Adapting to within-country export barriers: Evidence from the Japan 2011 Tsunami*

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September 28, 2017

Abstract

How is a firm's ability to export affected by changes in domestic trade costs? In particular we focus on the interaction between firms and ports to answer how strongly exports from one port are affected by changes in the cost of exporting at neighbouring ports? To answer these questions we extend the standard trade model with heterogeneous firms to have a multiple port structure where exporting is subject to port specific local transportation costs and port specific fixed export costs as well as international bilateral trade costs. We derive a gravity equation with multiple ports and show that gravity distortion due to firm heterogeneity is conditional on port comparative advantage and resulting substitution of export across differentiated ports. We present evidence of the substitution effect using the 2011 Great East Japan Earthquake and following tsunami, which suggest that about 50% of the exports was substituted to other ports following the disaster.

Keywords: firm heterogeneity, extensive margins, transportation costs, fixed costs, natural disasters.

JEL classification: F14, O18, R1

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*This paper was presented at Newcastle University (Newcastle, UK), Keio University (Tokyo, Japan), CEPII (Paris, France), Nagoya City University (Nagoya, Japan), Nihon University (Tokyo, Japan), University of Sydney (Sydney, Australia), McMaster University (Hamilton, Canada), and the conferences of the Irish Economic Association, British Royal Economic Society, and French National Economics Association. We thank Brock D. Smith, Gerhard Toews, Gianluca Orefice, Svetlana Demidova and Toshihiro Okubo for discussions and advice as well as seminar participants for helpful and constructive comments.

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1 Introduction

In this paper we investigate how firms respond to changes in the domestic costs of exports. We do this in two ways. First, we develop a theoretical framework based on a trade model with heterogenous firms and multiple ports between which a firm can choose to export. From a firms' perspective, each port will have a particular combination of fixed and variable cost. A profit maximising firm will minimise the cost of exports. We derive the implications for trade when fixed and variable costs change for one port and how this affect the trade for *other* ports. We hereby extend the gravity framework in heterogenous firms model with internal trade costs and explicit interaction effects between trade routes. Secondly, we test the predictions of the theoretical model with Japanese customs data, exploiting the Great Japanese Earthquake of 2011 as a natural experiment, to infer how firms adapted to changes between ports of the costs to export.

Barriers to trade are an important driver of firm performance. Firms that can access foreign markets have a great potential to grow their business and invest further at their manufacturing locations. It is well known that countries with access to seas have better trade performance (e.g. Limão and Venables, 2001), while within countries domestic trade costs matter too (e.g. Agnosteva et al., 2017; Atkin and Donaldson, 2015; Volpe Martinicus et al., 2017). As external barriers to trade have fallen dramatically over the last decades, the interest in the role of domestic trade costs or internal barriers to trade has increased (Allen and Arkolakis, 2014; Coşar and Fajgelbaum, 2016; Ramondo et al., 2016). Policy makers interested in facilitating trade may make more progress by focusing on within country barriers relative to between countries. Our paper informs what mechanisms are in play when policy makers decide to invest in trade infrastructure (e.g. roads, railways, domestic waters or sea ports) in one location, leaving other locations unchanged but potentially still impacted by spatial spillovers.[1]

The disaster that Japan experienced on 11 March 2011, albeit gruesome, is interesting from an economic point of view because, as we will substantiate further, the shock can be considered to be primarily a supply shock on port-infrastructure with very little direct damage to firms on average over the time period that we consider. This is in contrast to earlier research on aggregate economic growth using natural disasters or firm level outcomes that could not distinguish between demand shocks for firms and supply shocks at the firm and regional level.[2]

Starting from the above observation, we build a model of multiple ports based on Melitz (2003) and Chaney (2008). The number of ports in a country is exogenously

[1] One can also think of port competition in the European Union, where the internal borders have disappeared but ports may still be fiercely competing for trade and national governments can choose to invest in the infrastructure that facilitates trade through their national ports. That ports specifically are important for the facilitation of trade is well understood (Clark et al., 2004; Feenstra and Ma, 2014).

[2] See Kirchberger (2017) for references in the economics literature on natural disasters.

given and ports from which heterogeneous firms export are differentiated with respect to their variable and fixed export costs. Variable costs could represent the distance to the port from each firm, while fixed costs could represent a port's specialization into certain product categories such as goods shipped in containers or in bulk. Given a firm's location, trade facilitation of each port depends on its comparative advantage between port specific local transportation costs and port specific fixed export costs. It is shown that exports are shipped through multiple ports in equilibrium as long as there exist such a comparative advantage structure.

In the presence of this port comparative advantage, we establish a port specific gravity equation and decompose trade flow of each port into extensive, intensive and composition margins of export as in Chaney (2008). A rise in internal trade cost to a specific port induces a decrease in exports from that port while exports from the another competing port increases. Through such a substitution of export from one port to the another, aggregate exports of a country fluctuate to some extent. Therefore, "internal" gravity matters for aggregate trade flow. Changes in port specific fixed export costs also induces a similar substitution across ports, however, with a different magnitude depending on comparative advantage of the ports.

We test the prediciton of cross-port substitution on Japanese sea ports using the tsunami that followed the 2011 Great East Japane Earthquake as an exogenous change in internal trade costs that affected some ports but not others. For each port we calculate measures of trade using monthly data of exportsover 9-digit product categorisations and destination from 2009 onwards. The tsunami following the earthquake destructed a number of ports on the north-eastern Honshu coast in the Tohoku region, especially those directly in the line of the Tsunami. Other ports, further away, or protected by natural bays were much less or not affected by the natural disaster. As the port counter-factual we use all other ports in Japan, who were far removed from the disaster region.

We find a substitution effect for the export value and extensive margins for ports that are located in the same region but suffered no damage during the disaster. For some months, substitution ports may have gained up to 30% additional trade and gained up to 2 percentage points in their extensive margin, representing a 7.3% increase from their pre-disaster margins. Overall, during the first 12 months after the earthquake, our estimates suggest that about 50% of the exports was substituted to other ports.

Although we do use a natural disaster for our identification strategy our focus is different from many paper in the literature on the economic consequences of natural disasters. Firstly, we are also particularly interested in the effect of areas that were *not* hit by the disaster, which is often neglected in the existing research. Secondly, we argue that the destruction was limited to the coast of north-eastern Honshu, and did not extend further inland. In a sense, the destruction was specifically targeted at ports only. Despite the dramatic images of inundated coastal villages, these presented local extremes that should not be held as representative for the entire region.

Major earthquakes, such as one around Kobe in 1995, have been exploited to understand how such disasters propagate through an economy (Cole et al., 2015b; Hosono et al., 2012; Tanaka, 2015). First analysis on the 2011 Great Japanese Earthquake has come out, for instance with respect to the consequences on the energy market following the failure of the Fukushima-Dashi Nuclear power plant. A collection of research to the energy implications is presented in (Economics of Energy & Environmental Policy, 2015), while Coulomb and Zylberberg (2016) study the effect the disaster had on risk perceptions in the UK. Cavallo et al. (2014) studies product availability and prices in supermarkets. Zhu et al. (2016) studies the decision of off-shoring of japanese firms in the aftermath of the disaster.

