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MELTING ICE CAPS AND THE ECONOMIC IMPACT OF OPENING THE NORTHERN SEA ROUTE*

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One consequence of melting Arctic ice caps is the commercial viability of the Northern Sea Route, connecting East Asia with Europe. This represents a sizeable reduction in shipping distances and average transportation days compared to the conventional Southern Sea Route. We examine the economic impact of opening this route in a multi-sector Eaton–Kortum model with intermediate linkages. We find remarkable shifts in trade flows between Asia and Europe, diversion of trade within Europe, heavy shipping traffic in the Arctic and a substantial drop in Suez traffic. Projected shifts in trade also imply substantial pressure on an already threatened Arctic ecosystem.

Arctic ice caps have been melting as a result of global warming (Kay *et al.*, 2011; Day *et al.*, 2012; Barnhart *et al.*, 2016). The steady reduction of the Arctic sea ice has also been well documented (Rodrigues, 2008; Kinnard *et al.*, 2011; Comiso, 2012) and there is broad agreement on continued ice reductions through this century (Wang and Overland, 2009, 2012; Vavrus *et al.*, 2012).[1] Recent satellite observations, furthermore, suggest that climate model simulations may be underestimating the melting rate (Kattsov *et al.*, 2010; Rampal *et al.*, 2011). This implies that in the near future the extent of the Arctic ice caps will be greatly reduced and even completely ice-free during the summer. Besides the environmental effects, another consequence of this climatic phenomenon is the possibility of opening up the Northern Sea Route (NSR) for high volume commercial traffic. This shipping route will connect East Asia (Japan, South Korea, Taiwan and China) with Northwestern Europe through the Arctic Ocean (see Figure 1). In practical terms, this represents a reduction in the average shipping distances and days of transportation by around one third with respect to the currently used Southern Sea Route (SSR). These reductions translate not only into fuel savings and overall transport costs but also to significant transport time savings that may effectively force supply chains in industries between East Asia and Europe to change. They also imply high shipping volumes through the Arctic, likely adding to underlying shocks to the ecosystem.

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[1] The ice caps in Greenland and Antarctica have also been melting at an ever-quicker pace since 1992 (Kerr, 2012; Shepherd *et al.*, 2012).

Fig. 1. *The Northern Sea Route and Southern Sea Route Shipping Routes*
Note. Colour figure can be viewed at wileyonlinelibrary.com.

The NSR is already open during summer and a number of ships have already used the route.[2] Until 2011, there was still controversy about the feasibility of the commercial use of the NSR. However, the ever-quicker melting pace found in several studies (Kerr, 2012; Shepherd *et al.*, 2012; Stroeve *et al.*, 2012; Steig *et al.*, 2013) has broadened the consensus in favour of its likely commercial use in the near future. A growing number of papers find that this shipping route could be fully operational for several months or all-year round at different points in the future (cf. Verny and Grigentin, 2009; Khon *et al.*, 2010; Liu and Kronbak, 2010; Stephenson *et al.*, 2013; Rogers *et al.*, 2015).[3] As a consequence, there has been increased economic interest in

[2] These include recent shipping milestones: the first supertanker to use the NSR (*Barents Observer*, 2011*a*) and the fastest crossing (*Barents Observer*, 2011*b*).

[3] The differences on the approximate year and the yearly extent for which the NSR will be fully operational varies much between papers, depending on different assumptions and estimates regarding the pace of the ice caps melting and developments in the shipping industry with respect to the new route.

the NSR: Asia's largest exporters – Japan, South Korea and China – are already investing in ice-capable vessels, while Russia has plans to develop this shipping lane further (Astill, 2012). Accordingly, the NSR will also have concrete geopolitical implications, with an expected decline in the shipping transit through the Indian Ocean and the Suez Canal as well as an increased political interest in the Arctic. China, in particular, has already shown political interest in the Arctic by signing a free trade agreement (FTA) with Iceland in April 2013 and most recently – together with Japan and South Korea – it gained observer status on the Arctic Council.

The main contribution of this article is to analyse and estimate the economic impact of the opening of the NSR.[4] Given the current uncertainties regarding the relationship between the ice cap melting pace and the transport logistic barriers associated with the NSR, it is hard to predict the exact year when the NSR will become fully operational. Throughout the article, we use a what-if approach where we assume that by the year 2030 the ice caps have melted far enough and logistics issues related to navigating the Arctic have been resolved, so the NSR is fully operational all year round.[5] In practical terms, this also implies that we use an 'upper bound' scenario that assumes that the NSR becomes a perfect substitute for the SSR and, as such, all commercial shipping between East Asia and Northern Europe will use the shorter and cheaper NSR instead of the SSR. Furthermore, since the opening of the NSR 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.

Our economic analysis follows a three-step process. In the first step we recalculate physical distances between countries to account for water-transportation shipping routes. In the second step, we map out a multi-sector general equilibrium model with intermediate linkages and trade modelled as in Eaton and Kortum (2002) and derive a gravity equation to estimate the trade elasticities structurally and to map the new distance calculations – for both the SSR and the NSR – into estimates of the bilateral trade cost reductions between trading partners at the industry level. In the third step we simulate the effect of the commercial opening of the NSR on bilateral trade flows, macroeconomic outcomes and changes in CO_2 emissions employing our theoretical model.

With our model set-up and calibration we are between the older computable general equilibrium (CGE) models (Dixon and Jorgenson, 2013) and the recent quantitative trade models (see Costinot and Rodríguez-Clare, 2013, for an overview). The interaction of both analytical frameworks generates important synergies. Following the new quantitative trade models we improve the CGE estimates in two fundamental ways. First, we model trade linkages with the improved micro-founded Eaton and Kortum (2002) structure. Second, we estimate the trade parameters structurally employing a gravity model derived from the theoretical model using the same trade data that are used in the numerical simulations. But we also retain important elements of CGE modelling, which are not present in the new quantitative trade models. Comparing our model with the

[4] It is important to note that the melting of the Arctic ice caps will be a global climate phenomenon with widespread ecological and economic impacts. In this article, we focus solely on the economic impact of the NSR.

[5] The use of 2030 as our benchmark year is mainly for illustrative purposes and the use of another year does not affect our main economic results. For instance, we ran simulations using 2020 and 2040 as our benchmark year and our main results remain robust to these changes.

model employed by Caliendo and Parro (2015), currently the most extensive quantitative study of changes in trade policy based on the Eaton–Kortum model, we include three additional features.[6] First, we explicitly model a transport services sector as part of the trade costs between countries. This feature is important for our study of the economic impact of the NSR, since the reductions in trade costs as a result of the NSR operate partially through reduced costs of transport services. Second, we match the model more closely with the data in trade statistics and national accounts. In particular, we account for different aggregate import shares across different agents (private consumption, government consumption, and the purchase of intermediate inputs), which has not been done thus far in the quantitative trade literature based on Eaton–Kortum. Third, we use a more extensive general equilibrium framework that serves to bring the model closer to a realistic description of the world economy. In particular, we include non-homothetic preferences for private consumption, we model savings and investment, we work with multiple factors of production with varying degrees of mobility and we include linkages to CO_2 emission data.[7]

The NSR reduces shipping distances and time between Northwestern Europe and East Asia by about one third. These overall trade cost reductions can further be separated into actual shipping cost reductions (i.e. fuel savings and other transport costs) and distance-related iceberg trade costs (e.g. transport time savings that can effectively create new supply chains in certain industries). We find transport cost reductions in the range of 20–30% between both regions using the NSR intensively, while iceberg trade cost reductions are estimated to be around 3% of the value of goods sold.

Using our model, we find that the direct consequence of opening-up the NSR is that international shipping volumes (defined as total tonne-kilometres of shipping) fall by 0.2%, whereas global trade values increase by 0.3%. Although global trade value changes are not very high, they are completely concentrated in trade between East Asia and Northwestern Europe, which increases by around 6%. We estimate that the share of World trade that is re-routed through the NSR will be about 4.7%. For instance, 13.4% of Chinese trade will use the NSR in the future. The projected shift of trade to the Arctic route implies substantial pressure on an already threatened ecosystem. Roughly 8% of world trade is currently transported through the Suez Canal, and we estimate that this share would drop by around two-thirds with a re-routing of trade over the shorter Arctic route. Since on average around 15,000 commercial ships crossed the Suez Canal yearly between 2008 and 2012, the re-routing of ships through the NSR will represent about 10,000 ships crossing the Arctic yearly.[8] This implies incentives for

[6] Other papers employing a multi-sector Eaton–Kortum model to study a range of questions are Dekle *et al.* (2008), Chor (2010), Costinot *et al.* (2012), Shikher (2012) and Levchenko and Zhang (2016). The work by Caliendo and Parro (2015) seems the closest to our framework in calibrating to real-world data and including trade policy details, and therefore we compare our work to theirs.

[7] Caliendo and Parro (2015) employ a quantitative Eaton–Kortum trade model to evaluate the effect of NAFTA. Additionally, they argue against the use of CGE-models claiming that they are black boxes. By explicitly mapping out our entire model, including a description of all endogenous variables, parameters and equilibrium equations, we provide a clear overview of the modelling mechanisms, which are indeed complex but do not constitute a black box. Moreover, the additional realistic features of the model enrich the information set and the interpretation of the results in the counterfactual analysis, which are still driven by the basic trade mechanism in Eaton and Kortum (2002). Furthermore, the detailed break-down of trade costs is essential for our analysis of the NSR.

[8] Transit data are available from the Suez Canal Authority (http://www.suezcanal.gov.eg).

large-scale construction of physical infrastructure in sensitive Arctic ecosystems, heightened economic security interests linked to Arctic trade and tremendous pressure on the facilities and economies servicing the older SSR (including Egypt and Singapore).

This huge increase in bilateral trade between these two relatively large economic zones also results in a significant diversion of trade. The bilateral trade flows between East Asia and Northwestern Europe significantly increase at the expense of less trade with other regions. In particular, there is a sizeable reduction in intra-European trade, with less trade between Northwestern Europe and South and Eastern Europe. Bilateral exports from Northwestern Europe (Germany, France, The Netherlands and the UK) to and from East Asia (China, Japan and South Korea) increase significantly, while Southern European exports remain unchanged. The Eastern countries of the European Union (EU) experience a combination of dramatic increases in exports to Asia in some countries, such as Poland and the Czech Republic, but no significant changes in exports of other countries, such as Hungary and Romania.

The changing opportunities for trade translate into macroeconomic impacts as well: real incomes and GDP are estimated to increase modestly in the countries that benefit directly from the NSR. East Asia and Northwestern Europe experience the biggest gains. On the other hand, most Southern and Eastern European countries experience real income declines. Hence, the disruption in intra-EU trade and regional production value chains caused by the opening of the NSR will negatively affect the Southern and Eastern EU member states. For the affected countries, these impacts – in the range of less than half a percentage point of GDP – are comparable to estimated effects from an EU-US FTA, or the Doha and Uruguay Rounds of multilateral trade negotiations (Francois, 2000; Francois *et al.*, 2005; Egger *et al.*, 2015).

Finally, we also estimate the impact of the NSR on changes in CO_2 emissions. We find that although the much shorter shipping distances will reduce the emissions associated with water transport of a given quantity of goods, these gains are all but offset by a combination of higher quantities traded between East Asia and Northwestern Europe, and the shift towards emission-intensive production in East Asia.

