	16.98	19.16	18.70
EU27	14.51	17.33	15.01	14.39	17.24	14.70
USA	0.72	-0.09	-0.03	13.48	4.80	4.49

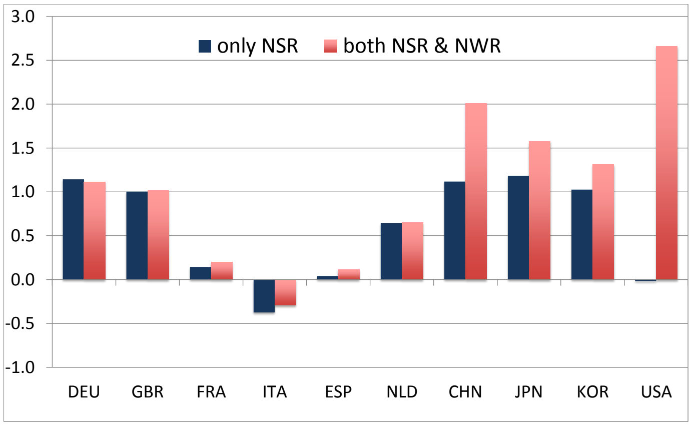
Source: Francois and Rojas-Romagosa (2015) and own estimations using GTAP database.

This pattern is confirmed in Figure 7 where total exports from Europe remain fairly constant, East Asian exports increase (mainly for China) and the US experiences the sharpest increase in total exports from nearly zero to more than 2.5%.

[27]It is important to note that the reported CO_2 estimates are relative to the baseline scenario we chose, but different baselines would yield the same qualitative result as long as relative emission patterns are similar.

[28]Recall from Section 2 that the NSR is more likely to be commercially feasible than the NWR. This fact explains the two choices of Arctic routes: only NSR, and both NSR and NWR.

Figure 7: Total exports for selected countries using different Arctic routes, percentage changes



Source: Francois and Rojas-Romagosa (2015) and own estimations using the GTAP database.

Export changes are translated into GDP and welfare (i.e. per capita utility) effects. The US moves from negative to positive GDP and welfare changes, while China experiences a doubling on both variables. This relatively big increases are associated with the baseline scenario where China is the country with the largest growth rate, and as such, has more capacity to expand exports and take advantage of both Arctic routes. On the contrary, Japan and Korea do not experience much changes from the first scenario to the second in which the NWR is also commercially feasible. For Europe, the changes from one scenario to the other are also small, but in general the positive and negative effects are reduced, because trade diversion through the NSR only, is less intensive with the opening of the NWR: East Asia exports more to the US in this second case.

Table 8: GDP and welfare changes associated with different Arctic routes

	only NSR		both NSR & NWR	
	GDP	Welfare	GDP	Welfare
Germany	0.18	0.32	0.10	0.11
United Kingdom	0.01	0.10	-0.01	-0.05
France	-0.25	-0.22	-0.20	-0.23
Italy	-0.51	-0.52	-0.35	-0.37
Spain	-0.27	-0.25	-0.20	-0.26
Netherlands	0.21	0.32	0.12	0.15
China	0.57	0.56	1.02	1.13
Japan	0.29	0.27	0.29	0.36
Korea	0.73	0.70	0.76	0.78
United States	-0.03	-0.04	0.03	0.08

Source: Francois and Rojas-Romagosa (2015) and own estimations using GTAP database.

Finally, in Table 21 in Appendix C we observe that CO_2 emissions are increasing for both scenarios, but the increase is smaller for the case where both the NSR and NWR are used. This is explained by the emission reductions in the US (using the shorter NWR than the Panama Canal) that compensates for the increased emissions from China, which is expanding its exports using both Arctic routes.

7 Summary

Continued melting of the Arctic ice caps is expected to allow the commercial feasibility of the Northern Sea Route and the North Western Route. Use of the Arctic shipping lanes would significantly reduce shipping distances and travel times between Northeast Asia and two of the world's largest economies, the EU and US, which will create opportunities for growth in trade between these critical regions. US Customs data shows that two thirds of US trade with Northeastern Asia travels through the Panama Canal, which represents 35% of the ship traffic through the canal. The distance reductions between the US and key Northeast Asian countries given use of the NWR rather than the Panama Canal range from 9% to 11% which corresponds to estimated shipping services cost reductions ranging from nearly 7% to more than 11% from the US and from 20% to 40% from Western Europe to Northeast Asian countries.

Therefore, if the NWR becomes a full-year commercially feasible route between East Asia and North America, it is then expected that the current commercial traffic that goes through the Panama Canal will be reduced by up to one-third and between 4000 and 4500 vessels will be using the NWR. These shipping route changes will generate massive geopolitical implications for both Panama and Canada (where most of the NWR is located). Nevertheless, the transition from the Panama Canal to the NWR will be a very gradual process conditional on the pace of icecap melting.

The decreased distances, transportation and trade cost reductions associated with both Arctic routes are expected to increase trade flows between Northeast Asia and the US by values ranging from 3.1% to nearly 13.5%, and increases in Northeast Asia-EU trade between 7.9% to 17.2%, depending on bilateral trade partners. These trade increases are translated into improvements in welfare and GDP growth in the countries that experience the biggest exports changes from the opening of the Arctic routes. In particular, China, Japan and Korea will benefit the most from these new shipping routes.

There are minor increases in CO_2 emissions expected, given increased global trade volumes and corresponding changes in region and sector-specific production. This undoubtedly raises additional questions regarding the environmental impacts of potential future commercial use of the Arctic routes as viable shipping lanes. Furthermore, trade diversion effects will negatively impact some (Central and Southern) European countries that suffer from decreases in intra-European trade, as well as potential labor displacement given production responses that are region and sector specific.

Overall, Northeast Asian countries, the US and a subset of European countries stand to benefit from commercial use of Arctic shipping lanes. When we compare two Arctic shipping scenarios –i.e. only the NSR is available, and both the NSR and NWR are used– the main difference is that the US will experience a significant export increase and a move from negative to positive GDP and welfare increases. China is expected to benefit the most from the joint use of both Arctic routes.