Closer to our work is Todo et al. (2015) who explore the role of local supply chain networks on firms recovery time after the 2011 earthquake using survey data. Cole et al. (2015a) investigate the role of pre-disaster planning on post-disaster firm level performance. Studies that use firm level data are more limited on the frequency of the observed data, which also limits their ability to deal with endogeneity issues. Using our monthly trade data we can closely follow the dynamics of recovery and substitution while controlling explicitly for pre-tsunami circumstances, although our focus must be on ports rather than firms and so complements these studies. Volpe Martinicus and Blyde (2013) test the effect of firm level shipments following the 2009 earthquake in Chile that destroyed a large portion of the transport network.

What we bring to this literature is a new extension to a familiar model of trade that can be directly brought to datasets such as we present here while at the same time offer an empirical case with a credible identification of exogenously changed trade costs.

The paper is organized as follows. In Section 2 the theoretical model is presented and we derive the gravity equation with multiple ports. We calibrate the theoretical model and provide a numerical simulation. In Section 3,we present the results of our regression analysis based on Japanese exports data from multiple regions. Section 4 concludes.

2 The model

We start from a general description of the theoretical model and explain the specific empirically motivated three port cases, namely tsunami hit and substitute ports relative to the rest, in the following subsection.

Our model builds on the heterogeneous firms framework of Melitz (2003) following Chaney (2008). There are N number of countries in the world. In a country n, there are multiple ports k and locations o whose total number is exogenously given by K_n and O_n. The population and labour supply is also exogenously given by L_n. In each country, sector 0 provides homogenous goods which serve as a *numéraire* and traded worldwide without any transportation cost while other sectors (whose total number is amount to H) are made of differentiated goods. Firms, that are heterogeneous in terms of their specific productivity level, are monopolistically competitive in differentiated sectors. These firms (exporters or non-exporters) are located in different space in their origin country.[3] Our model departs from Chaney (2008) by allowing firms to choose a specific port for exporting.

2.1 Households

Households of a typical country gain utility from the consumption of a set of differentiated product varieties in each sector, Ω_h, as well as homogenous goods (omitting country specific subscripts for readability) :

$$C = c_0^{\alpha_0} \prod_{h=1}^{H} \left(\int_{\Omega_h} \left(q\left(\omega\right) c\left(\omega\right) \right)^{1-\frac{1}{\sigma_h}} d\omega \right)^{\frac{\alpha_h}{1-\frac{1}{\sigma_h}}},$$

where c_0 is the consumption of homogenous goods. The consumption of a particular product variety, $c\left(\omega\right)$, is either produced locally or imported. The 'quality' of that good, $q\left(\omega\right)$, can be interpreted as an exogenous demand which is origin-destination (-sector) specific. The elasticity of substitution of product varieties in each sector is given by σ_h (> 1). The expenditure weight on homogenous goods is given by α_0 and that on goods in sector h is given by α_h.

2.2 Ports and Firms

Firms in country i in a particular location o are assumed to be heterogeneous in terms of their specific labour productivity level, φ, and are facing the following choice: export or not export, and if export, a choice in ports. Production involves only labour as input. Exporting from an origin country i to a destination country j requires port specific fixed costs, f_{ijk}, and port k and location o specific iceberg type of local transportation costs within country, μ_{ok} (> 1), as well as an iceberg type of bilateral trade costs, $\tau_{ij}(> 1)$. [4]

For a firm with a specific productivity, φ, total costs in producing y units of a good and exporting these goods from location o of country i of port k to country j is thus given by

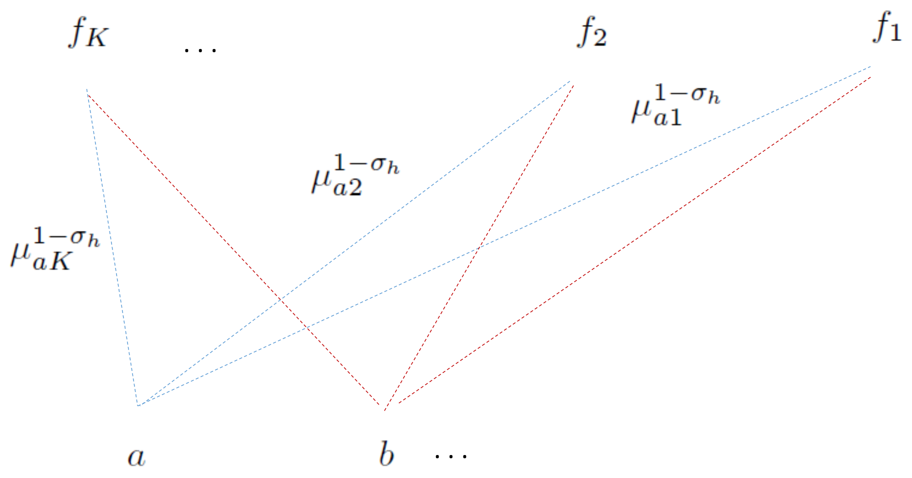
$$TC_{ijok}\left(\varphi\right) = \frac{w_i \mu_{ok} \tau_{ij}}{\varphi} y + f_{ijk},$$

where w_i denotes real wages in country i which is found to be 1 due to our choice of *numéraire*. Figure 1 summarises the setting of our model. From now on, we focus on

[3]We exclude the possibility of FDI such as argued in Helpman et al. (2004)

[4]Note that $\tau_{ij} > 1$ andμ_{ok} (> 1) for $i \neq j$ and $\tau_{ii} = \mu_{ok} = 1$.

Figure 1: Multiple Ports and Multiple Locations (for specific sector in a country)



firms in a specific sector and location and drop sector index h and location index o when there is no room for confusion.

2.3 Demand for differentiated goods

Due to the monopolistic competition, production scale is determined by demand. The demand addressed to the firm that has a productivity level φ from a destination country j is given by

$$c_{ijk}(\varphi) = q_{ij}^{\sigma-1}\left(\frac{p_{ijk}(\varphi)}{P_j}\right)^{-\sigma}\alpha C_j, \tag{1}$$

with

$$p_{ijk}(\varphi) = \frac{\sigma}{\sigma-1}\frac{w_i\mu_k\tau_{ij}}{\varphi}. \tag{2}$$

In the above expression, P_j is the ideal price index for a particular sector in country j.

If the firm exports from port k, dividends are given by $d_{ijk}(\varphi) = p_{ijk}(\varphi)\, c_{ijk}(\varphi) - TC_{ijk}(\varphi)$. Plugging the demand (1) and optimal price (2), we get

$$d_{ijk}(\varphi) = \frac{1}{\sigma}\left(\frac{p_{ijk}(\varphi)/q_{ij}}{P_j}\right)^{1-\sigma}\alpha Y_j - f_{ijk} \tag{3}$$

where Y_j is total income or total expenditure of country j, namely, $Y_j = P_jC_j = w_jL_j(1+d)$ where d is the dividends from a global mutual fund that corrects and distributes dividends from all over the world. Following Chaney (2008), we assume that the share of dividends is proportional to the total labor income of each country and that the potential number of entrants in exporting market is proportional to the total labor income in the country, w_jL_j. Specifically, the latter assumption simplifies the analysis by abstracting from free entry of firms.

2.4 Decision to Export and Port Choice

A cutoff productivity level $\overline{\varphi}_{ijk}$ above which firms export is determined by $d_{ijk}\left(\overline{\varphi}_{ijk}\right) = 0$ for each port. By solving the above zero-profit-cutoff (ZPC) condition, we have:

$$\overline{\varphi}_{ijk} = \lambda_1 \left(\frac{w_i \mu_k \tau_{ij}}{q_{ij} P_j}\right) \left(\frac{f_{ijk}}{Y_j}\right)^{\frac{1}{\sigma-1}}, \tag{4}$$

where $\lambda_1 = (\sigma/\alpha)^{\frac{1}{\sigma-1}} [\sigma/(\sigma-1)]$. Note that the cutoff level is port specific due to port specific local transportation costs μ_{ijk} and port specific fixed export costs f_{ijk}.