The article is organised as follows. In Section 1, we analyse the logistic issues and projections for commercially using the NSR in the future. We then explain how we estimate the new water transportation distances in Section 2. In the next Section we map out the theoretical structure to evaluate the impact of the NSR. In Section 4, we discuss calibration of the model, derive a gravity equation and estimate the gravity equation to calculate the effect of the new distance measures on trade costs. The simulations and macroeconomic results are presented in Section 5. Section 6 concludes by summarising our main results.

1. Commercial Feasibility of the Northern Sea Route

There are two elements that limit the NSR becoming a fully viable commercial substitute of the SSR. The first is the ice levels in the Arctic that is the main barrier to the commercial use of the NSR. As mentioned before, there is ample scientific evidence of the melting of the Arctic ice cap (Rodrigues, 2008; Kinnard *et al.*, 2011; Comiso, 2012) and that it will continue melting in the future (Wang and Overland, 2009, 2012; Vavrus *et al.*, 2012); other studies even suggest that the melting process may accelerate in the future as well (Kattsov *et al.*, 2010; Rampal *et al.*, 2011). Stammerjohn *et al.* (2012) note that some Arctic regions are already more ice-free now than predicted by climate models for 2030, 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. These elements will make the commercial use of the NSR more likely in the near future. Figure 2 further illustrates the current degree of ice cap melting (until 2007) and the forecasts produced by the National Oceanic and Atmospheric Administration (NOAA). From this Figure, one can see that by 2030 the ice cap will have melted enough to make the NSR ice-free, although it is not clear if this will be the prevalent condition year-round by then. These predictions have been also supported by more recent research (Wang and Overland, 2012).

The second barrier to the NSR are the transport logistic issues associated with the opening of a new commercial shipping route in a region with extreme weather conditions. Even though a number of ships have already used the NSR during

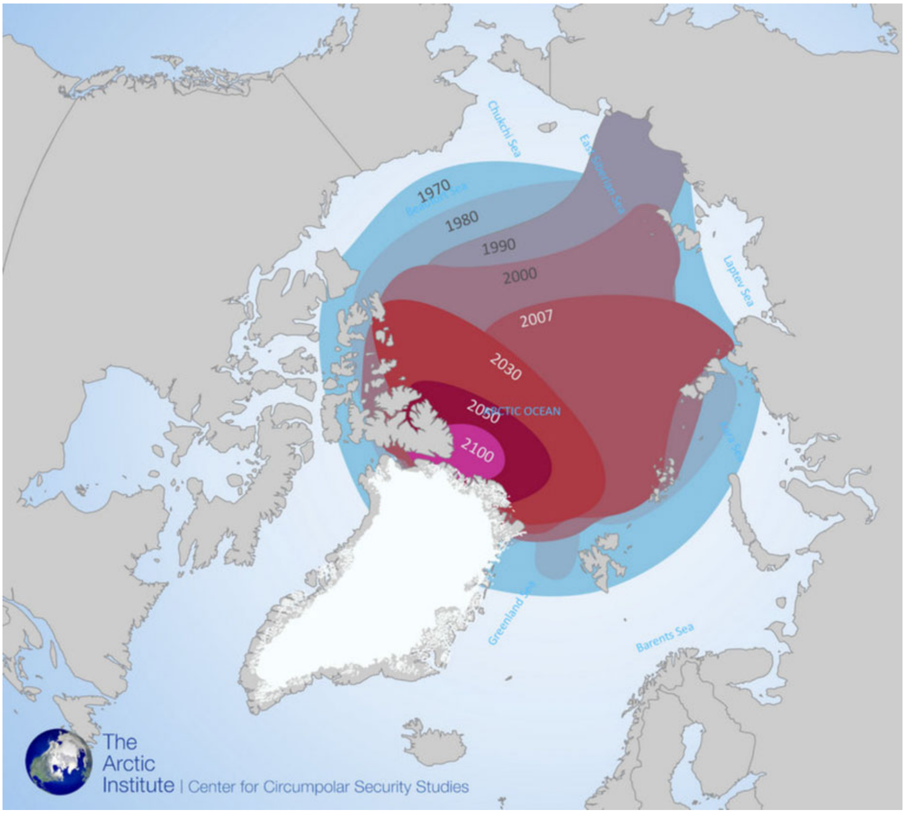

Fig. 2. *Arctic Sea Ice Extent Observations (1970–2007) and Forecast (2030–2100)*
Source. NOAA GFDL model reproduced in Humpert and Raspotnik (2012) by The Arctic Institute. Colour figure can be viewed at wileyonlinelibrary.com.

summer months, significant logistical obstacles remain. These include slower speeds, Russian fees and customs clearance, 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 Bräthen, 2011). These conditions not only affect the insurance premia currently charged to use the NSR but they also limit the commercial viability of shipping operations, which are dependent on predictability, punctuality and economies of scale (Humpert and Raspotnik, 2012). However, with the number of ships using the NSR increasing every year and the political and economic interest of Russia and other stakeholders to develop the NSR, it is expected that these logistic limitations will be gradually overcome in the near future.[9]

The uncertainties surrounding both the pace and extent of ice cap melting and the logistical conditions associated with full commercial use of the NSR are translated into a wide range of estimates regarding the precise date when the NSR will be fully operational. The uncertainties regarding both elements are also directly related and reinforce each other. In particular, a quicker pace of melting will also make it easier to overcome the logistical obstacles. Therefore, the assessments of the feasibility of the NSR range from studies that see limited use of the NSR for many years to come (cf. Lasserre and Pelletier, 2011, and papers referred therein) and more optimistic papers that foresee the commercial use of the NSR within 10 years (Verny and Grigentin, 2009).

In our study, we take a middle-point approach and use 2030 as our benchmark year, for which we assume that the NSR will be fully operational all-year round. However, our economic estimates are not dependent on this occurring precisely in 2030. We needed to choose a benchmark year for reporting, since we expect to have quantitatively similar results if we used another benchmark year, either an earlier one (2020) or later one (2040).[10]

The main fact needed for our estimates to be relevant, however, is that the NSR must become (at some point in time) fully commercially viable during the whole year, so it is in practical terms, a fully viable (and perfect) substitute to the SSR. This implies that we use an 'upper bound' scenario that will estimate the largest expected trade and economic impact from the NSR.[11]

[9] For instance, Russia created a federal state institution in March 2013 to administer the NSR: The Northern Sea Route Administration (www.nsra.ru), which provides logistical assistance throughout the route. In addition, Russia has also already started setting up 10 relief ports along the route.

[10] As a robustness analysis, we use these two different years as our benchmarks: 2020 and 2040. Our results show that the use of different benchmark years affects the size of some of the results, but the main qualitative results and patterns described for 2030 remain robust to the use of different years. The results for 2020 and 2040 are available upon request.

[11] For instance, if the NSR is 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 in particular seasons. Another potential limitation of the NSR fully substituting the SSR is the increased pressure on current transport infrastructure. In particular, current hubs – i.e. the Port of Rotterdam – may need to expand. However, since the opening of the NSR will be a gradual process, we expect that any additional infrastructure needs can be developed, while the NSR becomes fully operational. Besides the opening of the NSR, additional economic impacts may include the possibility to exploit natural resources in the Arctic Ocean and the Arctic region (i.e. Siberia and Northern Scandinavia), and the potential opening of the North Western Route connecting East Asia with the East Coast of Canada and the US.

2. Estimating Shipping Distance Reductions Using the Northern Sea Route

As the first step of our analysis, we estimate the precise distance reductions for bilateral trade flows associated with the NSR. To do so, we first need to include shipping routes in the estimation of the distance between two trading partners. 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).[12] However, these measures use the shortest physical distance and thus, are not appropriate for the present exercise. Shipping routes are usually longer than the shortest physical distance and melting sea ice will not change the physical distance between Tokyo and London, for example.

2.1. *Current Shipping Distances*

Rather we need a more precise measure of actual shipping distances. To this end, we first build a new measure of distance between trading countries. Given the importance of ocean transport for global trade in goods, we take water distances between trading partners into account. Globally, 90% of world trade in goods by volume and 80% by value – and the overwhelming majority of trade between non-neighbouring countries – is carried by ship (OECD, 2011, 2013).[13] For the country pairs and trade flows, we focus on here, water transportation, or multi-modal transport (water and land) accounts for a majority of trade.

Therefore, to obtain more accurate measures of trade distance, we work with shipping industry data on the physical distance of shipping routes between ports in combination with land-transport distances. We continue to use CEPII's bilateral distances to represent land routes (and so the land component of combined land-water routes), while the water routes were provided by the commercial company AtoBviaC. In online Appendix A.1, we explain in detail how the shipping distances are calculated.

2.2. *New Shipping Distances Using the NSR*

For the new distances related to the opening up of the NSR, we use the estimates by Liu and Kronbak (2010).[14] In Table 1, we show the great-circle formula distances, current shipping distances (using the SSR), the new NSR distances and the percentage reductions between East Asia's biggest exporters (China, Japan, South Korea and Taiwan) and the four Northern European countries with the busiest container ports: Netherlands (Rotterdam), Belgium (Antwerpen), Germany (Hamburg and

[12] In particular, CEPII's GeoDist database (www.cepii.fr) estimates geodesic distances, which are calculated, using the geographic coordinates of the capital cities. A simple measure is the distance between countries' capitals on the surface of a sphere (i.e. the great-circle formula). A more recent and sophisticated approach is to measure distance between two countries using the population weighted average index created by (Head and Mayer, 2010; de Sousa *et al.*, 2012). This last measure also incorporates the internal distances of a country.

[13] The rest moves primarily by land. 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).

[14] In online Appendix A.2, we explain how the new NSR distances are calculated.

Table 1
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	UK	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	UK	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	UK	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	UK	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).

Bremerhaven) and the UK (Felixstowe). The commercial use of the NSR implies a significant shipping distance reduction. For instance, the effective distance is reduced by around 37% from Japan to Northern European countries, while the same figure is around 31% for South Korea, 23% for China and 17% for Taiwan.

It is important to note that the NSR only makes the shipping distance shorter for countries in East Asia but not for countries closer or below the equator in Asia. For instance, the shipping distances from the Philippines and Papua New Guinea to Northern Europe are slightly shorter using the NSR (by around 1,500 kilometre), but countries that are located South and East from these countries have shorter shipping distances, using the SSR (e.g. Vietnam, Thailand, Singapore, Indonesia, Malaysia and India).

3. Model

Since the opening of the NSR is a global phenomenon that affects several countries at once, it will create inter-related shocks between different trading economies. Trade facilitation through the NSR will not only affect bilateral trade but also sectoral production and consumption patterns, relative domestic and international prices and the way production factors are used in different countries. Therefore, we employ a general equilibrium model with multiple countries, multiple sectors, intermediate linkages and multiple factors of production. Trade is modelled as in Eaton and Kortum (2002) with the remaining structure of the model largely following the GTAP model (Hertel, 2013). Below we provide a detailed description of the model with many of the formal details presented in online Appendix B.[15]

[15] The standard GTAP model is also described in Rutherford and Paltsev (2000) and Hertel (2013).