Environmental and socio-political concerns, however, may affect the degree to which these emerging trade routes may be utilized in the future. Above all, the degree to which these emerging trade routes are viable shipping options depend on the future condition of the Arctic icecaps and the ability of the shipping industry to overcome transport logistic issues that will allow the routes to become fully operational.

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A Gravity model specification

We estimate trade price and distance elasticities structurally, based on the underlying theoretical structure of the trade equations in our computational model. The computational model includes CES (constant elasticity of substitution) based demand for intermediate and final goods differentiated either by firm or country. This depends on whether the sector is modeled with Armington preferences, or with monopolistic competition following Krugman (1980). In both cases, trade flows can be represented as a log-linear function defined over relevant arguments. Using this functional form as our estimating equation is consistent with both the structure of the computational model, and with the recent gravity literature.[29] The gravity model is a standard and well-known empirical workhorse in international trade. An econometrically estimated gravity model provides estimates of how much physical and socio-economic distance between partners, as well as policy, determines bilateral trade flows. Importer and exporter fixed effects are used to capture structural determinants of trade that are country specific (Anderson and Yotov, 2012).

The basic estimating equation takes the following form:

$$v_{jsd} = e^{D_{js}+D_{jd}+\sum\limits_{i}\beta_{ji}X_{isd}+\eta_{jsd}} \tag{4}$$

where the term v_{jsd} is the value of bilateral imports in sector j originating in source country s and exported to destination country d. In addition to a vector of pairwise variables X_{isd} –where i is a sector different from j– the importer and exporter fixed effects D capture country specific (i.e. not varying by partner) structural properties (Anderson and Yotov, 2012). The vector of β_{ji} coefficients apply to our pairwise variables and η_{jsd} are the error terms.

Our trade, distance, and socio-economic data for estimating equation (4) represent bilateral trade between 107 countries. Trade data are taken from COMTRADE. Data for tariffs come from the World Bank/UNCTAD WITS database. Regarding tariffs, importer fixed effects capture the most favored nation (i.e. MFN or non-preferential) tariff, while the log difference between the MFN rate $ln(1+t_{MFN})$ and the preferential tariff (where there is a free trade agreement or customs union) is included as a pairwise tariff variable. In addition to the shipping distances discussed above, socio-economic data are from Dür et al. (2014), the CEPII database (Mayer and Zignago, 2011), and the Quality of Governance (QoG) expert survey dataset

[29] See for example Anderson and van Wincoop (2003), Baldwin and Taglioni (2006), Francois and Woerz (2009), Egger et al. (2011) and Anderson and Yotov (2012).

(Teorell et al., 2011).[30] The coefficient on the tariff term is known as the trade or price elasticity. In CES based trade models, it has varying interpretations, though in the present context it serves in our structural model as an estimate of the trade substitution elasticity. Distance data, as discussed above, are based on the length of shipping routes. Following Santos Silva and Tenreyro (2006, 2011), we estimate equation (4) with a Poisson pseudo-maximum likelihood (PPML) estimator, both for total goods trade, and for trade for each sector in the computational model. The results are shown in Table 9.

[30] Following Egger et al. (2011), we instrument preferential trade agreements by a set of political economy variables from Teorell et al. (2011). We include policy, functioning of government, corruption, and civil liberties measures, as well as lagged trade network embeddedness (Easley and Kleinberg, 2010; De Benedictis and Tajoli, 2011; Zhou, 2011), distance, common border, common language, former colonial ties, population and GDP. Preferential trade agreements are free trade agreements and customs unions that have been agreed at least four years previously (Dür et al., 2014). The political economy variables also include pairwise measures of similarity, reflecting evidence that homophily is important in explaining direct economic and political linkages (De Benedictis and Tajoli, 2011).

Table 9: PPML gravity estimates for total trade and by sector for all manufacturing goods

	TOTAL TRADE	primary agriculture	fisheries	forestry	primary energy
ln(1+tariff)	-10.398***	-3.348***	-13.448***	-4.881**	-23.292***
ln(distance)	-0.480***	-0.758***	-1.233***	-0.799***	-0.917***
common colony	0.524***	0.527***	0.406	2.020***	0.036
common language	0.288***	0.373**	-0.369**	0.171	0.559***
common border	0.623***	0.770***	1.180***	1.950***	0.767***
ln(polity)(similarity)	-83.950***	58.596	-125.361	243.660**	-28.045
former colony	0.230**	0.014	0.859***	0.348*	0.700***
PTA	0.315**	0.125	0.930***	-0.161	0.158
obs	11,145	11,058	10,330	11,075	9,436
R-squared	0.848	0.784	0.928	0.933	0.636

	processed foods	beverages, tobacco	textiles	clothing	footwear
ln(1+tariff)	-2.299***	-4.229***	-9.780***	-3.652***	-8.172***
ln(distance)	-0.688***	-0.642***	-0.593***	-0.550***	-0.210**
common colony	0.415	1.196***	-0.390	-0.092	0.447*
common language	0.386***	0.581***	0.429***	0.565***	-0.021
common border	0.767***	0.677***	0.361**	0.378**	0.587***
ln(polity)(similarity)	99.367***	206.950***	-165.480***	-207.661***	-131.572**
former colony	0.280**	0.652***	0.165	0.216*	0.384**
PTA	0.085	0.398	0.619***	0.812***	0.828***
obs	11,077	11,088	11,125	11,055	11,108
R-squared	0.767	0.819	0.947	0.972	0.966

	wood, wood products	paper, publishing	petro-chemicals	chemicals, rub-bev, plastic	metals, metal products
ln(1+tariff)	-9.401***	-8.307***	-5.073	-5.532**	-8.010***
ln(distance)	-0.509***	-0.661***	-0.885***	-0.564***	-0.685***
common colony	0.991***	0.827***	-0.398*	0.083	0.347
common language	0.073	0.371***	0.433***	0.195**	0.007
common border	1.117***	1.018***	0.559***	0.483***	0.680***
ln(polity)(similarity)	-76.946	39.196	43.319	64.571**	11.589
former colony	0.156	0.211	-0.046	0.370***	0.314***
PTA	0.636***	0.191	0.357	0.240*	0.018
obs	11,084	11,079	10,870	11,118	11,068
R-squared	0.887	0.800	0.617	0.877	0.713

	motor vehicles	other trans-port equipment	office machinery	other machines	other manufacturing
ln(1+tariff)	-12.989***	-16.167***	-33.576***	-14.207***	-10.862***
ln(distance)	-0.309***	-0.138**	-0.398***	-0.441***	-0.463***
common colony	0.707*	0.791**	0.352	0.411**	2.297***
common language	0.339**	-0.229	0.107	0.342***	0.434**
common border	0.945***	1.149***	0.435***	0.514***	-0.115
ln(polity)(similarity)	60.023	-32.008	-150.531**	-141.534***	-176.474**
former colony	-0.530***	0.517**	0.140	0.279**	0.226
PTA	1.015***	0.165	0.328	0.277*	0.217
obs	11,102	11,082	11,097	11,115	11,113
R-squared	0.882	0.865	0.930	0.906	0.913