Having computed the cutoff productivity level for each port, we rank them according to their size as

$$\overline{\varphi}_{ijK_n} < \overline{\varphi}_{ijK_n-1} < ... < \overline{\varphi}_{ij2} < \overline{\varphi}_{ij1}. \tag{5}$$

Note that the above ranking is just a conceptual device which eases the reasoning that follows. Thus this is not an assumption on the model, but for convenience of representation and without loss of generality. For any pair of cutoff productivity level $\overline{\varphi}_{ijk}$ and $\overline{\varphi}_{ijs}$ with $k = 2...K_n$ and $k > s$, we can further define another cutoff productivity level $\overline{\varphi}_{ijks}$ for which firms are indifferent in exporting from either port as $d_{ijk}\left(\overline{\varphi}_{ijks}\right) = d_{ijs}\left(\overline{\varphi}_{ijks}\right)$. Solving this even-profit-cutoff condition (EPC), we have

$$\overline{\varphi}_{ijks} = \lambda_1 \left(\frac{w_i \tau_{ij}}{q_{ij} P_j}\right) \left[\frac{f_{ijs} - f_{ijk}}{Y_j\left(\mu_s^{-(\sigma-1)} - \mu_k^{-(\sigma-1)}\right)}\right]^{\frac{1}{\sigma-1}}. \tag{6}$$

Two competing ports k and s through their cutoff productivity level $\overline{\varphi}_{ijk}$ and $\overline{\varphi}_{ijs}$ have different port specific features with respect to local transportation costs and fixed export costs. This cut-off is meaningful in the following sense. Firms in this location, with productivity level $\overline{\varphi}_{ijks}$ will be indifferent between exporting through port k and s. For this firm, the relative variable costs and relative fixed costs exactly yield the same profit for the firm. To make this more concrete, we can say that one port, say s is more efficient in terms of local transportation costs, but less efficient in terms of its fixed export costs than port k. Therefore, firms in location o chose either ports k or s, depending on their level of labour productivity φ, and therefore both ports will export some goods. Precisely speaking, we can establish a *port comparative advantage* in the following proposition.

Proposition 1 .

Under $f_{ijs}/f_{ijk} > (\mu_s/\mu_k)^{1-\sigma} > 1$ for $k = 2...K_n$ with $k > s$, we have $\overline{\varphi}_{ijk} < \overline{\varphi}_{ijs} < \overline{\varphi}_{ijks}$. In this case, firms with $\overline{\varphi}_{ijks} < \varphi$ prefer to export from port s while firms with $\varphi < \overline{\varphi}_{ijks}$ prefer to export from port k and multiple ports are in action. Port k is said to have a comparative advantage in variable export costs, while port s has a comparative advantage in fixed costs.

Proof. See Appendix A. ■

When $(\mu_s/\mu_k)^{1-\sigma} > 1$, a marginal increase in profits of exporting from port s is higher than that from port k for firms with $\overline{\varphi}_{ijks} < \varphi$. Therefore, exporters spread into either port with which they earn higher exporting profits. Having established even-profit-cutoff productivity levels for any pairs of port provided by the ranking of zero profit cutoff productivity levels for each port as in (5), the firm with φ eventually chooses to export from one specific port k^* that maximises its exporting profits $d_{ijk^*}(\varphi_{ijlk})$. See also Figure 2 where we provide a specific case with $K_n = 3$ and $\overline{\varphi}_{32} < \overline{\varphi}_{31} < \overline{\varphi}_{21}$.

When $(\mu_s/\mu_k)^{1-\sigma} < 1$ however, firms absolutely prefer to export from port k independent of their productivity level and we have the following corollary.

Corollary 1 *When $\mu_1 > \mu_2 > ... > \mu_{K_n-1} > \mu_{K_n}$, all exporters export from port K_n.*

By removing the port comparative advantage, the port K_n has now absolute advantage in both fixed export costs and local transportation costs, which results in attracting all local exporters. The analogy is that firms' location changes the variable costs aspect for the ports from which they can choose to export. While a firm in one location might face the comparative advantage situation described above, a firm in another location might only see an absolute advantage.

Having established the above export decision and port decision, we can compute the ideal price index in country j as

$$\left(\frac{\sigma-1}{\sigma}P_j\right)^{1-\sigma} = \sum_{n=1}^{N} w_n L_n \sum_{o=1}^{O_n} \left[\int_{\overline{\varphi}_{njoK_n}}^{\overline{\varphi}_{njoK_nK_n-1}} \left(\frac{w_n \mu_{oK_n} \tau_{nj}}{q_{nj}}\right)^{1-\sigma} dG(\varphi) + \dots + \int_{\overline{\varphi}_{nj21}}^{\infty} \left(\frac{w_n \mu_{o1} \tau_{nj}}{q_{nj}}\right)^{1-\sigma} dG(\varphi) \right] \quad (7)$$

2.5 Tsunami Hit and Substitute Port

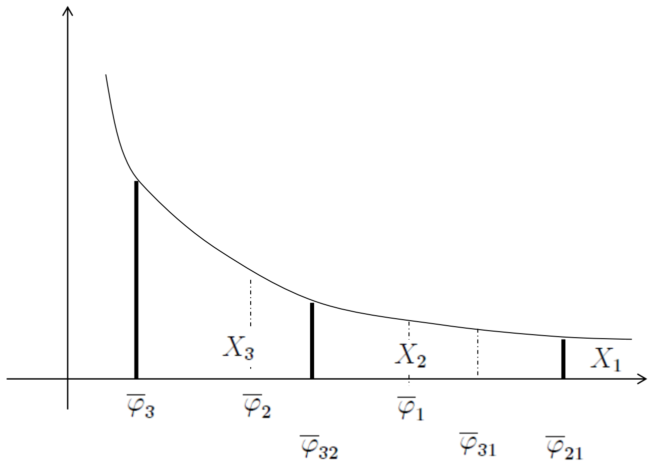
We can now think of a structure of the model that fits our empirical strategy and data. First, we choose one specific location of firms inside of Japan, namely Tohoku region (i =Japan and o =Tohoku). Second, we regroup ports into three categories and let each be represented by their mean of the ports in each category, with abuse of notations, namely group of ports H, ports S and ports C.[5] Ports in group H are those hit by tsunami at the Great East Japan Earthquake. The 'tsunami hit' ports are mainly in Tohoku region.[6] Ports in group S are exposed to potential substitution of exporting from port H. The 'substitute' ports are hence in the neighboring area of Tohoku. Ports in group C are

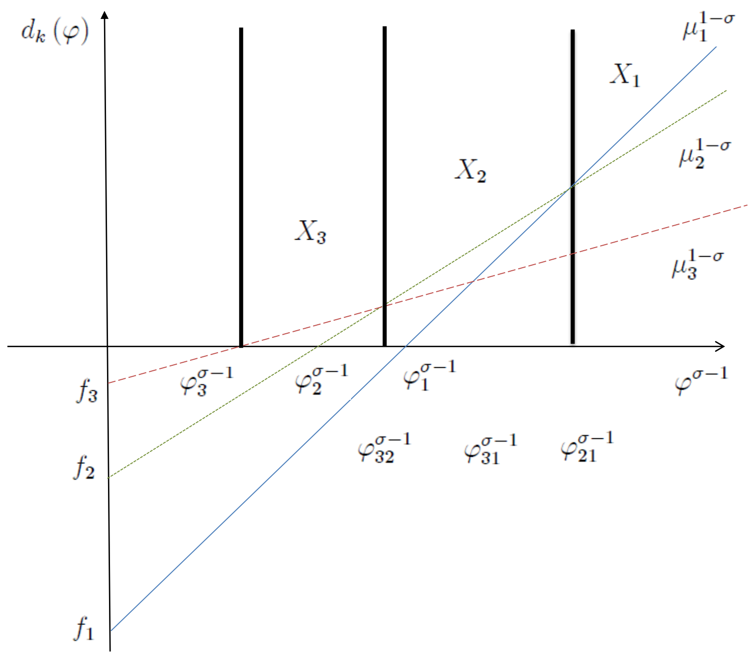
[5] Tsunami hit ports H is not related to the sectors, nor are the counter-factuals C related to consumption.