3.1. *Demand*

We work with $J = 100$ countries. In each country (j), a representative agent has a Cobb–Douglas utility function over three aggregate goods, private goods (q_j^{pr}), government goods (q_j^{go}), and savings (q_j^{sa}):

$$u_j = \left(q_j^{\mathrm{pr}}\right)^{\kappa_j^{\mathrm{pr}}}\left(q_j^{\mathrm{go}}\right)^{\kappa_j^{\mathrm{go}}}\left(q_j^{\mathrm{sa}}\right)^{\kappa_j^{\mathrm{sa}}}. \tag{1}$$

Savings are included in the static utility function to prevent that a shift away from savings – and thus implicitly from future consumption – towards current consumption has large welfare effects. The formal underpinning comes from Hanoch (1975) who showed that the expressions for consumption in an inter-temporal setting can also be derived from a static utility maximisation problem with savings in the utility function. Since preferences for private goods are non-homothetic, it is not possible to define a price for private goods. Therefore, we cannot maximise utility in (1) subject to a conventional budget constraint. Instead we maximise utility in (1) subject to the following implicit budget constraint, where we write expenditures on category c goods (e_j^c) as a function of the quantity of private consumption (q_j^c):

$$\sum_c e_j^c\left(q_j^c\right) = x_j. \tag{2}$$

This leads to the following expression for spending (x_j^c) on the three categories of goods, $c \in \{\mathrm{pr}, \mathrm{go}, \mathrm{sa}\}$, as a function of total expenditure (x_j):

$$x_j^c = \kappa^c\left(\frac{\Psi_j^c}{\Psi_j}\right)x_j;\;\; c = \mathrm{pr}, \mathrm{go}, \mathrm{sa}, \tag{3}$$

where Ψ_j^c is the elasticity of quantity (q_j^c) with respect to expenditure (x_j^c) and Ψ_j is the elasticity of utility (u_j) with respect to total expenditure (x_j). For goods with homothetic preferences – savings (sa) and public goods (go) – this elasticity is 1 ($\Psi_j^{\mathrm{go}} = \Psi_j^{\mathrm{sa}} = 1$). So with homothetic preferences, (3) would generate the standard expression for Cobb–Douglas expenditure shares. With non-homothetic preferences for private goods the share of spending on private goods is larger than the Cobb–Douglas parameter κ^{pr} if the elasticity of private quantity (q_j^{pr}) with respect to private expenditure (x_j^{pr}) is larger than 1. This gives the consumer an incentive to spend a more than proportional amount on private goods.

Ψ_j^{pr} follows from log differentiating the indirect utility function for private goods defined below in (6) with respect to quantity (q_j^{pr}) and expenditure (x_j^{pr}). This gives the following expression:

$$\Psi_j^{\mathrm{pr}} = \frac{1}{\sum_{s=1}^{S} s_{js}^{\mathrm{pr}}\eta_{js}}, \tag{4}$$

where s_{js}^{pr} is the share of private expenditure spent on good s. Ψ_j follows from maximisation of utility in (1):[16]

[16] See McDougall (2000) for further discussion and online Appendix B.1 for a formal derivation.

$$\Psi_j = \sum_c \Psi^c \kappa^c = \Psi^{\text{pr}} \kappa^{\text{pr}} + \kappa^{\text{go}} + \kappa^{\text{sa}}. \tag{5}$$

Preferences for private goods across the different sectors are described by the non-homothetic constant distance elasticity (CDE) implicit expenditure function:

$$\sum_{s=1}^{S} \alpha_{js} \left(q_j^{\text{pr}} \right)^{\gamma_{js}\eta_{js}} \left(\frac{p_{js}^{\text{pr}}}{x_j^{\text{pr}}} \right)^{\gamma_{js}} = 1, \tag{6}$$

where q_{js}^{pr} and p_{js}^{pr} are respectively the quantity and price of private goods in country j and sector s, x_j^{pr} is private expenditure in country j, while α_{js}, γ_{js} and η_{js} are, respectively, the distribution, substitution and expansion parameters. Private demand (q_{js}^{pr}) as a function of private expenditure (x_j^{pr}) and prices (p_{js}^{pr}), can be derived by log-differentiating (6) with respect to p_{js}^{pr} and x_j^{pr} and applying Shepherd's lemma:

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

With CDE preferences, the model allows for shifting average and marginal budget shares as a country grows. At the same time, the model stays tractable in a setting with a large number of countries and sectors, since a limited number of parameters can be calibrated from income and own-price elasticities of demand.

Preferences for spending by the public sector across the different sectors are Cobb–Douglas, implying the following demand function for government goods in sector s (q_{js}^{go}) as a function of government sector prices (p_{js}^{go}) and and aggregate prices (p_j^{go}):

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

For public goods and savings, quantity and expenditure are simply related by the following expression, $q_j^c = x_j^c / p_j^c;\ c = \text{go, sa}$. For private goods we cannot define a price index. Quantity (q_j^{pr}) and expenditure (x_j^{pr}) are implicitly related through the indirect expenditure function in (6). The price of government goods is given by a standard Cobb–Douglas price index expression. The price of savings is a weighted average of the price of investment goods in the different countries. Savings are used to finance investment. Savings in all countries are collected by a 'global bank' channelling the savings to investment in different countries until the rate of return on investment is equalised. Net investment beyond depreciation will expand the amount of capital available in production. A formal description of saving and investment is provided in online Appendix B.3.

3.2. *International Trade*

Within each of our $s = \{1, \ldots, 17\}$ sectors international trade is modelled as in Eaton and Kortum (2002). So there is a continuum of varieties, $q_{js}(\omega_s)$, each country can produce under perfect competition. There are four groups of agents (ag) demanding goods: private households (pr), the government (go), firms (fi) and investors (in). They have an identical constant elasticity of substitution (CES) utility function across the continuum:

$$q_{js}^{\mathrm{ag}} = \left[\int_0^\infty q_{js}(\omega_s)^{\frac{\sigma_s-1}{\sigma_s}} \mathrm{d}\omega_s\right]^{\frac{\sigma_s}{\sigma_s-1}}. \tag{9}$$

The cost, insurance and freight (cif) price of delivering variety ω_s from source i to destination j in sector s is given by:

$$p_{ijs}^{\mathrm{cif}}(\omega_s) = \frac{t_{is}^{\mathrm{prod}} c_{is} t_{ijs}^{\mathrm{exp}} + \gamma_{ijs} p_{ijs}^{\mathrm{ts}}}{z_{is}(\omega_s)}, \tag{10}$$

where c_{is} is the price of input bundles and t_{is}^{prod} is the tax on input bundles in country i and sector s. t_{ijs}^{exp} is the destination-specific export tax. p_{ijs}^{ts} is the price of transport services and γ_{ijs} is a shifter determining the share of cif-value spent on transport services. All taxes are expressed in power terms, i.e. as one plus the ad valorem tax rate. We assume that the cif-quantity is a Leontief aggregate of the fob-quantity and the quantity of transport services, reflecting the lack of substitution possibilities away from transport services when they get more expensive. Firms can choose between different modes of transport (m), in particular between surface transport (sur) and air transport (air), according to a Cobb–Douglas function. This distinction is important in modelling the impact of the NSR. Adding up the demand for transport services between all regions generates the global demand for transport services. Global transport services generate, in turn, demand for transport services from the different supplying countries of transport services according to a Cobb–Douglas function.[17]

The productivity $z_{is}(\omega_s)$ is drawn from a Frechet distribution with technology parameter λ_{is} and dispersion parameter θ_s, as:

$$F_{is}(z) = \exp\left[-\left(\frac{z}{\lambda_{is}}\right)^{-\theta_s}\right]. \tag{11}$$

Multiplying the cif price by one plus the import tariff (t_{ijs}^{imp}), general iceberg trade costs (τ_{ijs}), group-specific iceberg trade costs ($\tau_{js}^{\mathrm{so,ag}}$) and group-specific and source-specific taxes ($t_{js}^{\mathrm{so,ag}}$) with domestic and imported sources (so = dom, imp), and different agents (ag = go, pr, fi, in) results in an expression for the landed price p_{ijs}^{ag}:

$$p_{ijs}^{\mathrm{ag}}(\omega_s) = \frac{\left(t_{is}^{\mathrm{prod}} c_{is} t_{ijs}^{\mathrm{exp}} + \gamma_{ijs} p_{ijs}^{\mathrm{ts}}\right) t_{ijs}^{\mathrm{imp}} \tau_{ijs} \tau_{js}^{\mathrm{so,ag}} t_{js}^{\mathrm{so,ag}}}{z_{is}(\omega_s)}. \tag{12}$$

Domestic iceberg trade costs and domestic group-specific trade costs are normalised at 1. Because of the detailed GTAP-data, we can also include export taxes and international transport margins as components of trade costs. This extension in

[17] Due to a lack of data there is no direct link between the supplying country and the demanding countries of these international transport services. The demand and supply of transport services are first aggregated up into global transport services. The formal details of the transport sector component of the model are provided in online Appendix B.5.

comparison to previous Eaton–Kortum multi-sector applications is important for our purposes as it allows us to model international transport services explicitly and study the effect of the NSR on transport services.

c_{is} is the price of input bundles used for production in country i and sector s, determined by the price of intermediates used from all sectors and the price of factor input bundles. The choice between intermediates and factor inputs and between intermediates from different sectors is Leontief. There are six factor inputs: land, low-skilled, medium-skilled and high-skilled labour, capital and natural resources. The choice between factor input bundles is CES. Land and natural resources are not perfectly mobile between sectors, as modelled with an elasticity of transformation function. Labour supply is endogenous, based on a labour-leisure trade-off, and formally described in online Appendix B.2.

Continuing our description of international trade in the model, we observe that the distribution of import prices is also Frechet, since the price (p_{ijs}) is a function of productivity (z):

$$G_{ijs}^{\mathrm{ag}}(p) = 1 - \exp\left\{-\left[\frac{\left(t_{is}^{\mathrm{prod}} c_{is} t_{ijs}^{\mathrm{exp}} + \gamma_{ijs} p_{ijs}^{\mathrm{tr}}\right) t_{ijs}^{\mathrm{imp}} \tau_{ijs} \tau_{js}^{\mathrm{so,ag}} t_{js}^{\mathrm{so,ag}}}{\lambda_{is}}\right]^{-\theta_s} p^{\theta_s}\right\}. \tag{13}$$

The probability that a price in importer j is lower than p is equal to one minus the probability that none of the exporters (i) delivers a price lower than p. Therefore, the price distribution in country j is given by the following:

$$G_{js}^{\mathrm{ag}}(p) = 1 - \prod_{i=1}^{J}[1 - G_{ijs}^{\mathrm{ag}}(p)]. \tag{14}$$

Substituting (13) into (14) gives the following price distribution:

$$G_{js}^{\mathrm{ag}}(p) = 1 - e^{-\Phi_{js}^{\mathrm{ag}} p^{\theta_s}}, \tag{15}$$

with;

$$\Phi_{js}^{\mathrm{ag}} = \sum_{i}^{J}\left[\frac{\left(t_{is}^{\mathrm{prod}} c_{is} t_{ijs}^{\mathrm{exp}} + \gamma_{ijs} p_{ijs}^{\mathrm{ts}}\right) t_{ijs}^{\mathrm{imp}} \tau_{ijs} \tau_{js}^{\mathrm{so,ag}} t_{js}^{\mathrm{so,ag}}}{\lambda_{is}}\right]^{-\theta_s}. \tag{16}$$

Φ_{is}^{ag} is a measure for technology in country j in sector s, reflecting productivity (λ_{is}) and unit costs (c_{is}) in j's trading partners and the various trade costs *vis-à-vis* its trading partners.