Notes: All estimates include exporter and importer fixed effects (not shown).

Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Source: Own estimations.

B CGE model summary

The CGE modeling frameworks allow for economy-wide economic analysis. By employing a balanced and internally consistent global database, in tandem with an economic model that describes economic activity for a variety of sectors and agents in the global economy, any change in exogenous variables can be assessed to understand the effects on endogenous variables in the model. The key features of a CGE framework include the model that describes economic activity and behavior, the underlying database that accounts for initial equilibrium of the global economy, as well as the suit of parameters that drive responses of agents to any given perturbation to the initial equilibrium.

B.1 Standard GTAP model

The particular model we use in this paper is a modified version of the standard GTAP-class CGE model. The main characteristics and references to the standard GTAP model can be found at: www.gtap.agecon.purdue.edu/models/current.asp, while Hertel (2013) and Rutherford and Paltsev (2000) provide a detailed discussion of the GTAP-class models. Here we provide a summary of this model.

The standard GTAP model describes the global economy as a whole and the interaction among economic agents. Macroeconomic factors are accounted for, including GDP, savings and investment, as well as wages and rents. Microeconomic factors are also described including supply-side factors, firms' production decisions; demand-side factors, including behavior by households and governments; factor market conditions governing labor and capital, as well as international trade. The model is employed in tandem with actual data from a given base year to quantify the effects of an economic shock that causes a movement from the initial equilibrium of the economy (see Narayanan et al. (2012) for documentation on the GTAP 8 database, and Hertel (2013) on the full database project). The initial condition of the model is that supply and demand are in balance at some equilibrium set of prices and quantities where workers are satisfied with their wages and employment, consumers are satisfied with their basket of goods, producers are satisfied with their input and output quantities and savings are fully expended on investments. Adjustment to a new equilibrium, governed by behavioral equations and parameters in the model, are largely driven by price linkage equations that link all economic activity in the market. For any perturbation to the initial equilibrium, all endogenous variables (i.e. prices and quantities) adjust simultaneously until the economy reaches a new equilibrium. Constraints on the adjustment to a new equilibrium include a suit of accounting relationships that dictate that in aggregate, the supply of goods equals the demand for goods, total exports equals total imports, all (available) workers and capital stock is employed, and global savings equals global investment; unless adjustments to these assumptions are modified for a particular application. Economic behavior drives the adjustment of quantities and prices given that consumers maximize utility given the price of goods and consumers' budget constraints, and producers minimize costs, given input prices, the level of output and production technology.

From the consumption side, the model includes a Constant Difference of Elasticities (CDE) specification for household demand. Private consumption demands for composite commodities are modeled on a per capita basis, and each region is represented by a regional household. All partial elasticities of substitution for composite commodities as well as price and income elasticities drive demand responses to economic shocks.

The standard GTAP model provides an explicit and detailed treatment of international trade and transport margins. Bilateral trade is handled via CES (constant elasticity of substitution) preferences for intermediate and final goods, using the so-called Armington assumption, where the substitution of domestics and imports –as well as product differentiation– is driven by the region of origin (i.e. by import source). This assumption is generic to most CGE models as it is a simple device to account for "cross-hauling" of trade (i.e. the empirical observation that countries often simultaneously import and export goods in the same product category).

B.2 Particular CGE model specification of the paper

In our model, however, we employ a modified version of the standard GTAP model that allows for monopolistic competition and increasing returns to scale (Krugman, 1980; Francois et al., 2013a).[31] In this specification there is a representative firm for each sector that produces a unique variety of the good and hence, behaves as a monopolist in their specific market.

This specification substitutes the commonly used Armington specification for import demands, by allowing the demand for differentiated intermediate products to be based on firms, or product variety, rather than over regions of origin. While firms behave as monopolists, the existence of free entry drives economic profits to zero, so that pricing is at average cost, as is the case in the standard GTAP model specification.

In particular, we use the love-of-variety –i.e. Spence-Dixit-Stiglitz (SDS)– preferences for intermediate and final goods for non-agricultural sectors. Within a representative firm, one can assume individual varieties are symmetrical in terms of selling at the same price and quantity, but that increases in the number of varieties yielding benefits because they are perceived to be different by intermediate and final demand agents. This approach can be nested within a basic CES demand system that includes both Armington- and SDS-type demand systems for individual sectors using Ethier and Krugman-type monopolistic competition models –i.e. differentiated intermediate and differentiated consumer goods.[32]

[31] Moreover, this theoretical specification of the trade structure based on Krugman (1980), can be directly linked to a corresponding gravity equation (Costinot and Rodríguez-Clare, 2013).

[32] This can be done because one can reduce Ethier-Krugman-models algebraically to Armington-type demand systems with external scale economies linked to a variety of effects (Francois and Roland-Holst, 1997; Francois and Nelson, 2002).

Economies of scale are then modeled using the concept of variety-scaled goods. We can define 'variety-scaled output', which refers to physical quantities, with a 'scaling' or quality coefficient that reflects the varieties embodied on total physical output. This variety-scaled output can be substituted directly into an Armington-type demand system. The precise modeling in the CGE-GTAP code is done by means of a closure swap that yields output level and variety scaling effects at the sectoral level. This implies that sectoral productivity is now endogenous in the model and it adjusts to capture the output scale and variety effects.