[6] See the map of Figure 4 on page 19.

Figure 2: Multiple Port in Action ($K_n = 3$ and $\overline{\varphi}_{32} < \overline{\varphi}_{31} < \overline{\varphi}_{21}$)

(a)





(b)

neither tsunami hit nor substitutes. These 'counter-factual' ports are geographically far from Tohoku and neighboring area. [7]

For the simplicity of the presentation, we assume three groups of ports structure with the rest of the world. To solve the model we assume the Pareto distribution for firm specific productivity level as $G(\varphi) = 1 - \varphi^{-\kappa}$ where κ $(> \sigma - 1)$ is the shaping parameter of the distribution. When κ increases, firms are more concentrated at its minimum level of productivity, which we set as unity. Using the Pareto distribution and plugging the cutoff levels (4) and (6) in the ideal price index (7) together with the definitions of the substitute and hit ports, we have

$$P_j = \lambda_2 Y_j^{\frac{1}{\kappa} - \frac{1}{\sigma-1}} \vartheta_j,$$

where $\lambda_2 = [(1+d)/Y][\kappa - (\sigma-1)/\kappa][\sigma/(\sigma-1)]^{\kappa} (\sigma/\alpha)^{\frac{\kappa}{\sigma-1}-1}$ and

$$\vartheta_j^{-k} = \sum_{n=1}^{N} \frac{Y_n}{Y} \left(\frac{w_n \tau_{nj}}{q_{nj}}\right)^{-\kappa} \left[f_{njS}^{-\left(\frac{\kappa}{\sigma-1}-1\right)} \mu_S^{-\kappa} + \left(f_{njH} - f_{njS}\right)^{-\left(\frac{\kappa}{\sigma-1}-1\right)} \left(\mu_H^{-(\sigma-1)} - \mu_S^{-(\sigma-1)}\right)^{\frac{\kappa}{\sigma-1}} \right]. \tag{8}$$

Thus ϑ_j is the weighted average of origin and destination specific characteristics capturing the 'remoteness' of country j from the rest of the world. Different from the expression in Chaney (2008), however, the term includes the efficiency of ports in each county in the square bracket. Conventionally, the impact stemming from changes in bilateral trade cost of country n is considered to be negligible in ϑ_j. Similarly, we assume that any changes in port specific costs are negligible as $\partial\vartheta_j/\partial f_{njH} = \partial\vartheta_j/\partial f_{njS} = \partial\vartheta_j/\partial\mu_H = \partial\vartheta_j/\partial\mu_S = 0$.

With the above closed-form solution, exporting sales of firm φ that exports from Japan (country i) to country j, $x_{jk}(\varphi) = p_{jk}(\varphi)\, y_{jk}(\varphi)$ with $k = H$ or S, can be expressed as

$$\begin{aligned} x_{jH}(\varphi) &= \lambda_3 \left(\frac{Y_j}{Y}\right)^{\frac{\sigma-1}{\kappa}} \left(\frac{w_i \mu_H \tau_{ij}}{q_{ij}\vartheta_j}\right)^{1-\sigma} \varphi^{\sigma-1}, \text{ if } \overline{\varphi}_{ijSH} < \varphi, \\ x_{ijS}(\varphi) &= \lambda_3 \left(\frac{Y_j}{Y}\right)^{\frac{\sigma-1}{\kappa}} \left(\frac{w_i \mu_S \tau_{ij}}{q_{ij}\vartheta_j}\right)^{1-\sigma} \varphi^{\sigma-1}, \text{ if } \overline{\varphi}_{ijS} < \varphi < \overline{\varphi}_{ijSH}, \\ & 0 \text{ otherwise,} \end{aligned} \tag{9}$$

where $\lambda_3 = \sigma\lambda_4^{1-\sigma}$ and $\lambda_4^{\kappa} = [1/(1+d)][\kappa/\kappa - (\sigma-1)](\sigma/\alpha)$. Cutoff productivity levels are also rewritten as

$$\overline{\varphi}_{ijS} = \lambda_4 \left(\frac{Y_j}{Y}\right)^{\frac{\sigma-1}{\kappa}} \left(\frac{w_i \mu_S \tau_{ij}}{q_{ij}\vartheta_j}\right) f_{ijS}^{\frac{1}{\sigma-1}}$$

[7] It is possible to consider port substitution of firms located in other area than Tohoku. Our empirical analysis does not exclude such possibility while it does not change the theoretical analysis.

$$\overline{\varphi}_{ijSH} = \lambda_4 \left(\frac{Y_j}{Y}\right)^{\frac{\sigma-1}{\kappa}} \left(\frac{w_i \tau_{ij}}{q_{ij}\vartheta_j}\right) \left(\frac{f_{ijH} - f_{ijS}}{\mu_{ijH}^{-(\sigma-1)} - \mu_{ijS}^{-(\sigma-1)}}\right)^{\frac{1}{\sigma-1}}$$

Finally we have $Y_j = (1+d)\, w_i L_i$ where d is constant.

2.6 Gravity

Exports from tsunami hit port H is given by $X_{ijH} = w_i L_i \int_{\overline{\varphi}_{ijSH}}^{\infty} x_{ijH}(\varphi)\, dG(\varphi)$ while those from substitute port S is given by $X_{ijS} = w_i L_i \int_{\overline{\varphi}_{ijS}}^{\overline{\varphi}_{ijSH}} x_{ijS}(\varphi)\, dG(\varphi)$. Thanks to the closed-form expression, we can derive a gravity equation for each port. Exports from port H is given by

$$X_{ijH} = \alpha \frac{Y_i Y_j}{Y} \left(\frac{w_i \tau_{ij}}{q_{ij}\vartheta_j}\right)^{-\kappa} \mu_H^{-(\sigma-1)} \left(\mu_H^{-(\sigma-1)} - \mu_S^{-(\sigma-1)}\right)^{\frac{\kappa}{\sigma-1}-1} \left(f_{ijH} - f_{ijS}\right)^{-\left(\frac{\kappa}{\sigma-1}-1\right)}. \quad (10)$$