As a next step, we can determine the probability (π_{ijs}^{ag}) that goods in country j in sector s and by group ag are imported from trading partner i:

$$\pi_{ijs}^{\mathrm{ag}} = \frac{\left[\frac{(t_{is}^{\mathrm{prod}} c_{is} t_{ijs}^{\mathrm{exp}} + \gamma_{ijs} p_{ijs}^{\mathrm{ts}}) t_{ijs}^{\mathrm{imp}} \tau_{ijs} \tau_{js}^{\mathrm{so,ag}} t_{js}^{\mathrm{so,ag}}}{\lambda_{is}}\right]^{-\theta_s}}{\Phi_{js}^{\mathrm{ag}}}. \tag{17}$$

To determine the quantity sold from country i to j in sector s, we use Property b on page 1748 of Eaton and Kortum (2002) that the distribution of prices of goods actually sourced from country i in country j is given by the same distribution as the general distribution of prices in country j, $G_{is}(p)$.[18] The implication is that the average quantity purchased is the same for each source country i.[19] As a result the share of goods imported from country i in quantities is thus equal to the probability that goods are sourced from country i in (17):[20]

$$q_{ijs}^{\text{ag}} = \frac{\left[\dfrac{\left(t_{is}^{\text{prod}} c_{is} t_{ijs}^{\text{exp}} + \gamma_{ijs} p_{ijs}^{\text{ts}}\right) ta_{ijs} \tau_{ijs} \tau_{js}^{\text{so,ag}} t_{js}^{\text{so,ag}}}{\lambda_{is}}\right]^{-\theta_s}}{\Phi_{js}^{\text{ag}}} q_{js}^{\text{ag}} \text{pop}_j, \tag{18}$$

where $q_{js}^{\text{ag}}\text{pop}_j$ is the total demand for goods in sector s in country j by group ag and q_{ijs}^{ag} is the quantity imported by group ag with population size pop_j.[21] We can aggregate over the four groups of agents to generate an expression for total imports from country i, q_{ijs}:

$$q_{ijs} = \frac{\left[\dfrac{\left(t_{is}^{\text{prod}} c_{is} t_{ijs}^{\text{exp}} + \gamma_{ijs} p_{ijs}^{\text{tr}}\right) t_{ijs}^{\text{imp}} \tau_{ijs}}{\lambda_{is}}\right]^{-\theta_s}}{\Phi_{js}^{\text{imp}}} q_{js}^{\text{imp}}, \tag{19}$$

where q_{js}^{imp} is total import demand by all four groups of agents:

$$q_{js}^{\text{imp}} = \sum_{\text{ag}\in\{\text{pr,go,fi}\}} \frac{\left(\tau_{js}^{\text{imp,ag}} t_{js}^{\text{imp,ag}}\right)^{-\theta_s} \Phi_{js}^{\text{imp}}}{\left(\tau_{js}^{\text{imp,ag}} t_{js}^{\text{imp,ag}}\right)^{-\theta_s} \Phi_{js}^{\text{imp}} + \left(\dfrac{t_{js}^{\text{dom,ag}} c_{js}}{\lambda_{js}}\right)^{-\theta_s}} q_{js}^{\text{ag}} \text{pop}_j, \tag{20}$$

and Φ_{js}^{imp} is an average of import prices:

$$\Phi_{js}^{\text{imp}} = \sum_{i\neq j} \left[\frac{\left(t_{is}^{\text{prod}} c_{is} t_{ijs}^{\text{exp}} + \gamma_{ijs} p_{ijs}^{\text{tr}}\right) t_{ijs}^{\text{imp}} \tau_{ijs}}{\lambda_{is}}\right]^{-\theta_s}. \tag{21}$$

Equation (19) shows that a reduction in trade costs – for example, as a result of the opening of the NSR – generates both more trade along the intensive and the extensive

[18] As Eaton and Kortum (2002) point out this follows from calculating the distribution of prices of goods sourced from i in country j given that goods are actually sourced from country i. A formal derivation is in online Appendix B.4.

[19] Eaton and Kortum (2002) use this property to argue that average expenditure does not vary by source. The reasoning is identical for average quantity and average expenditure. Both are determined by prices. With a price distribution not varying by source average quantity and average expenditure do not vary by source. Formal derivations are in online Appendix B.4.

[20] Eaton and Kortum (2002) solve their model in terms of expenditures. Because of the presence of a transport sector we also need the quantity traded. An implication of the identical price distribution by source is that the quantity share is identical to the expenditure share in the Eaton and Kortum setup.

[21] Hence, quantities and values introduced in the previous Section (q_j, x_j, q_j^c, x_j^c, q_{js}^c) are all *per capita*, whereas quantities and values introduced in this Section (q_{ijs}^{ag}, q_{js}^{imp}, q_{js}^{dom}, x_{ijs}, x_{js}^{imp}) are aggregate.

margin in the model. With lower trade costs there are more sales of each variety within a sector and more varieties are sold.

3.3. *Equilibrium*

To close the model, we impose goods market equilibrium and derive the expression for expenditure of the representative household as a function of income. Since sectoral prices do not vary for an importer by source country in the Eaton and Kortum model, they do vary for an exporter for each destination country. As a result, sectoral quantities are not homogeneous for countries of destination and so we cannot express goods market equilibrium in terms of quantities as is often done in Armington-type models. Instead, we express goods market equilibrium in terms of values equalising the value of gross output with the value of import demand from the different trading partners.

Expenditure of the representative household is determined by household income and the fixed budget deficit, where household income is equal to gross factor income plus revenues from the different types of indirect taxes. CO_2 emissions are proportional to import and domestic demand of the four groups of agents. Changes in CO_2 emissions can be calculated residually based on the change in these demands. Formal details are respectively in online Appendices B.6 and B.8.

4. Calibration of the Model

In this Section, we map out three components of the model calibration: first the baseline data, second the estimation of the trade parameters and third the expected trade cost reductions as a result of the NSR.

4.1. *Baseline Data*

Since we examine the effects of opening the NSR in 2030 we need baseline data for this year. Therefore, we combine the detailed trade, production and consumption data from GTAP9 with base year 2011 (Aguiar *et al.*, 2016) with short-run projections by the IMF on changes in the trade balance and GDP growth up to 2015, long run projections for GDP growth from the OECD and growth in population and labour supply from the UN (Chateau *et al.*, 2012). To convert the 2011 values into 2015 values we endogenise total factor productivity and the trade balance, such that GDP growth and changes in the trade balance are as in the IMF data. We do this to eliminate the possible influence of the Great Recession on our results. Then we convert the data from 2015 to 2030 by endogenising productivity and solving for this variable imposing that GDP, population and labour supply are equal to their 2030 values predicted by the OECD and the UN. Further details on obtaining the baseline in 2030 and the employed projections are in online Appendix C.1.

The factor of proportionality between CO_2 emissions and demand by the different groups of agents of sector s goods ($\varsigma_{is,CO_2}^{ag,so}$) is based on the supplementary emissions data from the GTAP database. These values are based on a mapping of CO_2 emissions by energy sector into the amount of energy involved in the production in different sectors (see online Appendix C.2).

4.2. *Gravity Estimation of Trade Parameters*

To calibrate the model, we need values for the trade parameters, the preference parameters related to the CDE utility function and factor supply elasticities. Since the last two sets of parameters are based on estimates in the literature, they are further discussed in online Appendix C.2. The trade parameters required to implement the model numerically are the dispersion parameters (θ_s), the technology parameters (λ_{is}) and the iceberg trade costs (τ_{ijs}). To obtain the dispersion parameters, we estimate a gravity equation following from the theoretical structure with Eaton and Kortum production. As discussed above, the expression for the value of trade (x_{ijs}) is identical to the expression for the quantity of trade in (19), except for the fact that the import quantity demanded (q_{js}^{imp}) is replaced by the import value demanded (x_{js}^{imp}):

$$x_{ijs} = \frac{\left(\dfrac{t_{is}^{\text{prod}} c_{is} t_{ijs}^{\text{exp}} \text{itm}_{ijs} t_{ijs}^{\text{imp}} \bar{\tau}_{ijs} \tilde{\tau}_{ijs}}{\lambda_{is}}\right)^{-\theta_s}}{\Phi_{js}^{\text{imp}}} x_{js}^{\text{imp}}. \tag{22}$$

In (22) we have split up iceberg trade costs (τ_{ijs}) into an observable component ($\bar{\tau}_{ijs}$) driven by gravity type variables and an unobservable component ($\tilde{\tau}_{ijs}$). Also, we have defined the empirically observable international transport margin (itm_{ijs}), defined in power terms, as one plus the value of transport services divided by the fob value of trade:[22]

$$\text{itm}_{ijs} = 1 + \frac{p_{ijs}^{\text{ts}} \text{ts}_{ijs}}{c_{is} t_{is}^{\text{prod}} t_{ijs}^{\text{exp}} q_{ijs}} = 1 + \frac{\gamma_{ijs} p_{ijs}^{\text{ts}} q_{ijs}}{c_{is} t_{is}^{\text{prod}} t_{ijs}^{\text{exp}} q_{ijs}}. \tag{23}$$

Equation (22) contains an exporter-specific component $(t_{is}^{\text{prod}} c_{is}/\lambda_{is})^{-\theta_s}$, an importer-specific component ($x_{js}^{\text{imp}}/\Phi_{js}^{\text{imp}}$) and a bilateral component $(t_{ijs}^{\text{exp}} \text{itm}_{ijs} t_{ijs}^{\text{imp}} \bar{\tau}_{ijs} \tilde{\tau}_{ijs})^{-\theta_s}$. To turn (22) into an estimating equation, we capture the exporter-specific component by an exporter fixed effect (d_{is}), the importer-specific component by an importer-fixed effect (d_{js}) and we write $\bar{\tau}_{ijs}$ as a function of a vector of observable gravity regressors ($\mathbf{gr}_{ijs}$) and capture unobservable trade costs ($\tilde{\tau}_{ijs}$) by the error term (ε_{ijs}). This gives the following gravity equation for the total value of trade (x_{ijs}):

$$x_{ijs} = \exp(d_{is} + d_{js} - \theta_s \ln t_{ijs}^{\text{imp}} \text{itm}_{ijs} t_{ijs}^{\text{exp}} + \boldsymbol{\xi}_s \ln \mathbf{gr}_{ijs}) \varepsilon_{ijs}. \tag{24}$$

Following the theoretical gravity equation, import tariffs, the international transport margin and export taxes have the same coefficient and are thus included as one combined variable, $\ln t_{ijs}^{\text{imp}} \text{itm}_{ijs} t_{ijs}^{\text{exp}}$, which we call 'trade costs' in Table 2. As tariff variable ($\ln t_{ijs}^{\text{imp}}$) we employ the log difference between the most favoured nation (MFN) tariff rate and the preferential tariff rate (based on FTAs), with the MFN rate also captured by the importer fixed effect.