Another key specification that is distinguishes our model is the calculation of changes in CO_2 emissions by region and sector, given the emergence of new trade routes. The inclusion of CO_2 data and the corresponding model-predicted changes in CO_2 emissions allow for the analysis of environmental impacts that are expected, given the future use of the NSR.

B.3 CGE model limitations and alternative model specifications

One of the limitations of CGE models is that it assumes that after an exogenous shock (e.g. a trade cost change) the economy adjusts instantly. In practice, these adjustments may take time and the costs linked to these changes (for instance, shifting production and workers between sectors, changing consumption patterns, adjusting tax revenues between different sources) may be significant and CGE models are not designed to assess these adjustment costs. Nevertheless, the magnitude of the required changes implicit in the model simulations can provide a guide into assessing these short-term costs. However, in the context of this paper, where the use of the NSR and NWR is expected to be a gradual and medium to long-term process, the required adjustments will be spread over time and thus, more easily absorbed by different regions within several years.

More recently, a series of papers analyze the welfare and overall macroeconomic outcomes of employing different market structures and trade specifications into quantitative trade models (cf. Costinot and Rodríguez-Clare, 2013). These micro-theory based econometric models are highly stylized quantification methods, that are well grounded in recent micro-economic theory, and provide clear theoretical links between market structure and the gravity equation. However, given that most of these models are single-sector specifications, their scope is very limited in terms of actual analysis, and they are not capable of dealing with detailed analysis of global trade issues. In particular, these models are not able to deal with intermediate linkages associated with global supply chains and their associated carbon emissions; on how emissions are linked to country- and sector-specific transport activities; and on how to separate actual transport costs from time related costs that are sector-specific in nature. These are issues central to the evaluation of the economic and environmental effects of the Arctic routes that can only be tackled using a CGE model. The exception is a sub-class of models that employ a multi-sector trade structure specification following Eaton and Kortum (2002). However, these type of models are still not detailed enough to assess the effects of trade changes associated with alternative shipping routes as the NSR and NWR. In particular, they do not have an explicit international transport section, which is the key variable that explains the linkage between shipping trade cost reductions that are directly associated with the Arctic shipping lanes.

Different market structure specifications may generate different sectoral outcomes depending on the particulars of the specific sectors and how they are modeled –see Francois et al. (2013a) for a more technical discussion of demand systems and different market structures. However, at the aggregate level, there will be relatively small differences between model specifications. For example, Arkolakis et al. (2012) point out that welfare effects are similar for the different trade structure specifications.

Since the main driving force in our bilateral trade results is a reduction on the trading distance between partners that follows from the gravity model of trade, it is expected that similar bilateral trade results and overall welfare and macroeconomic effects will be found using a wider set of trade models –although the output implications can be different between both sets of models for specific sectors.

C Additional tables and figures

Table 10: Different distance values for selected countries

From:	To:	Great-circle formula (km)	SSR (km)	NSR (km)	NSR against SSR % change
China	Netherlands	7,831	19,942	15,436	-23%
China	Belgium	7,971	19,914	15,477	-22%
China	Germany	7,363	20,478	15,942	-22%
China	United Kingdom	8,151	19,799	14,898	-25%
Japan	Netherlands	9,303	20,996	13,172	-37%
Japan	Belgium	9,464	20,976	13,345	-36%
Japan	Germany	8,928	21,536	13,083	-39%
Japan	United Kingdom	9,574	20,779	13,182	-37%
South Korea	Netherlands	8,573	20,479	14,200	-31%
South Korea	Belgium	8,722	20,458	14,373	-30%
South Korea	Germany	8,140	21,019	14,110	-33%
South Korea	United Kingdom	8,875	20,262	14,210	-30%
Taiwan	Netherlands	9,457	18,822	15,601	-17%
Taiwan	Belgium	9,587	18,801	15,774	-16%
Taiwan	Germany	8,959	19,362	15,511	-20%
Taiwan	United Kingdom	9,790	18,605	15,611	-16%

Sources: Great-circle distances taken from the GeoDist database from CEPII. SSR and NSR distances are own estimations based on data from AtoBviaC, BLM Shipping, and Liu and Kronbak (2010).

Table 11: Sectoral description and aggregation

Code	Sector description	Aggregated GTAP sectors
S01	Agricultural products	OSD (oil seeds), C_B (sugar cane), PFB (plant-based fibbers), CTL (cattle), OAP (animal prods nec), RMK (raw milk), WOL (wool)
S02	Motor vehicles	MVH (motor vehicles and parts)
S03	Beverages and tobacco	B_T (beverages & tobacco products)
S04	Chemicals	CRP (Chemical, rubber and plastic products)
S05	Clothing	WAP (wearing apparel)
S06	Plant products	OCR (crops nec)
S07	Fisheries	FSH (fishing)
S08	Processed foods	PDR (paddy rice), WHT (wheat), GRO (cereal grains nec), V_F (vegetables & fruits), CMT (bovine meat prods), OMT (Meat prods nec), VOL (vegetable oils), MIL (diary prod), PCR (processed rice), SGR (sugar), OFD (food products nec)
S09	Leather products	LEA (leather products)
S10	Forestry	FRS (forestry)
S11	Metals	I_S (ferrous metals), NFM (metals nec), FMP (metal products)
S12	Office machinery	ELE (electronic equipment)
S13	Other machinery	OME (machinery and equipment nec
S14	Other manufactures	NMM (mineral products nec), OMF (manufactures nec)
S15	Petrochemicals and gas	P_C (Petroleum and coal products), GDT (gas manufacture and distribution)
S16	Mining and extraction	COA (coal), OIL (oil), GAS (gas), OMN (Minerals nec)
S17	Textiles	TEX (textiles)
S18	Transport equipment	OTN (transport equipment nec)
S19	Paper products and publishing	PPP (paper products and publishing)
S20	Wood products	LUM (wood products)
S21	Transport services	OTP (transport nec), WTP (water transport), ATP (air transport)
S22	Commercial services	WTR (water), CNS (construction), TRD (trade), CMN (communication), OFI (financial services nec), ISR (insurance), OBS (Business services nec)
S23	Public and consumer services	ELY (electricity), ROS (recreational and other services), OSG (Public Administration, Defence, Education, Health), DWE (dwellings)