Exports from port S is given by

$$\begin{aligned} X_{ijS} = {} & \alpha \frac{Y_i Y_j}{Y} \left(\frac{w_i \tau_{ij}}{q_{ij}\vartheta_j}\right)^{-\kappa} \\ & \left[\mu_S^{-\kappa} f_{ijS}^{-\left(\frac{\kappa}{\sigma-1}-1\right)} - \mu_S^{-(\sigma-1)} \left(\mu_H^{-(\sigma-1)} - \mu_S^{-(\sigma-1)}\right)^{\frac{\kappa}{\sigma-1}-1} \left(f_{ijH} - f_{ijS}\right)^{-\left(\frac{\kappa}{\sigma-1}-1\right)}\right]. \quad (11) \end{aligned}$$

Total exports from country i to j is thus given by

$$\begin{aligned} X_{ij} &= X_{ijS} + X_{ijH} \\ &= \alpha \frac{Y_i Y_j}{Y} \left(\frac{w_i \tau_{ij}}{q_{ij}\vartheta_j}\right)^{-\kappa} \left[\mu_S^{-\kappa} f_{ijS}^{-\left(\frac{\kappa}{\sigma-1}-1\right)} - \left(\mu_H^{-(\sigma-1)} - \mu_S^{-(\sigma-1)}\right)^{\frac{\kappa}{\sigma-1}} \left(f_{ijH} - f_{ijS}\right)^{-\left(\frac{\kappa}{\sigma-1}-1\right)}\right]. \end{aligned}$$

Note that by abandoning the assumption of $\mu_S > \mu_H$, all firms in this location export from substitute port S and the expression collapses to a similar one as in Chaney (2008).

2.7 Margin Decomposition

In this subsection, we discuss the decomposition of trade flow as in the literature (Chaney, 2008; Head and Mayer, 2014). For the sake of notational simplicity we drop origin and destination index, i and j, when there is no room for confusion. Export flow from each port can be decomposed as $X_H = N_{XH}\widetilde{x}_H$ and $X_S = N_{XS}\widetilde{x}_S$ where $N_{XH} = wL\,(1 - G(\overline{\varphi}_{SH}))$ and $N_{XS} = wL\,(G(\overline{\varphi}_{SH}) - G(\overline{\varphi}_S))$ represent the number exporters and

$$\widetilde{x}_H = \left[\int_{\overline{\varphi}_{SH}}^{\infty} x_H(\varphi)\, dG(\varphi) / \left(1 - G(\overline{\varphi}_{SH})\right)\right]$$

Table 1: Margins Decomposition

Elasticities	E.M.	I.M.	C.M.	Total
$d\ln X_H/d\ln\tau$	$-\kappa$	$-(\sigma-1)$	$\sigma-1$	$-\kappa$
$d\ln X_H/d\ln q$	κ	$\sigma-1$	$-(\sigma-1)$	κ
$d\ln X_H/d\ln f_H$	$-\frac{\kappa}{\sigma-1}\mathsf{F}_H$	0	F_H	$-\left(\frac{\kappa}{\sigma-1}-1\right)\mathsf{F}_H$
$d\ln X_H/d\ln f_S$	$\frac{\kappa}{\sigma-1}\mathsf{F}_S$	0	$-\mathsf{F}_S$	$\left(\frac{\kappa}{\sigma-1}-1\right)\mathsf{F}_S$
$d\ln X_H/d\ln\mu_H$	$-\kappa\mathsf{U}_H$	$-(\sigma-1)$	$(\sigma-1)\mathsf{U}_H$	$-[\kappa-(\sigma-1)]\,\mathsf{U}_H-(\sigma-1)$
$d\ln X_H/d\ln\mu_S$	$\kappa\mathsf{U}_S$	0	$-(\sigma-1)\mathsf{U}_S$	$[\kappa-(\sigma-1)]\,\mathsf{U}_S$
$d\ln X_S/d\ln\tau$	$-\kappa$	$-(\sigma-1)$	$\sigma-1$	$-\kappa$
$d\ln X_S/d\ln q$	κ	$\sigma-1$	$-(\sigma-1)$	κ
$d\ln X_S/d\ln f_S$	$-\frac{\kappa}{\sigma-1}\Gamma_S$	0	$-\left(\frac{\kappa}{\sigma-1}-1\right)\Delta_S+\frac{\kappa}{\sigma-1}\Gamma_S<0$	$-\left(\frac{\kappa}{\sigma-1}-1\right)\Delta_S$
$d\ln X_S/d\ln f_H$	$\frac{\kappa}{\sigma-1}\Gamma_H$	0	$\left(\frac{\kappa}{\sigma-1}-1\right)\Delta_H-\frac{\kappa}{\sigma-1}\Gamma_H>0$	$\left(\frac{\kappa}{\sigma-1}-1\right)\Delta_H$
$d\ln X_S/d\ln\mu_S$	$-\kappa\Theta_S$	$-(\sigma-1)$	$-[\kappa-(\sigma-1)]\,\Lambda_S+\kappa\Theta_S<0$	$-[\kappa-(\sigma-1)]\,\Lambda_S-(\sigma-1)$
$d\ln X_S/d\ln\mu_H$	$\kappa\Theta_H$	0	$[\kappa-(\sigma-1)]\,\Lambda_H-\kappa\Theta_H>0$	$[\kappa-(\sigma-1)]\,\Lambda_H$

Trade effects by port, $k=H$, S, for various exogenous shocks: τ international trade costs q quality or demand shifter, f_k port specific fixed costs, μ_k port specific variable costs. The ports are differentiated by their relative fixed to variable cost of exporting. The decomposition of the total effect is given by Extensive margin (E.M.), Intensive margin (I.M.) and Composition margin (C.M.)

and

$$\widetilde{x}_S=\left[\int_{\overline{\varphi}_S}^{\overline{\varphi}_{SH}} x_S(\varphi)\,dG(\varphi)/\left(G(\overline{\varphi}_{SH})-G(\overline{\varphi}_S)\right)\right]$$

capture the average export flow among these exporters from tsunami hit port H and substitute port S, respectively. The number of exporters is called 'extensive margins.' The average export flow is further decomposed into 'intensive margins,' i.e. changes in average export scale given a cutoff productivity level, and 'composition margins,' i.e. remaining impact on average export flow induced by changes in cutoff productivity level. We provide the result of comparative statics analysis of each component in total export flow induced by exogenous changes in iceberg type of bilateral trade costs τ, aggregate labor productivity level Z_i, country and destination specific demand shifter q, port specific fixed export costs f_k and port specific local transportation costs μ_k. Namely, we compute

$$\frac{d\ln X_k}{d\ln v}=\frac{d\ln N_{Xk}}{d\ln v}+\frac{d\ln\widetilde{x}_k}{d\ln v},$$

where $k=H$ or S, $v=\tau$, Z_i, q, f_k, μ_k and $d\ln\widetilde{x}_k/d\ln v$ includes both intensive margins and composition margins. Table 1 presents elasticities of each margin as well as of total exports with respect to each exogenous shock for each export from tsunami hit port H and substitute port S, respectively. In Table 1, $\overline{f}_H$, $\overline{f}_S$, $\overline{\mu}_H$ and $\overline{\mu}_S$ represent the steady state value of port specific fixed costs and local transportation costs. Capital letters in Table 1 are a function of parameters given these steady state values which are detailed in Table 2.