Data on the international transport margin are taken from the GTAP database. We cannot use transport margins directly for two reasons. First, transport margins are calculated as international transport services divided by fob-trade flows and thus suffer

[22] We have used $\text{ts}_{ijs} = \gamma_{ijs} q_{ijs}$ following from the Leontief specification of transport services.

Table 2

PPML Gravity Estimates for Manufacturing Sectors

Variables/ sectors	P_C	B_T	CRP	ELE	MTL	MVH	OGD	OMC	PRA	PRE	PRF
Trade costs	−8.298	−1.352	−7.971	−16.052	−11.764	−3.412	−6.545	−17.373	−2.401	−5.252	−5.759
	(4.18)***	(2.39)**	(6.75)***	(4.40)***	(7.27)***	(2.74)***	(5.64)***	(7.22)***	(2.36)**	(3.38)***	(8.39)***
ln(distance)	−0.655	−0.658	−0.400	−0.404	−0.464	−0.456	−0.559	−0.342	−0.721	−0.558	−0.598
	(16.15)***	(29.90)***	(20.09)***	(16.71)***	(24.12)***	(18.57)***	(22.34)***	(17.30)***	(32.79)***	(17.39)***	(31.31)***
PE index 1	−0.015	−0.216	0.017	0.247	0.052	−0.025	0.174	0.116	0.134	0.144	0.015
	(0.46)	(4.81)***	(0.58)	(6.26)***	(2.25)**	(0.51)	(5.66)***	(3.47)***	(3.87)***	(4.95)***	(0.51)
PE index 2	0.141	0.079	−0.217	−0.127	0.056	−0.080	−0.045	−0.170	0.037	−0.081	−0.055
	(2.08)**	(1.31)	(6.60)***	(2.57)**	(0.93)	(1.64)*	(1.23)	(4.81)***	(0.63)	(1.11)	(1.47)
Common colony	0.485	0.394	0.093	0.806	0.052	−0.230	−0.243	0.157	−0.232	−0.023	−0.278
	(1.70)*	(1.82)*	(0.51)	(2.36)**	(0.24)	(0.53)	(0.82)	(0.74)	(1.17)	(0.06)	(0.84)
Language	0.315	0.425	0.302	0.546	0.331	0.214	0.375	0.366	0.546	0.425	0.366
	(1.98)**	(3.62)***	(2.63)***	(3.85)***	(3.10)***	(1.58)	(3.51)***	(3.63)***	(4.93)***	(1.96)**	(4.52)***
Contiguous	0.695	0.214	0.584	0.406	0.878	0.551	0.941	0.590	0.626	0.950	0.741
	(3.11)***	(1.83)*	(7.28)***	(3.39)***	(11.42)***	(4.47)***	(10.21)***	(6.56)***	(4.48)***	(4.21)***	(9.83)***
Former colony	0.056	0.723	0.284	0.154	0.435	−0.398	0.221	0.335	0.061	0.243	0.093
	(0.31)	(4.48)***	(1.87)*	(0.92)	(2.98)***	(1.98)**	(1.85)*	(2.69)***	(0.48)	(1.04)	(0.95)
Shallow FTA	1.567	−1.173	0.711	0.463	0.547	−0.252	0.413	1.150	−0.456	0.078	0.973
	(3.56)***	(3.82)***	(4.51)***	(1.98)**	(4.09)***	(0.67)	(1.76)*	(6.26)***	(1.91)*	(0.20)	(3.58)***
Medium FTA	1.214	−0.269	0.032	−0.197	−0.216	0.475	−0.490	−0.374	0.110	1.185	−0.218
	(3.68)***	(1.30)	(0.19)	(0.65)	(1.11)	(1.96)**	(3.32)***	(2.40)**	(0.63)	(3.46)***	(2.01)**
Deep FTA	4.147	1.467	1.182	1.528	0.881	2.124	1.053	1.710	2.378	1.432	1.235
	(8.85)***	(3.82)***	(5.89)***	(5.20)***	(4.11)***	(8.31)***	(3.55)***	(5.83)***	(8.30)***	(3.47)***	(7.22)***
EU	−5.471	−0.994	−0.627	−0.638	−0.748	−1.146	−0.742	−1.727	−1.356	−0.957	−0.860
	(6.87)***	(3.08)***	(3.04)***	(2.14)**	(3.63)***	(4.51)***	(2.44)**	(5.86)***	(4.49)***	(1.93)*	(5.67)***
N	7,406	9,011	9,011	9,011	9,011	9,011	9,011	9,011	9,011	8,916	9,011
Pseudo R^2 DistVar	0.0344	0.1101	0.0215	0.0174	0.0254	0.0335	0.0463	0.0123	0.0955	0.0494	0.0693

Notes. Poisson pseudo-maximum likelihood (PPML) estimates, all including source and destination fixed effects (not shown). PE index 1 and PE index 2 are composite variables of similarity in political economy indicators as discussed in the text. 'Language' is the common ethnic language variable. The variables shallow FTA (DESTA = 1,2), medium FTA (DESTA = 3,4,5) and deep FTA (DESTA = 6,7) have been instrumented for. Standard errors in parenthesis. Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Sector codes: P_C petrochemicals, B_T beverages & tobacco; CRP chemicals, rubber, plastics; ELE electrical machinery; MTL metals; MVH motor vehicles; OGD other goods; OMC other machinery; PRA primary agriculture; PRE primary energy; PRF processed foods; TOT all manufacturing sectors. 'Dist Var' is the statistic V for distance share of variance for predicted log-linear trade values, defined as: b_2^2VAR [ln(distance)]/VAR [ln(trade)].

from an endogeneity problem. Second, data on transport margins are themselves limited to a subset of countries. To address these issues, we employ an instrumental variables approach by using fitted values of a pooled regression of transport margins. As explanatory variables we use the same set of explanatory variables as those used in the gravity equation (excluding tariffs) and an index of the restrictiveness of trade in services from the World Bank STRI database (Borchert *et al.*, 2014), calculated as the multiplication of the ad valorem equivalent of the index for the exporting country and the importing country from Jafari and Tarr (2015). The latter variable thus serves as our instrument. The regression results of the first stage (see Table C5 in online Appendix C) show that this instrument is highly significant in the first stage.

$\mathbf{gr}_{ijs}$ is a vector consisting of observable gravity variables explaining iceberg trade costs (τ_{ijs}). As observable variables we include the standard gravity variables: distance, common colony, common ethnic language, common border (contiguous), former colony, dummies for shallow, medium and deep FTAs and a dummy for trade between EU-members. FTAs are preferential trade agreements and customs unions that have been agreed at least four years previously (Dür *et al.*, 2014). To control for endogeneity of the formation of FTAs we follow the approach in Egger *et al.* (2015).[23] Since we do not have data on trade by mode of transport we cannot estimate separate gravity equations. Instead we include as distance variable the weighted average of shipping distance ($\text{dist}_{ij}^{\text{sur}}$) and air distance ($\text{dist}_{ij}^{\text{air}}$). As weights we use the shares of trade by surface and air calculated from the Eurostat data set on trade by mode-shares. Including both distance measures separately is not feasible because of multicollinearity problems. In online Appendix C.3, we provide a formal underpinning for the use of the mode-weighted average distance.

Besides these traditional gravity regressors, we include two political economy variables, PE index 1 and PE index 2, measuring the pairwise similarity of the two trading partners. These variables reflect evidence that homophily is important in explaining direct economic and political linkages (De Benedictis and Tajoli, 2011). The two political economy variables are calculated as the two first principal components of the following four variables: the difference in polity, the functioning of governance difference, the corruption score difference and the difference in civil society scores.

We estimate (24) for the 11 non-services sectors using a sample of 100 countries in 2011. Trade data are taken from the GTAP database to create consistency between the estimates and the simulations. Using COMTRADE data gives almost exactly the same coefficient estimates. Data for tariffs come from the World Bank/UNCTAD WITS database. Distance data, as discussed above, are based on our own data of the length of

[23] Based on Terza (1998) and Egger and Larch (2011) a control function is included in the gravity regression to account for the endogeneity of FTA-formation. The trade outcome and FTA-formation are assumed to be jointly normally distributed. By including a control function the potential endogeneity bias in the FTA-variable is eliminated. To generate the control function, first stage probit regressions are estimated explaining a certain level of depth (shallow, medium and deep) of the FTA. As explanatory variables only variables exogenous with respect to the trade and FTA-outcome are included, i.e. the variables also present in the gravity equation except for the endogenous variable ‘trade costs’ and the dummy for EU membership, and also including a variable for the lagged trade network embeddedness (Easley and Kleinberg, 2010; De Benedictis and Tajoli, 2011; Zhou, 2011) and a variable for the joint economic mass of the two trading partners, measured as GDP of the source country times GDP of the destination country.

shipping routes for surface distance and the CEPII measure for air distance (Mayer and Zignago, 2011). Other socio-economic data are from Dür *et al.* (2014), the CEPII database and the Quality of Governance (QoG) expert survey data set (Teorell *et al.*, 2011).

Following Santos Silva and Tenreyro (2006, 2011), we estimate (24) with Poisson pseudo-maximum likelihood (PPML) for trade for each manufacturing sector in the computational model. The elasticities on the variable trade costs give us the dispersion parameters (θ_s).[24] The distance elasticities are used to calculate the total trade cost reductions as a result of the reduction in shipping distances.[25]

As shown by Fally (2015) the combined use of PPML and fixed effects together with a balanced data set implies that the importer and exporter fixed effects have a structural interpretation and can be used to solve for the multilateral resistance terms. However, since our numerical model is written in relative changes, we do not need to know the precise values of trade costs (τ_{ijs}), technology (λ_{is}) and inward multilateral resistance (Φ_{is}^{imp}) to calibrate the model. With the model in relative changes we only need initial market shares (taken from the data) and the relative change of the variables changing in the counterfactual analysis (trade costs as discussed in the next subsection). As such our approach is similar to studies like Caliendo and Parro (2015) who use the exact hat-algebra methodology proposed in Dekle *et al.* (2008). Also in these studies the initial levels of iceberg trade costs and technology are not needed to perform a counterfactual analysis.

4.3. *Trade Cost Reductions*

The reduction in distance as a result of the NSR has an impact on two types of trade costs: international transport services and iceberg trade costs. The percentage reduction in the surface international transport margin, $\widetilde{\text{itm}}_{ijs}^{\text{sur}} = p^{\text{sur}}\zeta_{ijs}^{\text{sur}}\gamma_{ijs}/c_{is}t_{is}^{\text{prod}}t_{ijs}^{\text{exp}}$,[26] is calculated from the reduction in distance and the elasticity of the surface international transport margin with respect to distance, $\epsilon_{\text{itm,dist}}$:

$$\frac{\Delta\widetilde{\text{itm}}_{ijs}^{\text{sur}}}{\widetilde{\text{itm}}_{ijs}^{\text{sur}}} = \left(\frac{\text{dist}_{ij}^{\text{sur,NSR}}}{\text{dist}_{ij}^{\text{sur}}}\right)^{-\epsilon_{\text{itm,dist}}} - 1. \tag{25}$$

To calculate $\epsilon_{\text{itm,dist}}$, the international transport margin ($\widetilde{\text{itm}}_{ijs}^{\text{sur}}$) is regressed on distance, while controlling for port infrastructure in the importer country and including industry fixed effects.[27] This equation is estimated restricting the sample to European and East Asian countries for three reasons. First, the quality of the transport service data are poor for many other countries – in particular, the African countries. Second, the NSR is about a reduction in shipping distances between Europe and East Asia. And third, the empirical literature on the determinants of shipping costs shows

[24] Since we cannot estimate tariff elasticities for the services sector, we use the trade elasticities employed in the GTAP model corresponding with a value of 2.8 for the dispersion parameters.