Table 12: Regional aggregation

	Code	Country / Region		Code	Country / Region
1	AUT	Austria	21	SVK	Slovakia
2	BEL	Belgium	22	SVN	Slovenia
3	CYP	Cyprus	23	ESP	Spain
4	CZE	Czech Republic	24	SWE	Sweden
5	DNK	Denmark	25	GBR	United Kingdom
6	EST	Estonia	26	BGR	Bulgaria
7	FIN	Finland	27	ROU	Romania
8	FRA	France	28	NOR	Norway
9	DEU	Germany	29	CHN	China
10	GRC	Greece	30	HKG	Hong Kong
11	HUN	Hungary	31	JPN	Japan
12	IRL	Ireland	32	KOR	South Korea
13	ITA	Italy	33	PHL	Philippines
14	LVA	Latvia	34	PNG	Other Asia Pacific
15	LTU	Lithuania	35	TWN	Taiwan
16	LUX	Luxembourg	36	USA	United States
17	MLT	Malta	37	OCD	Other OECD
18	NLD	Netherlands	38	SSA	Sub-Sahara Africa excl. ZAF
19	POL	Poland	39	ROW	Rest of the World
20	PRT	Portugal			

Table 13: Northeast Asia, changes in trade volumes, percentage changes

	China		Japan		South Korea	
	exports	imports	exports	imports	exports	imports
Germany	12.61	21.06	18.51	30.29	13.17	24.03
United Kingdom	13.32	21.25	17.92	28.26	8.74	22.94
France	3.54	8.25	11.67	21.54	9.42	10.75
Italy	-2.14	1.25	4.24	11.50	3.09	5.14
Spain	2.62	5.24	8.31	14.96	7.65	9.40
Netherlands	11.14	20.75	17.74	33.43	20.91	23.30
USA	4.97	12.67	3.34	6.06	4.47	5.14

Source: Own estimations using the GTAP database.

Table 14: Changes in export values by destination region, percentage changes

	Total intra-EU,	of which:			Northeast Asia	Other regions	Total
		South EU	East EU	Northwest EU			
Austria	-1.14	-0.20	-1.35	-1.57	23.31	0.37	0.44
Belgium	-0.39	0.38	-0.79	-0.70	18.62	0.09	0.76
Bulgaria	-0.91	-0.24	-0.93	-0.90	0.69	0.51	0.05
Cyprus	-0.41	-0.20	-0.44	-0.41	0.39	0.31	-0.03
Czech Republic	-0.83	1.36	-1.02	-1.29	20.99	1.70	0.11
Denmark	-0.95	0.10	-1.18	-1.11	20.88	0.25	0.88
Estonia	-1.15	-0.68	-1.53	-1.04	26.37	0.64	0.47
Finland	-1.65	0.37	-2.59	-1.91	17.44	1.10	1.68
France	-1.04	-0.38	-1.56	-1.19	7.87	0.61	0.20
Germany	-1.27	-0.31	-1.83	-1.37	18.72	0.73	1.11
Greece	-0.60	-0.34	-0.27	-0.82	-0.57	0.35	-0.10
Hungary	-1.46	0.09	-1.37	-1.74	5.53	1.04	-0.54
Ireland	-0.96	0.09	-1.80	-1.09	14.72	0.61	0.34
Italy	-1.32	-0.49	-1.63	-1.35	2.59	0.42	-0.29
Latvia	-1.00	-0.43	-0.99	-1.05	26.46	1.04	0.50
Lithuania	-1.28	-0.98	-1.30	-1.27	37.05	0.53	0.15
Luxembourg	-0.56	0.07	-0.97	-0.57	8.32	0.12	0.03
Malta	-1.85	-0.36	-1.33	-1.85	2.55	0.25	-0.36
Netherlands	-0.58	0.11	-1.21	-0.56	15.49	0.74	0.65
Poland	-1.23	0.93	-1.20	-1.27	37.93	0.34	1.12
Portugal	-1.01	-0.49	-1.93	-1.14	5.21	0.65	-0.01
Romania	-0.87	-0.08	-0.29	-0.95	-1.35	1.16	-0.05
Slovakia	-0.83	1.22	-0.79	-0.90	16.40	1.61	0.08
Slovenia	-1.08	-0.24	-1.09	-1.11	3.53	0.61	-0.26
Spain	-0.79	-0.30	-1.59	-0.77	4.79	0.44	0.12
Sweden	-1.05	-0.30	-1.63	-1.01	19.95	0.03	0.58
United Kingdom	-0.58	0.13	-1.09	-0.58	14.57	0.86	1.01
China	7.77	-0.23	9.51	8.43	-0.19	0.86	2.01
Japan	11.68	6.83	10.66	4.72	-0.08	0.53	1.57
Korea	8.12	3.07	7.83	2.83	0.66	0.30	1.31
Taiwan	1.70	-1.91	0.71	1.00	0.69	0.22	0.59
Hong Kong	0.00	-0.13	-0.37	0.52	0.86	0.30	0.44
USA	-1.61	-0.80	-2.85	6.15	11.29	-0.55	2.66

Notes: South EU is: Cyprus, Greece, Italy, Malta, Portugal and Spain. East EU is: Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia and Slovenia. Northwestern EU is: Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Luxembourg, the Netherlands, Sweden and the United Kingdom. Northeast Asia is: China, Japan, South Korea, Hong Kong and Taiwan.

Source: Own estimations using the GTAP database.