As shown in Table 1, shocks that are independent of port characteristics, namely τ, Z_i and q, have exactly the same impact on exports from port H, X_H and those from port

Table 2: Parameters

$\overline{f}_H > 0,\ \overline{f}_S > 0,\ \overline{\mu}_H > 0,\ \overline{\mu}_S > 0$	$\overline{f}_H/\overline{f}_S > (\overline{\mu}_H/\overline{\mu}_S)^{\sigma-1} > 1$
$\mathsf{F}_H = \frac{1}{1-\frac{\overline{f}_S}{\overline{f}_H}} > 1$	$\mathsf{F}_S = \frac{1}{\frac{\overline{f}_H}{\overline{f}_S}-1} > 0$
$\mathsf{F}_H > \mathsf{U}_H = \frac{1}{1-\left(\frac{\overline{\mu}_H}{\overline{\mu}_S}\right)^{\sigma-1}} > 1$	$\mathsf{U}_S = \frac{1}{\left(\frac{\overline{\mu}_S}{\overline{\mu}_H}\right)^{\sigma-1}-1} > \mathsf{F}_S > 0$
$\Gamma_S = \frac{1}{1-\left(\frac{\mathsf{F}_S}{\mathsf{U}_S}\right)^{\frac{\kappa}{\sigma-1}}} + \frac{\mathsf{F}_S}{\left(\frac{\mathsf{U}_S}{\mathsf{F}_S}\right)^{\frac{\kappa}{\sigma-1}}-1} > 1$	$\Delta_S = \frac{1}{1-\left(\frac{\mathsf{F}_S}{\mathsf{U}_S}\right)^{\frac{\kappa}{\sigma-1}-1}} + \frac{\mathsf{F}_S}{\left(\frac{\mathsf{U}_S}{\mathsf{F}_S}\right)^{\frac{\kappa}{\sigma-1}-1}-1} > 1$
$\Theta_S = \frac{1}{1-\left(\frac{\mathsf{F}_S}{\mathsf{U}_S}\right)^{\frac{\kappa}{\sigma-1}}} + \frac{\mathsf{U}_S}{\left[\left(\frac{\mathsf{U}_S}{\mathsf{F}_S}\right)^{\frac{\kappa}{\sigma-1}}-1\right]} > 1$	$\Lambda_S = \frac{1}{1-\left(\frac{\mathsf{F}_S}{\mathsf{U}_S}\right)^{\frac{\kappa}{\sigma-1}-1}} + \frac{\mathsf{U}_S}{\left[\left(\frac{\mathsf{U}_S}{\mathsf{F}_S}\right)^{\frac{\kappa}{\sigma-1}-1}-1\right]} > 1$
$\Gamma_S > \Gamma_H = \frac{\mathsf{F}_H}{\left(\frac{\mathsf{U}_S}{\mathsf{F}_S}\right)^{\frac{\kappa}{\sigma-1}}-1} > 0$	$\Delta_S > \Delta_H = \frac{\mathsf{F}_H}{\left(\frac{\mathsf{U}_S}{\mathsf{F}_S}\right)^{\frac{\kappa}{\sigma-1}-1}-1} > 0$
$\Theta_S > \Theta_H = \frac{\mathsf{U}_H}{\left(\frac{\mathsf{U}_S}{\mathsf{F}_S}\right)^{\frac{\kappa}{\sigma-1}}-1} > 0$	$\Lambda_S > \Lambda_H = \frac{\mathsf{U}_H}{\left(\frac{\mathsf{U}_S}{\mathsf{F}_S}\right)^{\frac{\kappa}{\sigma-1}-1}-1} > 0$

S, X_S as well as for each margin.. For instance, when bilateral trade costs τ rises, extensive margins decrease with the elasticity of $-\kappa$ while average export remains unchanged because of reduced intensive margins by $-(\sigma-1)$ but expanding export of surviving exporters by $\sigma-1$ (composition changes). The result is exactly the same for tsunami hit port H and substitute port S.[8]

Port specific shocks, however, have dramatically different implications across ports. On the one hand, with respect to trade flow X_H, when fixed export costs f_H increase, extensive margins decrease by $-\frac{\kappa}{\sigma-1}\mathsf{F}_H$ and composition margins increase by F_H. This is because a number of less productive firms switch their use from the tsunami hit port H to the substitute port δ following a rise in f_H. Total impact on export X_H is thus given by $-\left(\frac{\kappa}{\sigma-1}-1\right)\mathsf{F}_H$. Since $\mathsf{F}_H > 1$, both extensive and composition margins are amplified compared to the results obtained in Chaney (2008) who find $-\frac{\kappa}{\sigma-1}$ and 1 for each extensive and composition margin, respectively with a single port. On the other hand, for the same increase in f_H, extensive margins of substituting port S increase by $\frac{\kappa}{\sigma-1}\Gamma_H$ and composition margins increases by $\left(\frac{\kappa}{\sigma-1}-1\right)\Delta_H - \frac{\kappa}{\sigma-1}\Gamma_H$. As a result total exports X_S increase by $\left(\frac{\kappa}{\sigma-1}-1\right)\Delta_H$. This is due to the above mentioned port substitution effect through which some exporters switch from tsunami hit port H to substitute port S in exporting following a rise in fixed export costs in tsunami hit port H, f_H.

A similar argument holds for a rise in fixed export costs in substitute port S, f_S albeit with a different degree of substitution effect. So if we were to switch the two ports in their comparative advantage structure we will find the same signs of the effects, but the magnitudes will be different. The reason is that the firms that allocate to the two ports are different, so any change in the ports fixed or variable costs, affects a different set of firms, giving rise different magnitudes in the effect of exports.

When local transportation costs to port H, μ_H, increase, exporters switch from tsunami hit port H to substitute port S in exporting. As a result, total exports X_H decrease in tsunami hit port H by $-[\kappa-(\sigma-1)]\,\mathsf{U}_H-(\sigma-1)$ while total exports in

[8]The same expression is provided by Chaney (2008) with a single port case.

substitute port S, X_S increase by $[\kappa - (\sigma - 1)]\,\mathsf{\Lambda}_H$. In achieving such a change in X_H, the number of exporters decrease by $-\kappa\mathsf{U}_H$, intensive margins decrease by $-(\sigma - 1)$ while composition margins increase by $(\sigma - 1)\mathsf{U}_H$ in tsunami hit port H. Since $\mathsf{U}_H > 1$, the size of the change of each margin is amplified compared to the case with a rise in international bilateral trade costs τ. We have a mirror image for each margin in competing substitute port S where total exports rise by $[\kappa - (\sigma - 1)]\,\mathsf{\Lambda}_H$ through rise in extensive margins by $\kappa\Theta_H$ and changes in composition margins by $[\kappa - (\sigma - 1)]\,\mathsf{\Lambda}_H - \kappa\Theta_H$. Again, a similar argument holds for a rise in local transportation costs to substitute port S, μ_S albeit with a different degree of substitution effect.