[25] The importance of changes in shipping distances is analysed in online Appendix C.5.

[26] itm_{ijs} without tilde is the transport margin in power terms.

[27] A derivation of the equation estimating the parameter $\epsilon_{\text{itm,dist}}$ from the theoretical model is provided in online Appendix C.4.

that the effect is nonlinear, presents large variations between goods and is asymmetric in costs between the same routes (OECD, 2008). Table 3 shows that the estimated elasticity, $\epsilon_{\mathrm{itm,dist}}$, equals 0.789.[28]

In Table 4 we present a summary of the transport cost reductions based on (25). These vary by country pairs and are asymmetric, since our distance data are asymmetric.

A fall in distance as a result of the NSR not only affects international transport service costs but also other barriers to bilateral trade such as information costs,

Table 3

Regression of the International Transport Margin for Europe-Asia Trade

Ports	−0.088
	(8.54)***
ln(distance)	0.895
	(5.81)***
R^2	0.82
N	2,448

Notes. Poisson pseudo-maximum likelihood estimates of the international transport margin on ports and distance, including industry and source country dummies. Ports is a WEF/World Bank index of port quality in the importer country.

Table 4

International Transport Cost Reductions for Selected Countries

From	To	Percentage reduction	From	To	Percentage reduction
DEU	CHN	18.9	CHN	DEU	20.1
DEU	JPN	30.7	CHN	FRA	5.8
DEU	KOR	23.5	CHN	GBR	20.7
			CHN	NLD	20.5
FRA	CHN	4.3			
FRA	JPN	19.4	JPN	DEU	30.8
FRA	KOR	10.2	JPN	FRA	19.4
			JPN	GBR	31.8
GBR	CHN	19.6	JPN	NLD	31.4
GBR	JPN	31.7			
GBR	KOR	24.3	KOR	DEU	24.7
			KOR	FRA	11.7
NLD	CHN	19.4	KOR	GBR	25.5
NLD	JPN	31.3	KOR	NLD	25.2
NLD	KOR	24.1			

Notes. Country codes: DEU (Germany), FRA (France), GBR (UK), NLD (Netherlands), CHN (China), JPN (Japan) and KOR (South Korea). ¶*Source.* Own estimations.

[28] A series of papers find that the elasticity of shipping costs to distance is around 0.2 (Radelet and Sachs, 1998; Fink *et al.*, 2000; Limão and Venables, 2001; Micco and Pérez, 2002; Clark *et al.*, 2004). However, the OECD (2008) study uses the most comprehensive shipping costs dataset, and therefore our relatively high elasticity can be reconciled with the existing literature, because distance seems to matter more for shipping costs between East Asia and Europe.

business networks, cultural barriers, time, coordination and other non-shipping service costs (cf. Hummels and Schaur, 2013).

In our framework, these additional trade barriers are captured by the iceberg trade costs (τ_{ijs}). The percentage reduction in these costs (from τ_{ijs} to τ_{ijs}^{NSR}) is calculated based on the elasticity of iceberg trade costs with respect to distance and the reduction in surface distance as a result of the NSR, taking into account that only a share, s_{ijs}^{sur}, of trade takes place by surface:[29]

$$\frac{\tau_{ijs}^{\text{NSR}}}{\tau_{ijs}} - 1 = \frac{s_{ijs}^{\text{sur}}\left(\text{dist}_{ij}^{\text{sur,NSR}}\right)^{\frac{\xi_s^{\text{dist}}}{\theta_s}} + s_{ijs}^{\text{air}}\left(\text{dist}_{ij}^{\text{air}}\right)^{\frac{\xi_s^{\text{dist}}}{\theta_s}}}{s_{ijs}^{\text{sur}}\left(\text{dist}_{ij}^{\text{sur}}\right)^{\frac{\xi_s^{\text{dist}}}{\theta_s}} + s_{ijs}^{\text{air}}\left(\text{dist}_{ij}^{\text{air}}\right)^{\frac{\xi_s^{\text{dist}}}{\theta_s}}} - 1 \tag{26}$$

where $\xi_s^{\text{dist}}/\theta_s$ is the elasticity of iceberg trade costs with respect to distance calculated as the elasticity of trade flows with respect to distance (ξ_s^{dist}) divided by the trade elasticity (θ_s). Since international transport services are also included as a regressor in the gravity equation, the effect of distance on trade costs and thus on trade flows through international transport services is accounted for separately. Therefore, we can attribute the entire effect of distance from the gravity equation to a reduction in iceberg trade costs. Our estimates of $(\tau_{ijs}^{\text{NSR}}/\tau_{ijs}) - 1$ are summarised in Table 5.[30]

In defining the above shocks to transport and iceberg trade costs, we have assumed that the share of trade by surface (as opposed to air) stays constant. To justify this assumption, we examined the development of the share of trade by mode of transport in Eurostat data over the last 15 years. Figures C1–C2 in online Appendix C display the share of total trade by surface between the EU and the world and between the EU and East Asia. The Figures show that the shares are fairly constant and are actually increasing slightly. In light of this time-series evidence, we can conservatively assume that the shares stay constant.[31]

5. Counterfactual Analysis of Reductions in Trade Costs through the NSR

In this Section, we examine the effect of opening the NSR. In our counterfactual analysis, we compare the trade and macroeconomic outcomes in 2030 assuming that the NSR is fully operational with a baseline scenario where the NSR cannot be used

[29] The percentage change in τ_{ijs} corresponds with *ams* in the GEMPACK code.

[30] Note that these iceberg trade costs are country-pair-sector-specific and asymmetric, because the gravity equation is estimated for each sector separately and because the distance data are asymmetric.

[31] Feyrer (2009) uses a rising share of trade by air over time and a declining shipping distance elasticity to construct a time-varying distance-instrument for trade. Our results are not at odds with the findings in Feyrer (2009). First, Feyrer (2009) cites work by Hummels (2007) on the development in the US share of air transport since 1960. Although this work shows an increasing trend since the 1960s, this trend has stopped and been reversed since the beginning of 2000 (Figure 1 in Feyrer 2009). The data we present on transport mode shares in the last 15 years are in line with these findings. Second, Feyrer's results that the elasticity of trade flows with respect to shipping distance are falling and with respect to air distance are rising over time is not necessarily driven by changes in mode shares. Shipping distance elasticities could have fallen for other reasons, for example, strong growth in Asia leading to strong increases in shipping trade between Asia and Europe and North America.

Table 5

Iceberg Trade Cost Reductions for Non-services Sectors for Selected Countries

		Iceberg cost reductions					Iceberg cost reductions		
From	To	Average	Max	Min	From	To	Average	Max	Min
DEU	CHN	2.89	11.76	0.29	CHN	DEU	3.09	12.51	0.31
DEU	JPN	4.92	19.60	0.50	CHN	FRA	0.85	3.52	0.08
DEU	KOR	3.67	14.78	0.37	CHN	GBR	3.19	12.92	0.32
					CHN	NLD	3.15	12.77	0.31
FRA	CHN	0.62	2.58	0.06					
FRA	JPN	2.96	12.00	0.29	JPN	DEU	4.95	19.68	0.50
FRA	KOR	1.51	6.21	0.15	JPN	FRA	2.96	12.03	0.29
					JPN	GBR	5.13	20.36	0.52
GBR	CHN	3.00	12.18	0.30	JPN	NLD	5.07	20.13	0.52
GBR	JPN	5.11	20.28	0.52					
GBR	KOR	3.80	15.31	0.38	KOR	DEU	3.86	15.54	0.39
					KOR	FRA	1.74	7.16	0.17
NLD	CHN	2.97	12.04	0.30	KOR	GBR	4.00	16.07	0.40
NLD	JPN	5.05	20.06	0.51	KOR	NLD	3.95	15.89	0.40
NLD	KOR	3.76	15.14	0.38					

Notes. Average is the mean iceberg cost reductions between all 11 manufacturing sectors, while max and min are the maximum and minimum cost reductions, respectively. Codes: DEU (Germany), FRA (France), GBR (UK), NLD (Netherlands), CHN (China), JPN (Japan) and KOR (South Korea). ¶*Source.* Own estimations.

and instead the SSR is used. In the counterfactual scenario, we include both the transport cost and iceberg trade cost reductions as a result of the NSR as described in subsection 4.3. In this Section, we discuss in turn the trade, macroeconomic, labour market, and CO_2 effects and conclude with a robustness analysis.

5.1. *Trade Effects*

The counterfactual simulation generates our predicted changes in global and bilateral trade. First, we find that using the NSR will reduce international shipping volumes (defined as total tonne-kilometres) by 0.2%.[32] The opening of the NSR increases global trade values by 0.3%. Although these global trade changes are not very high, they are completely concentrated in trade changes between East Asia (i.e. China, Japan and South Korea) and Northern Europe. For instance, we predict that the share of World trade that is re-routed through the NSR will be 4.7%. Of the total Chinese trade in 2030, we project that 13.4% will use the NSR.

Table 6 shows the change in bilateral trade values for goods and services for three East Asian exporters. We observe significant changes in export and import values of the three main Asian countries that benefit from the NSR: China, Japan and South Korea.

On the one hand, we observe how Northern and Central European countries significantly increase their trade with China, Japan and South Korea. On the other hand, Southeastern and Mediterranean European countries (with the exception of

[32] Also air transportation volumes fall by 0.2%, as there is a substitution effect towards the cheaper transport mode shipping.

Table 6

East Asia, Changes in Total Trade Values for Selected Countries, Percentage Changes

	China		Japan		South Korea	
	Exports	Imports	Exports	Imports	Exports	Imports
Austria	12.48	6.68	14.12	17.90	9.86	9.51
Belgium	11.70	10.50	13.88	14.33	12.73	7.49
Bulgaria	−1.44	0.63	−0.65	0.46	−0.82	0.41
Croatia	−1.17	0.63	−1.03	−0.34	−0.72	0.24
Czech Republic	7.69	14.90	16.23	13.02	13.36	16.12
Denmark	9.52	5.50	3.89	10.72	7.31	7.16
Estonia	8.46	9.06	11.96	14.79	12.13	9.06
Finland	9.47	6.06	11.30	15.76	9.27	7.23
France	1.10	2.94	7.60	9.60	3.82	4.71
Germany	10.34	9.45	11.42	14.33	7.31	10.69
Greece	−0.98	0.46	−0.51	0.21	−0.82	0.16
Hungary	−1.62	0.43	−1.21	0.57	−1.00	0.45
Ireland	7.03	1.78	2.25	8.55	23.22	3.01
Italy	−1.26	0.90	−0.90	0.25	−0.84	0.34
Latvia	10.70	10.67	4.11	7.37	9.78	14.50
Lithuania	11.98	9.12	13.45	12.97	16.52	10.38
Netherlands	10.19	4.29	7.23	15.71	16.05	7.42
Poland	11.45	13.51	14.48	18.83	10.02	9.42
Portugal	−0.48	0.92	3.86	3.27	3.32	1.25
Romania	−1.44	0.89	−1.13	0.28	−1.12	0.20
Slovakia	8.29	8.76	13.89	11.95	11.29	11.63
Slovenia	−1.46	1.18	−1.08	0.49	−0.95	0.80
Spain	−0.51	0.75	6.26	6.54	2.51	1.36
Sweden	13.72	6.12	11.01	15.77	10.95	8.09
UK	11.65	6.04	10.74	10.54	8.36	5.45
EU28	6.73	5.92	8.79	10.03	6.84	6.36
Norway	11.07	6.26	10.93	11.98	3.95	6.07
Turkey	−1.13	0.54	−0.88	0.16	−0.71	0.27
US	−0.66	0.43	−0.49	0.05	−0.31	0.13

Source. Own estimations using the GTAP database.