Table 15: Sectoral changes in export sales to USA for selected countries, percentage changes

	FRA	DEU	ITA	NLD	ESP	GBR	CHN	JPN	KOR
Sector:									
S01	2.4	2.2	2.5	1.5	2.3	2.1	6.9	14.6	12.1
S02	0.3	-0.9	-0.4	0.9	0.1	0.3	7.7	2.6	1.7
S03	0.0	0.3	-0.2	0.2	0.0	0.2	7.5	9.9	9.9
S04	-0.4	0.6	-0.4	-0.5	-0.4	0.3	6.7	7.0	5.2
S05	-0.8	-1.0	-0.8	-1.6	-0.5	-1.8	5.5	5.3	5.2
S06	0.6	0.5	0.8	0.2	0.6	0.5	5.7	11.9	8.8
S07	-1.2	4.0	0.4	2.3	0.1	2.8	0.0	14.0	7.4
S08	0.2	0.5	0.0	0.5	0.2	0.5	6.4	10.2	9.4
S09	-1.3	0.0	-1.7	1.8	-1.3	0.3	1.0	5.7	2.5
S10	-0.2	-10.6	0.5	-2.4	2.0	3.8	4.9	15.5	11.7
S11	0.0	-1.4	0.2	-1.5	-0.3	-0.3	6.4	7.9	7.7
S12	-1.5	0.7	-3.2	3.8	-1.0	3.4	2.0	1.7	0.1
S13	-0.8	-0.3	-1.2	-0.1	-0.8	0.2	4.8	2.8	4.5
S14	-2.9	-1.1	-4.4	2.8	-3.7	0.2	3.5	0.0	6.9
S15	0.1	0.6	0.2	0.5	0.2	0.2	7.8	9.2	8.0
S16	2.8	0.4	3.6	4.0	0.8	2.6	23.9	21.4	48.3
S17	-1.4	-0.2	-2.4	1.0	-1.8	0.4	2.8	4.7	4.3
S18	0.0	-0.2	-0.8	0.8	-0.4	0.1	8.9	1.0	1.5
S19	-0.4	-0.4	-0.6	-0.2	-0.6	0.2	8.0	8.5	9.0
S20	-1.1	0.0	-0.8	2.0	-0.8	5.5	7.6	5.9	6.6
S21	0.1	0.4	0.0	0.3	0.2	0.2	0.6	-0.2	0.0
S22	-0.1	0.1	-0.4	0.1	0.0	0.1	0.6	-0.5	0.1
S23	1.3	0.1	1.2	-0.2	1.2	0.9	-2.3	-1.1	-1.7
Simple average	-0.2	-0.2	-0.3	0.7	-0.2	1.0	5.5	6.9	7.4

Notes: The description of each sector is given in Table 11.

Source: Own estimations using the GTAP database.

Table 16: Sectoral changes in export sales to China for selected countries, percentage changes

	FRA	DEU	ITA	NLD	ESP	GBR	JPN	KOR	USA
Sector:									
S01	10.2	30.4	2.9	26.7	7.4	26.6	3.9	3.1	8.6
S02	9.2	14.4	3.2	20.9	7.3	12.3	1.3	0.8	6.6
S03	7.5	22.9	1.4	20.5	5.5	20.8	2.0	2.6	8.4
S04	6.4	23.0	0.5	18.9	4.7	20.3	0.5	0.1	6.0
S05	5.2	15.8	1.2	13.5	4.1	12.8	0.4	0.9	3.4
S06	8.1	27.8	1.0	24.7	5.7	24.2	1.6	0.0	7.3
S07	46.3	128.6	11.7	85.5	22.9	47.5	4.6	6.5	37.7
S08	8.9	26.5	2.0	24.1	6.5	23.1	2.3	2.8	9.3
S09	9.0	15.5	4.4	16.1	6.4	13.1	3.2	4.0	8.3
S10	8.8	16.4	1.1	23.5	8.4	31.0	5.9	3.6	6.2
S11	7.5	22.4	1.5	19.7	5.0	21.3	0.5	1.3	8.0
S12	10.4	25.9	4.8	32.1	12.3	29.3	0.0	1.3	9.9
S13	7.7	16.9	2.7	16.6	6.5	15.7	0.1	1.1	7.3
S14	11.9	33.0	3.0	33.8	11.1	24.5	1.3	1.6	11.2
S15	8.2	32.6	0.3	29.0	5.5	27.3	0.0	0.0	6.1
S16	12.1	20.1	-1.7	23.5	5.3	22.9	-1.2	-3.5	14.3
S17	29.0	28.1	5.0	27.1	10.2	24.6	2.6	2.3	13.5
S18	6.8	10.5	4.7	19.5	7.7	10.4	1.7	2.6	6.1
S19	9.0	24.0	2.6	24.4	6.7	21.9	1.1	1.4	10.4
S20	16.8	35.0	8.2	38.8	14.6	32.4	6.5	5.1	20.0
S21	0.3	0.6	0.2	0.5	0.4	0.4	0.0	0.2	0.1
S22	0.3	0.5	0.1	0.6	0.5	0.5	0.0	0.5	0.5
S23	4.5	3.3	4.4	3.1	4.4	4.1	2.1	1.5	3.3
Simple average	10.6	25.0	2.8	23.6	7.3	20.3	1.8	1.7	9.2

Notes: The description of each sector is given in Table 11.

Source: Own estimations using the GTAP database.

Table 17: CGE results on GDP, real income and welfare

	GDP index	Real Income	Welfare (per capita utility) % changes	Welfare (equivalent variation in US$ million)
Austria	-0.02	0.00	0.06	336
Belgium	0.77	0.85	0.89	5,577
Cyprus	-0.21	-0.22	-0.24	-72
Czech Republic	-0.51	-0.50	-0.43	-1,232
Denmark	0.35	0.39	0.49	2,389
Estonia	0.14	0.16	0.30	116
Finland	0.09	0.13	0.22	654
France	-0.20	-0.23	-0.18	-6,259
Germany	0.10	0.11	0.23	9,067
Greece	-0.18	-0.18	-0.21	-880
Hungary	-0.50	-0.54	-0.53	-939
Ireland	0.21	0.20	0.29	1,271
Italy	-0.35	-0.37	-0.37	-8,868
Latvia	-0.01	-0.08	0.04	19
Lithuania	-0.19	-0.19	-0.10	-52
Luxembourg	0.00	0.01	0.03	25
Malta	-0.38	-0.38	-0.42	-49
Netherlands	0.12	0.15	0.23	2,673
Poland	-0.22	-0.21	-0.10	-892
Portugal	-0.25	-0.31	-0.26	-753
Slovakia	-0.58	-0.54	-0.50	-757
Slovenia	-0.21	-0.26	-0.22	-153
Spain	-0.20	-0.26	-0.20	-3,409
Sweden	-0.06	-0.07	0.06	466
United Kingdom	-0.01	-0.05	0.08	3,554
Bulgaria	-0.09	-0.14	-0.10	-85
Romania	-0.14	-0.20	-0.16	-447
Norway	0.10	0.31	0.36	3,511
China	1.02	1.13	1.02	149,194
Hong Kong	0.37	0.27	0.28	1,139
Japan	0.29	0.36	0.27	11,535
South Korea	0.76	0.78	0.74	13,187
Philippines	0.35	0.36	0.33	1,107
Other Asia Pacific	0.74	1.15	1.08	1,905
Taiwan	0.19	0.25	0.19	1,532
United States	0.03	0.08	0.09	23,838
Other OECD	-0.02	0.08	0.03	1,691
Sub-Sah Africa exc. ZAF	0.03	0.25	0.12	3,366
Rest of the World	-0.13	0.01	-0.08	-30,503
Total (World)	0.10	0.19	0.15	182,801