2.8 Numerical Simulation

Here we calibrate the theoretical model and provide the results of a numerical simulation. The parameter value of the elasticity of substitution and the extent of product heterogeneity are set as $\sigma = 6$ and $\kappa = 10$, respectively. These values are standard and in line with the literature. The steady state level of port specific fixed cost and internal transportation cost of each tsunami hit H and substitute S port are found based on the mean values of tsunami hit ports and substitute ports prior to the Great East Japan Earthquake.[9]

Having in mind a port and road destruction in Tohoku region, in Table 3 we only report the results following a port specific fixed export cost shock and internal transportation cost shock in tsunami hit port, namely, a one percentage point increase in f_H and μ_H, respectively.[10] First, following a one percentage points increase in f_H, due to a larger steady state size of S (substitute) ports compared to H (hit) ports in terms of export share ($X_H/X_S = 0.1762$), extensive margins ($EM_H/EM_S = 0.3677$) and intensive margins ($IM_H/IM_S = 0.8211$), there is a smaller adjustment for substitute S port in all types of margins as well as total export. For instance, extensive margins decrease by -2.05 percentage points for tsunami hit H port while those for substitute S port increases by 0.06 percentage points. Second, the adjustment in terms of extensive margins is larger than that in intensive and composition margins for both types of ports. Third, it is striking to notice that there is a *positive* adjustment for aggregate trade flow. Total export *increases* by 0.09 percentage point following f_H shock, respectively. This is due to a substitution effect across ports that we have argued combined with a larger size of

[9]Namely, we find the steady state value of f_H, μ_H and μ_S that minimise the distance between empirical moments and implied theoretical moments using optimisation solver with constraints, fmincon function in Matlab. The empirical moments that we target are the relative pre-mean share, extensive margins and intensive margins of tsunami hit port and substitute ports. Namely, there are $X_H/X_S = 0.40/2.27$, $EM_H/EM_S = 8.63/23.47$ and $IM_H/IM_S = 3.81/4.64$ which are summarised in Table 4 in the empirical section. The above procedure gives $\overline{f}_H = 39.9358$, $\overline{\mu}_H = 0.7591$, $\overline{\mu}_S = 1.1373$ while we set $\overline{f}_S = 1$ without loss of generality at the initial steady state.

[10]The numerical results for other types of shocks are available upon on request.

Table 3: Margins Decomposition

Elasticities	E.M.	I.M.	C.M.	Total
$d\ln X_H/d\ln f_H$	−2.05	0.00	1.03	−1.03
$d\ln X_S/d\ln f_H$	0.06	0.00	0.15	0.21
$d\ln X/d\ln f_H$	−0.48	0.00	0.51	0.09
$d\ln X_H/d\ln \mu_H$	−11.53	−5.00	5.76	−10.76
$d\ln X_S/d\ln \mu_H$	0.34	0.00	0.83	1.17
$d\ln X/d\ln \mu_H$	−2.72	−2.08	2.88	0.02

Simulation results for both ports of a shock to a tsunami hit (H) port represented by its fixed f_H and variable μ_H cost. The effects are measured in percentage points deviations from steady state following a 1% shock. Steady state margins are based on empirical margins of Japanese ports. See main text for further underlying assumptions.

substitute port at the steady state. The above mentioned three patterns are similar for internal transportation costs shock, μ_H but with a larger magnitude.

Figure 3 shows the results of the sensitivity analysis against the elasticity of substitution, σ.[11] The first column in the figure shows the results for f_H shock for each tsunami hit and substitute port as well as aggregate flow. For extensive margins, with a lower value of σ, there exists a stronger negative adjustment in tsunami hit H port. On the other hand, a stronger positive adjustment appears with a higher value of σ for substitute S port following the same shock. However, such a non-linearity disappears for intensive and composition margins and the adjustments are insensitive with respect to the value of σ for both types of ports. The second column in the figure shows the result for μ_H shock where we find a similar result but with a larger magnitude.[12]

3 Empirics

3.1 Identification strategy

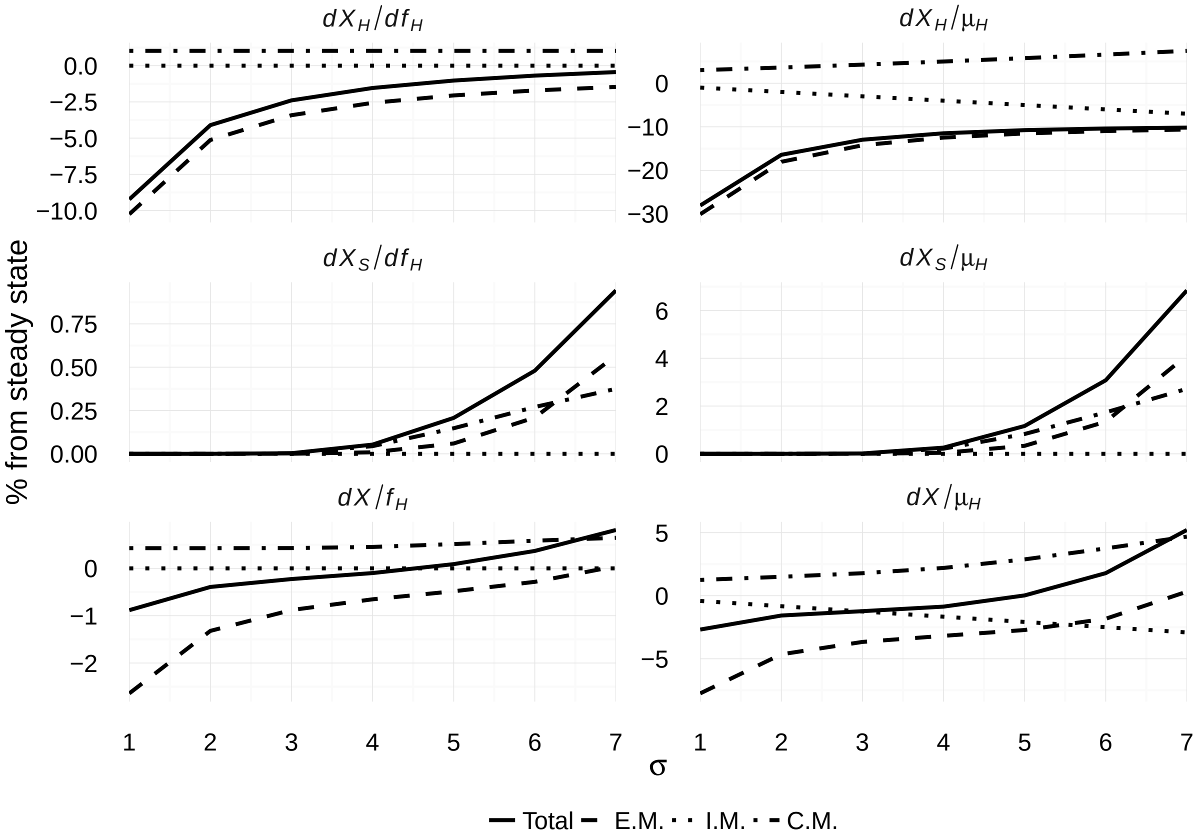
The theoretical model, following equations (10) and (11), suggests the following linearized equation of exports,

$$\ln X_{ijk} = \ln \frac{Y_i}{Y} + \ln \frac{Y_j}{Y} - \kappa \ln \tau_{ij} + \kappa \ln M_i + \kappa \ln \vartheta_j + a \ln \mu_{ijk} + b \ln \mu_{ijl} + c \ln f_{ijk} + d \ln f_{ijl}$$

[11] In computing Figure 3, we fix κ and f_H, f_S, μ_H and μ_S as in 3. Restrictions on parameters that allow a multiple port structure as argued in Proposition 1 are satisfied in the figure.

[12] The results for other types of shock and those obtained with the sensitivity analysis of different values of κ are available upon request.

Figure 3: Sensitivity Analysis on σ



Simulation results for both ports of a shock to a tsunami hit (H) port represented by its fixed f_H and variable μ_H cost. The effects are measured in percentage points deviations from steady state following a 1% shock. Steady state margins are based on empirical margins of Japanese ports. See main text for further underlying assumptions.

for exports X from port k in country i to country j. One can add a subscript h for each variable to capture the different effects at the sectoral level. We are particularly interested identifying the effects of changes in the variable and fixed costs on the export level of ports and their decomposition of the margins. We propose to use the event of the earthquake and tsunami of March 2011 that struck the north-east coast of Japan as an exogenous variation in the cost of bringing goods to port for exports. The tsunami caused destruction for some ports at a specific point in time and therefore leads to the potential of other ports to be affected through the trade spill-over that we modelled, since these ports were not directly affected by the earthquake and tsunami.