France) experience a slight reduction in their bilateral trade with East Asia.[33] As a bloc, the European Union increases its trade with China, Japan and South Korea by around 7%.

This remarkable increase in bilateral trade between two relatively large economic zones is translated into a significant diversion of trade – i.e. the bilateral trade flows between East Asia and Northwestern Europe significantly increase at the expense of less trade with other regions. The main diversion effect is that there is a sizeable reduction in intra-European trade, with less trade between Northwestern Europe and Southern and Eastern Europe. Figure 3 shows these trade diversion patterns by displaying the changes in exports of selected countries to all trading partners, East Asia and the EU28.[34] For instance, German trade increases by around 10% to East Asia, while trade with other European countries slightly decreases (by around a half

[33] In Table D3 in online Appendix D.2 we show the corresponding data for merchandise trade in quantities, which display a similar pattern as described above.

[34] The precise Figures for the countries in Figure 3 and additional countries are presented in Table D4 in online Appendix D.2.

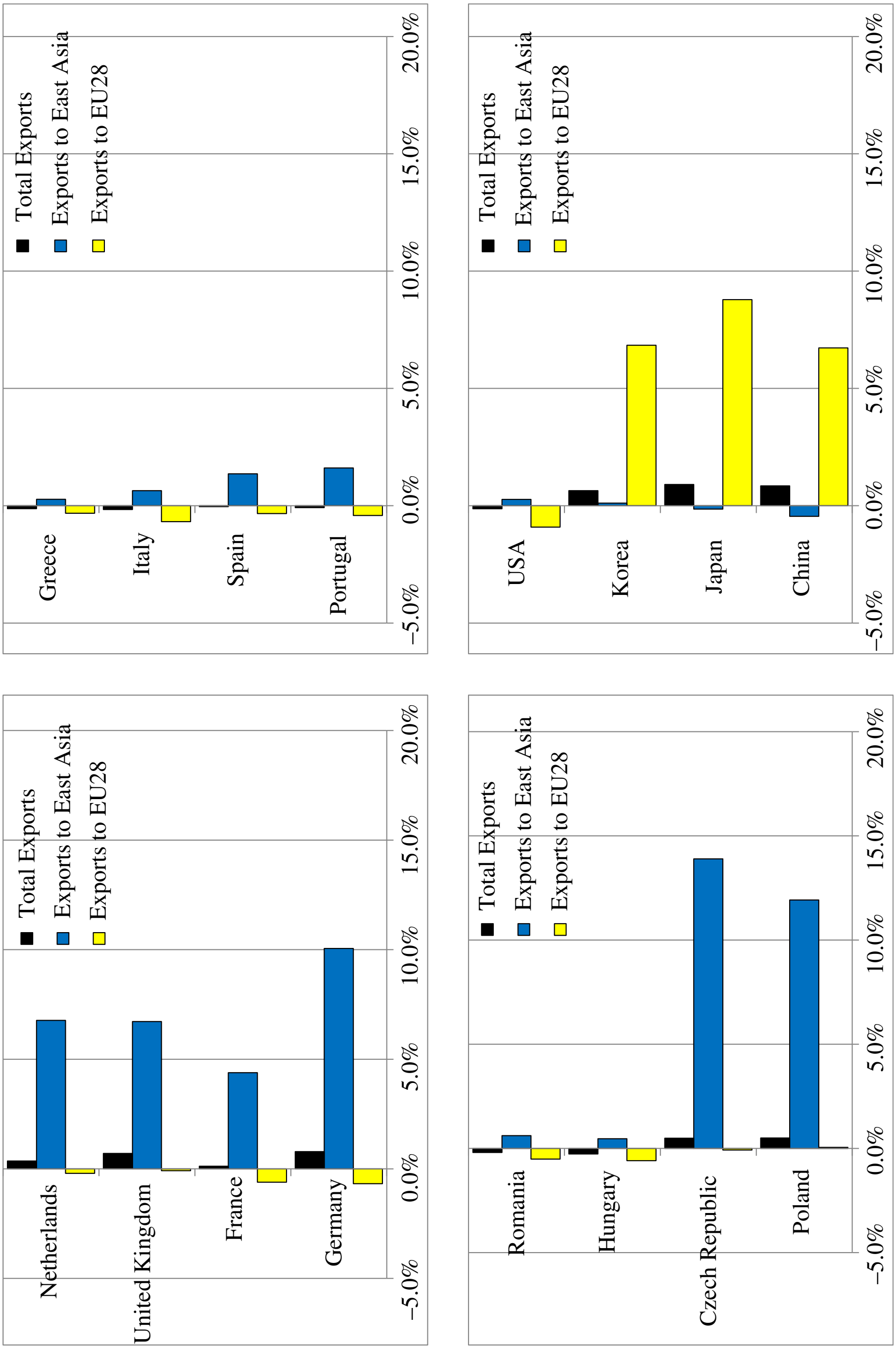

Fig. 3. *Trade Flows after Opening the Northern Sea Route: Percentage Changes in Exports by Selected Countries*
Source. Own estimations using the GTAP database. Colour figure can be viewed at wileyonlinelibrary.com.

percentage point). This pattern of changes in German exports is also replicated by the other Northwestern European countries (France, UK, Ireland, Scandinavian and Baltic countries, Belgium and the Netherlands). This is also the case for some Central and Eastern European countries that are closer to the North Sea (i.e. Austria, the Czech Republic and Slovakia). On the other hand, most Mediterranean countries and Southeastern European countries (Hungary, Romania and Bulgaria) experience a decrease in trade with both East Asia and the rest of Europe that is reflected in an overall reduction of trade. Finally, for the East Asian countries exports increase significantly to Northwestern Europe while declining slightly to third countries.

This pattern of trade diversion can also be observed with exports at the sectoral level. For instance, Tables D5 and D6 in online Appendix D.2 show the sectoral changes in exports to China and Germany. Changes in sectoral exports are evenly spread among all manufacturing sectors with few exceptions (mainly the services sectors). Looking at the trade flows to Europe, in Table D6 in online Appendix D.2 we show the percentage changes in export sales to Germany – which have a very similar pattern as exports to other Northwestern European countries. Here we find that China, Japan and South Korea significantly increase their exports to Germany in all manufacturing sectors, while all other European countries decrease their exports to Germany.

Despite the sizeable trade diversion, aggregate exports do not change significantly. In Figure 4 we show the changes in aggregate export values by country. We observe that Northern European countries increase their export values, since the increase of exports to Asia compensates for less intra-European trade. However, Southern European countries display a decrease in exports due to the reduction of exports to other Europe countries, which is not fully compensated by exports to third regions.

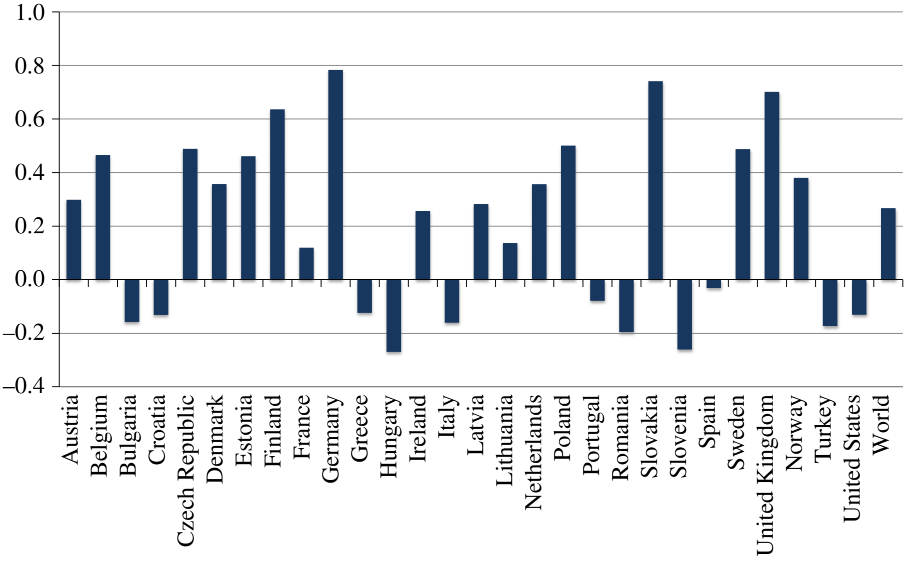

Fig. 4. *Changes in Export Values for Selected Countries, Percentage Changes*
Source. Own estimations using the GTAP database. Colour figure can be viewed at wileyonlinelibrary.com.

5.2. *Macroeconomic Effects*

The changes in trade flows are translated into macroeconomic impacts as well. First, GDP and welfare (measured by household utility u_j) increase modestly in the countries that benefit directly from the NSR (see Figure 5).[35] East Asia, Northwestern Europe (and also Poland and the Czech Republic) experience the biggest gains. On the contrary, most Southern European countries experience GDP decreases. This last effect is caused by the disruption in intra-EU trade and regional production value chains caused by the opening of the NSR. The associated trade diversion pattern therefore negatively affects the Southern EU Member States.

We can observe from Figure 6 that there is a direct relationship between these real income changes and the country-specific changes in exports values. In general, countries that increase their exports are those that also benefit from the opening of the NSR. The linkage between trade and welfare gains, therefore, is provided by the use (or not) of the new trade possibilities associated with the NSR. In particular, the positive welfare and GDP effects are driven by the reduction in the transportation and trade costs associated with the commercial use of the NSR.