Source: Own estimations using the GTAP database.

Table 18: CGE results for the labour market, real wages and total employment changes for unskilled and skilled workers, percentage changes

	Changes in real wages				Changes in total employment			
	fixed labour supply		flexible lab. supply		fixed labour supply		flexible labour supply	
	unskilled	skilled	unskilled	skilled	unskilled	skilled	unskilled	skilled
AUT	0.00	0.04	-0.01	0.02	0	0	0.00	0.00
BEL	0.90	0.91	0.94	0.96	0	0	0.19	0.19
CYP	-0.27	-0.22	-0.30	-0.25	0	0	-0.06	-0.05
CZE	-0.58	-0.42	-0.72	-0.58	0	0	-0.14	-0.12
DNK	0.45	0.49	0.47	0.51	0	0	0.09	0.10
EST	0.12	0.31	0.11	0.28	0	0	0.02	0.06
FIN	0.12	0.17	0.09	0.13	0	0	0.02	0.03
FRA	-0.23	-0.20	-0.30	-0.27	0	0	-0.06	-0.05
DEU	0.08	0.15	0.08	0.14	0	0	0.02	0.03
GRC	-0.22	-0.19	-0.28	-0.24	0	0	-0.06	-0.05
HUN	-0.62	-0.45	-0.73	-0.57	0	0	-0.15	-0.11
IRL	0.25	0.26	0.34	0.35	0	0	0.07	0.07
ITA	-0.41	-0.40	-0.55	-0.54	0	0	-0.11	-0.11
LVA	-0.16	0.02	-0.18	-0.02	0	0	-0.04	0.00
LTU	-0.25	-0.03	-0.27	-0.07	0	0	-0.05	-0.01
LUX	0.11	0.10	0.09	0.08	0	0	0.02	0.02
MLT	-0.38	-0.28	-0.43	-0.34	0	0	-0.09	-0.07
NLD	0.23	0.26	0.24	0.27	0	0	0.05	0.05
POL	-0.34	-0.17	-0.40	-0.26	0	0	-0.08	-0.05
PRT	-0.34	-0.26	-0.42	-0.35	0	0	-0.08	-0.07
SVK	-0.71	-0.47	-0.87	-0.65	0	0	-0.17	-0.13
SVN	-0.30	-0.24	-0.35	-0.29	0	0	-0.07	-0.06
ESP	-0.25	-0.20	-0.31	-0.26	0	0	-0.06	-0.05
SWE	-0.05	0.05	-0.07	0.02	0	0	-0.01	0.00
GBR	-0.01	0.05	-0.02	0.04	0	0	0.00	0.01
BGR	-0.37	-0.22	-0.39	-0.26	0	0	-0.08	-0.05
ROU	-0.32	-0.30	-0.36	-0.34	0	0	-0.07	-0.07
NOR	0.24	0.24	0.24	0.24	0	0	0.05	0.05
CHN	0.98	0.89	0.87	0.83	0	0	0.17	0.17
HKG	0.25	0.25	0.28	0.27	0	0	0.06	0.05
JPN	0.27	0.29	0.27	0.28	0	0	0.05	0.06
KOR	0.69	0.70	0.63	0.64	0	0	0.13	0.13
PHL	0.27	0.27	0.18	0.18	0	0	0.04	0.04
PNG	0.98	1.01	1.02	1.04	0	0	0.20	0.21
TWN	0.19	0.14	0.11	0.07	0	0	0.02	0.01
USA	-0.04	-0.02	-0.05	-0.03	0	0	-0.01	-0.01
OCD	-0.10	-0.06	-0.09	-0.07	0	0	-0.02	-0.01
SSA	0.02	-0.03	0.03	-0.03	0	0	0.01	-0.01
ROW	-0.23	-0.19	-0.25	-0.22	0	0	-0.05	-0.04

Source: Own estimations using the GTAP database.

Table 19: CGE results for the labour market, labour displacement and employment changes for unskilled labour in selected sectors, percentage changes

	labour displacement				Sectoral employment changes			
	fixed labour supply		flexible lab. supply		Unskilled, flexible labour supply			
	unskilled	skilled	unskilled	skilled	S02: Motor vehicles	S05: Clothing	S11: Metals	S14: Other manu-factures
AUT	0.72	0.54	0.71	0.53	-0.04	-1.44	1.27	-3.79
BEL	0.81	0.62	0.76	0.58	0.92	0.50	1.21	-17.05
CYP	0.26	0.17	0.25	0.16	-1.72	-0.39	0.24	-1.24
CZE	1.01	0.67	0.95	0.62	-0.75	-2.57	1.11	-4.26
DNK	1.21	0.82	1.19	0.80	-1.70	-1.83	1.38	-9.99
EST	1.54	0.92	1.52	0.91	-1.07	-1.66	2.15	-9.95
FIN	1.29	0.89	1.28	0.88	-1.21	-4.31	3.42	-8.94
FRA	0.48	0.35	0.46	0.33	-1.29	-1.26	0.72	-2.74
DEU	1.25	0.97	1.23	0.96	-2.13	-2.84	2.22	-6.94
GRC	0.22	0.19	0.19	0.17	-0.92	-0.22	0.16	-0.63
HUN	0.65	0.52	0.58	0.47	-0.66	-0.66	0.82	-2.14
IRL	0.62	0.45	0.60	0.43	-3.17	-2.17	0.18	-6.42
ITA	0.36	0.31	0.29	0.25	-2.00	-0.45	0.48	-0.66
LVA	1.67	1.13	1.63	1.11	-1.22	-0.51	1.70	-14.14
LTU	1.19	0.68	1.17	0.67	-2.82	-1.37	1.18	-18.07
LUX	0.56	0.42	0.55	0.40	-0.52	-1.32	1.18	-1.81
MLT	0.65	0.44	0.60	0.40	-0.81	-1.17	0.50	-1.60
NLD	0.91	0.61	0.90	0.60	-0.82	-5.97	1.99	-5.72
POL	1.32	0.80	1.29	0.78	-0.29	-2.30	2.11	-5.42
PRT	0.54	0.41	0.50	0.37	-0.71	-0.62	0.67	-2.63
SVK	1.17	0.78	1.09	0.72	1.23	-1.29	0.52	-6.67
SVN	0.52	0.39	0.48	0.35	-2.39	-0.74	0.61	-1.40
ESP	0.50	0.40	0.47	0.38	-1.69	-0.53	0.70	-3.02
SWE	1.45	0.99	1.43	0.98	-0.73	-6.17	2.59	-17.05
GBR	0.91	0.65	0.90	0.64	-1.31	-3.41	1.84	-6.14
BGR	0.68	0.50	0.60	0.45	-0.01	-1.43	-1.91	-9.93
ROU	0.27	0.20	0.24	0.17	-0.14	-1.16	0.08	0.00
NOR	0.83	0.77	0.82	0.77	-6.19	-7.16	3.95	-14.41
CHN	0.61	0.28	0.58	0.27	1.06	1.27	-1.08	1.57
HKG	0.36	0.27	0.37	0.28	-0.51	1.04	-0.02	-6.31
JPN	0.52	0.43	0.50	0.42	2.47	-0.26	-0.59	-0.06
KOR	0.72	0.41	0.69	0.39	2.72	0.56	-0.86	-0.08
PHL	0.35	0.14	0.35	0.15	0.90	2.33	-1.35	-0.05
PNG	0.62	0.37	0.56	0.32	0.68	0.54	1.80	0.73
TWN	0.39	0.24	0.37	0.23	0.88	0.62	0.28	-0.11
USA	0.39	0.27	0.38	0.26	-0.70	-2.80	0.45	-3.44
OCD	0.24	0.16	0.21	0.14	-0.89	-0.37	-1.47	-0.35
SSA	0.16	0.06	0.14	0.06	-0.63	-0.26	-0.53	-0.34
ROW	0.27	0.15	0.22	0.12	-0.55	-0.69	-0.33	-0.70

Notes: Labour displacement is the weighted standard deviation of the sectoral changes. Source: Own estimations using the GTAP database.

Table 20: CGE results on CO_2 emissions

	CO_2 emission changes (MT)	CO_2 emission % changes	Benchmark CO_2 levels (projections in 2030)	Share in 2030 projections
Austria	0.07	0.09	80	0.1%
Belgium	0.51	0.40	127	0.2%
Cyprus	-0.06	-0.42	14	0.0%
Czech Republic	-0.57	-0.37	152	0.2%
Denmark	0.10	0.11	92	0.1%
Estonia	-0.06	-0.32	20	0.0%
Finland	-0.05	-0.07	71	0.1%
France	-0.64	-0.14	455	0.7%
Germany	-0.66	-0.09	729	1.1%
Greece	-0.37	-0.32	113	0.2%
Hungary	-0.18	-0.34	54	0.1%
Ireland	0.00	0.00	60	0.1%
Italy	-1.38	-0.32	426	0.7%
Latvia	-0.04	-0.21	18	0.0%
Lithuania	-0.10	-0.52	19	0.0%
Luxembourg	-0.03	-0.14	18	0.0%
Malta	-0.01	-0.24	4	0.0%
Netherlands	0.21	0.10	213	0.3%
Poland	-4.96	-1.23	399	0.6%
Portugal	-0.12	-0.17	68	0.1%
Slovakia	-0.26	-0.49	54	0.1%
Slovenia	-0.04	-0.22	20	0.0%
Spain	-1.03	-0.27	378	0.6%
Sweden	-0.02	-0.03	72	0.1%
United Kingdom	-0.59	-0.09	666	1.0%
Bulgaria	-0.04	-0.06	72	0.1%
Romania	-0.20	-0.17	119	0.2%
Norway	-0.22	-0.23	94	0.1%
China	130.05	0.46	28,418	44.1%
Hong Kong	1.47	0.81	181	0.3%
Japan	1.04	0.09	1,127	1.7%
South Korea	2.47	0.31	787	1.2%
Philippines	0.28	0.17	169	0.3%
Other Asia Pacific	0.48	1.01	48	0.1%
Taiwan	0.16	0.03	552	0.9%
United States	-81.65	-1.02	7,963	12.4%
Other OECD	-2.04	-0.13	1,549	2.4%
Sub-Sah Africa exc. ZAF	-0.24	-0.04	575	0.9%
Rest of the World	-28.83	-0.16	18,469	28.7%
Total (World)	12.46	0.019	64,446	100%

Source: Own estimations using the GTAP database.

Table 21: CO_2 emission changes associated with different Arctic routes

	only NSR		both NSR & NWR	
	CO_2 emission changes (MT)	CO_2 emission % changes	CO_2 emission changes (MT)	CO_2 emission % changes
Germany	-0.05	-0.01	-0.66	-0.09
United Kingdom	-0.25	-0.04	-0.59	-0.09
France	-0.73	-0.16	-0.64	-0.14
Italy	-1.68	-0.39	-1.38	-0.32
Spain	-1.04	-0.27	-1.03	-0.27
Netherlands	0.33	0.15	0.21	0.10
China	85.68	0.30	130.05	0.46
Japan	1.42	0.13	1.04	0.09
South Korea	2.49	0.32	2.47	0.31
United States	-7.76	-0.10	-81.65	-1.02
Total (World)	47.79	0.07	12.46	0.02

Source: Francois and Rojas-Romagosa (2015) and own estimations using GTAP database.