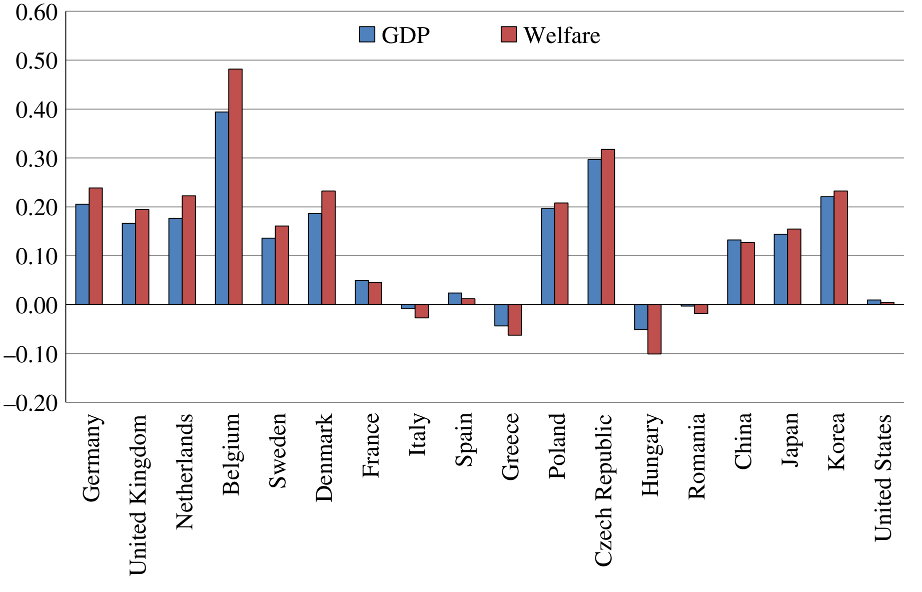

Fig. 5. *GDP and Welfare Changes Associated with the Opening of the Northern Sea Route for Selected Countries, Percentage Changes*

Note. Welfare is measured as *per capita* utility.

Source. Own estimations using the GTAP database. Colour figure can be viewed at wileyonlinelibrary.com.

[35] See also Table D7 in online Appendix D.2 for the GDP and real income changes for a broader selection of countries. In this Table we also present the changes in two welfare measures: *per capita* utility and equivalent variation in US$ million. Both measures of welfare experience changes that follow roughly the same pattern as GDP and real income changes, while the last welfare measure shows changes in US$ that are directly related to country size.

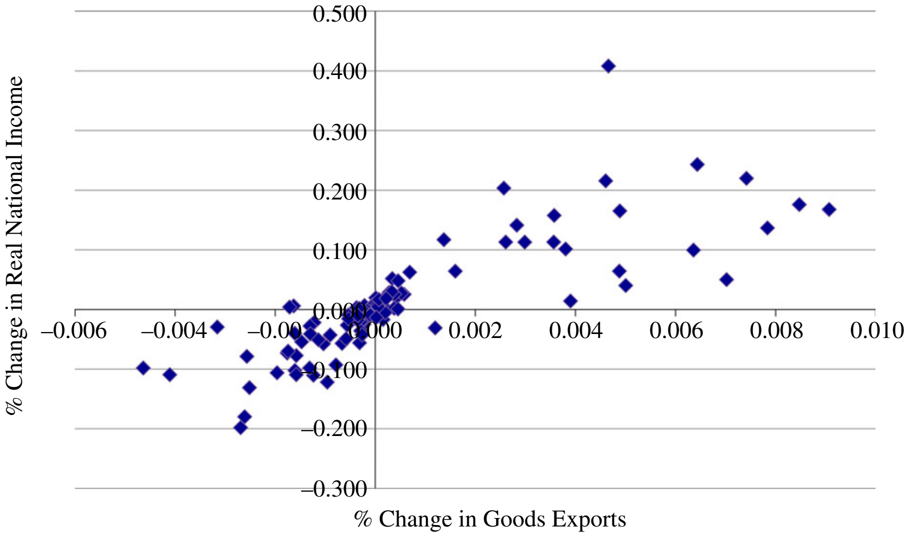

Fig. 6. *Total Export Values and Real Income, Percentage Changes*
Source. Own estimations using the GTAP database. Colour figure can be viewed at wileyonlinelibrary.com.

The countries that benefit from these trade cost reductions are those that will use the NSR intensively and, by extension, are the same countries that will also increase their trade quantities. On the other hand, countries that do not use the NSR will not benefit from the trade costs reductions and will, in addition, experience trade diversion (increased competition from other countries), which is associated with lower trade but also with lower welfare and GDP. However, given the relatively small aggregate trade changes, sectoral output follows a similar pattern. We find that much of the sectoral output in most EU countries does not change significantly.[36]

5.3. *Labour Market Effects*

The changes in wages and employment are closely linked to changes in GDP, which in turn are related to the possibility of benefiting from the use of the NSR as explained above. From Table D1 in online Appendix D.1 we observe, however, that real wage and aggregate employment changes by country are relatively small. Wages for all three skill types (low, medium and high) change by less than 0.5% and aggregate employment by less than 0.1%. Sectoral labour displacement is more significant (see Table D2) but we find that on average around 0.5% or less of the total labour force is displaced to another sector. Therefore, we do not expect any large scale labour adjustment shocks, since the changes in sectoral output and employment will be very modest and will occur gradually according to the speed at which the NSR substitutes for the SSR.[37]

[36] The specific sectoral results are available upon request.
[37] A more extensive description of labour market effects is in online Appendix D.1.

5.4. *Effects on CO_2 Emissions*

At first it is expected that the shorter shipping distances associated with the NSR will reduce fuel costs and emissions from the water transport sector. However, the increase in trade quantities also means that when the shipping distance is reduced, the shipping services are increased due to the rise in trade quantities between Northern Europe and East Asia. We find that the two effects almost offset each other, predicting nonetheless that there is a slight increase in global emissions of 0.07% – or around 18.7 million tonnes of CO_2 (see Table D8 in the online Appendix D.2). This increase is comparable to the annual emissions for small countries (e.g. Latvia or Lithuania).[38]

In our simulations we assume that the implicit emission levels by sector and country remain constant. This means that changes in emission levels are not counteracted by policy efforts (i.e. carbon taxes, emission permits) nor by technological changes, which could affect the effective emission levels by country and sector.

5.5. *Robustness Analysis*

We have conducted five sets of robustness tests. First, we checked whether changing the baseline period has an impact on the results. Choosing a different baseline year changes the shares of different countries in global GDP, which can also affect the impact of the opening of the NSR. As an alternative to our 2030 base-year, we also ran simulations using 2020 and 2040 as the baseline period.[39] We find that changing the baseline period has only very small effects on the results with slightly larger effects in 2020 and slightly smaller effects in 2040 on the trade values displayed in Figure 4. For example, we predict that in 2020, 2030 and 2040 Germany's total trade by value increases by 0.86%, 0.84% and 0.76%, respectively. The reason for the declining effect over time is that most emerging countries with above average growth will not use the NSR.

Second, we have examined the impact of higher shipping costs on the NSR. In particular, we explored the impact of 20% higher transport costs on the NSR, because the types of ships needed on the route are more expensive due to the harsher navigation conditions. A consequence of these higher trade costs is that for some country pairs, the NSR is not used anymore, whereas for some other country pairs, the NSR is still used even when the transport costs are higher than using the SSR. This is because the reductions in iceberg trade costs from using the NSR dominates the rise in transport costs in these cases. As expected, the overall trade and macroeconomic effects of the NSR are reduced significantly, by around one-third of our previous estimations, while the trade and macroeconomic patterns (distribution of effects) remain unchanged. Thus, with higher NSR transport costs, the impact of the NSR is scaled down, as the NSR will be used on less routes and be more expensive on the routes still predicted to be used.

[38] It is important to note that these particular CO_2 results 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.

[39] Summary tables for all sensitivity analysis are presented in online Appendix D.3. The set of tables with all the results for each sensitivity analysis are available upon request.

Third, we explored what happens if the NSR can only be used six months a year. To assess this scenario, we assume that firms use the cheapest way to transport goods whenever it is available and thus will in fact use the NSR for six months. This implies that the trade cost reductions as a result of the NSR will fall by half. The results in online Appendix D.3 show again that the sizes of the effects are scaled down, now by around one half in comparison to when the route is open all year, whereas the trade patterns remain the same.

Fourth, we evaluated the impact of changes in projected growth for China – a key potential user of the NSR – and for India and Africa. Here we assume that annual Chinese growth is respectively lower (4%) and higher (8%) than the baseline 6.5% projected by the OECD. Then we explored the impact of stronger catch-up growth in some of the major emerging economies: Africa and India, respectively. In particular, we evaluate the impact of 8% annual growth in Africa and India instead of 5.5% and 6%, respectively, as in the baseline, using OECD projections. For all these four sets of simulations, we find that the changes in our results are very minor. The reason is that the size of the shocks remains the same and that changes in the growth projections of one country or one continent do not change much relative to the baseline on which the shocks are operating.[40]

Finally, to address concerns that some of the parameters of the model are not structurally estimated we turn to a model where we only use the estimated trade elasticities and set the other CES nests back to Cobb–Douglas, following an approach in the recent quantitative trade literature aiming at a parsimonious calibration. In particular, we assume that private consumption demand across sectors is Cobb–Douglas, as well as the choice between intermediates and value added and the choice between production factors. Furthermore, we eliminate the labour supply parameters by making labour supply exogenous. As a result the only parameters left are the trade elasticities that are estimated structurally.[41] We find that our main results are robust to changes in these model parameter values. The changes in the trade effects are negligible, whereas the welfare effects for the countries affected are up to a quarter smaller. For example, for Germany, the increase in welfare drops from 0.24% to 0.18%. The main reason is that substitution elasticities between private goods are larger in the baseline model, generating larger overall welfare gains from lower prices as a result of the NSR.

Our main results, therefore, are only quantitatively changed when we increase the trade costs associated with the NSR by 20%, when we assume that the route is only opened half the year or when we set all parameters back to Cobb–Douglas. In the three cases, the qualitative results remain unchanged, but the economic impact of the NSR is scaled down.[42]

[40] The effect on welfare in China for example is 0.01% larger in the low growth scenario than the 0.13% increase in the baseline, while 0.02% smaller for the high growth scenario, which is a small effect. For the other scenarios the differences are even smaller.
[41] We also retain the parameters imposing that land and natural resources are partially immobile across sectors, as it would be very unrealistic to drop this assumption.
[42] See Figures D1 and D2 in online Appendix D.3.

6. Summary

The commercial use of the NSR – if ultimately made possible by further melting of the Arctic ice cap – will represent a major development for the international shipping industry. The NSR represents a reduction of about one-third of the average shipping distance and days of transportation with respect to the currently used SSR. Roughly 8% of World trade is transported through the Suez Canal and we estimate that two-thirds of this tonnage will be re-routed over the shorter Arctic route.

These shorter shipping distances are associated with substantial reductions in the transportation and trade costs between two major economic regions: East Asia and Northwestern Europe. We estimate that these overall trade cost reductions will increase the trade flows between both regions on average by around 10%, depending on the specific countries involved. This will transform the NSR into one of the busiest global trading routes, which in turn implies heightened economic and geopolitical interests linked to the Arctic and tremendous economic pressure on the countries currently servicing the older SSR (e.g. Egypt and Singapore). In addition, the NSR will also imply a large amount of trade diversion, which will have a negative economic impact on Southern Europe.

Finally, we estimate that the NSR will slightly increase CO_2 emissions. Although the much shorter shipping distances will reduce the emissions associated with water transportation, these gains are offset by the increasing trade quantities as a result of the NSR.

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Additional Supporting Information may be found in the online version of this article:

Appendix A. Shipping Distance Calculations.
Appendix B. Model.
Appendix C. Calibration.
Appendix D. Counterfactual Analysis.
Data S1.

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