3.1.1 Great East Japan Earthquake and evidence on firms

The tsunami was a devastating disaster for the coastal areas of the Tohoku and Kanto regions and around 16.000 people lost there lives. The earthquake had a magnitude of 9 on the richter scale, the strongest recorded for Japan ever, with the epicentre located 70 km off the coast at a depth of 30 km. The earthquake was followed by dozens of smaller quakes of magnitude 6 or higher. Multiple waves hit the shore of north eastern Honshu (Tohoku) with heights up to 6 meters from sea level. The force of the wave made the water surge inland as much as 40 meters above sea level, and in some areas a few kilometers from the coast, albeit these were local extremes.

Although devastating we argue that the destruction was largely limited to the immediate coastline rather then the hinterlands, as well as limited to the coastline closest to the epicentre and so would have limited direct effects on local business further inland and in Tohoky more generally. In order to give further backing to this argument we rely on firm surveys reported in earlier research, giving a direct indication, and calculated two measures that indirectly measure how much of the regional economy was affected by the tsunami. Firstly, Todo et al. (2015) and Cole et al. (2015a), based on a survey of firms in the area, indicate that the vast majority of firms was operational within one month, while a small minority was more severely affected up to the point where it could have entirely quit operations.[13]

Secondly, we calculated two measures using GIS methods. One measure is based on building structures identified on OpenStreetMaps, and another is based on satellite land cover data.[14] Both measures give similar results, in the Tohoku region around 5% of industrial and commercial land was affected by floods, while the relevant number for the

[13]Both papers use the same underlying dataset of firms in the “Special Great East Japan Earthquake Reconstruction Areas”, an area within the Tohohu and Kanto regions. In the sample of Todo et al. (2015) 5.7% of firms closed completely following the earthquake (p. 214), and 90% of the firms were operational within 30 days (p. 220), with a mean/median recovery time of 14.9/5 days (p. 215). In the sample of Cole et al. (2015a) 1.55% of plants reported major earthquake damage, while 3.4% experienced major Tsunami damage (p. 6). They found a mean stoppage time of 16 days (p. 22). Below, we will still present robustness results that control for prefecture level industrial output.

[14] See Appendix B.2 for further details.

Kanto region is much lower at 0.12% to 0.01% depending on the measure used.[15] These numbers are in line with the survey evidence of Todo et al. (2015) and Cole et al. (2015a). We note that sector or country wide consequences can be controlled for in our empirical specification.

3.1.2 Exogenous nature of tsunami to treated and control ports.

In terms of empirical identification we rely on the unexpected nature of the tsunami, which struck all ports at the same day. Although Japan is well adapted to the risk of earthquakes and the potential of tsunamis, the precise location, moment and magnitude of such events is for all practical purposes random, while the force of the Tsunami was unprecedented in modern times. This random occurrence of the tsunami makes that ports were randomly assigned this 'treatment'.

Figure 4 presents a map of northern Japan giving an overview of the ports that were hit by the March 2011 Tsunami (squares) and all other ports (triangles and circles). For reference, Tokyo is located just south of the tsunami-hit ports where a cluster of circles denotes the various ports in the Tokyo area and the Fukushima-Dachi power plant, which failed when it was flooded by the tsunami, is located at the coast of the most southern prefecture of the Tohoku region. From the Japanese Ministry of Industry we have the recorded wave heights for each port (Ministry of Land, Infrastructure, Transport and Tourism, 2011). The ports closest to the earthquake epicentre were hit by the highest waves.

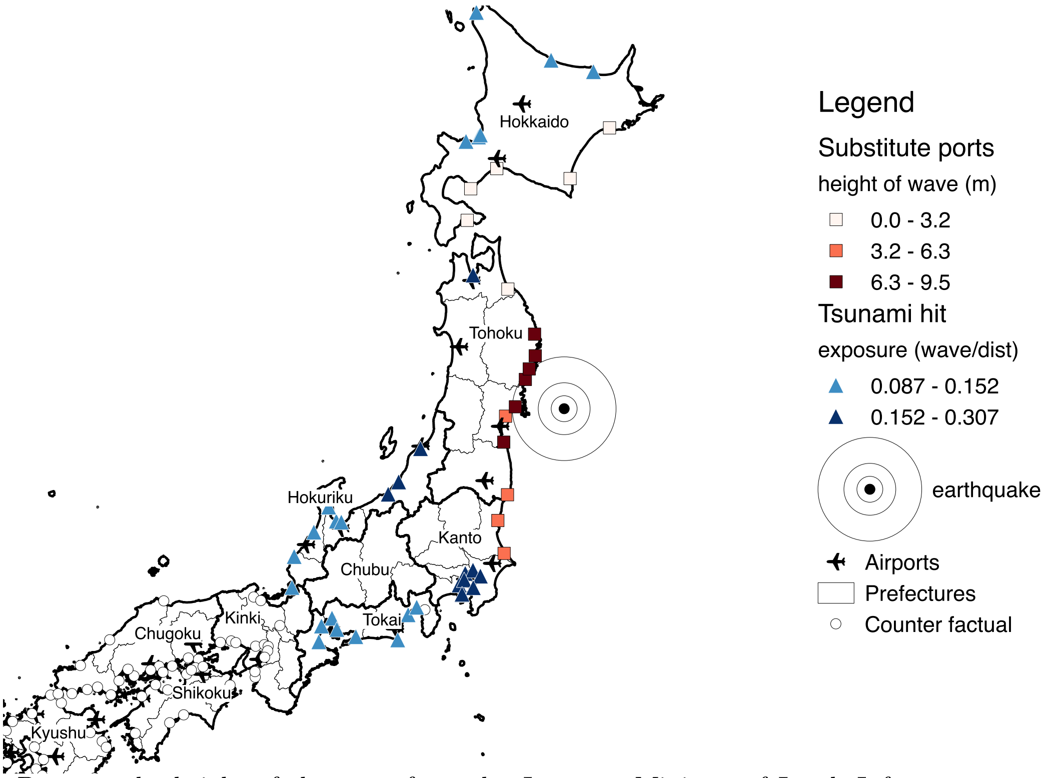
What is evident is that the ports hit by the tsunami are clustered in one region of Japan, Tohoku, and to a lesser extent Kanto. We are principally interested in the response from ports that were *not* hit by the tsunami but regionally close enough to be able to absorb additional exports from the firms in the Tohoku and Kanto region. We define these ports as substitutes, indicated with triangles in Figure 4.

As further substitutes we find that ports in the Hokoriku and Tokai region may also have been close enough to be impacted. The northern island Hokkaido is a special case. As a separate island with no road links (there is a train tunnel from Aomori, at the north of Honshu, to Hakodate on Hokkaido) it is unlikely that its ports are affected by a substitution effect from the Tohoku region. Some ports of Hokkaido were exposed to the tsunami, but the recorded wave heights are minimal such that coastline barriers and storm protection may have proved sufficient to avoid severe destruction. We will explore the designation of the substitution ports further in the empirical section.

Additionally, levels of potential substitution may be varying. Below we define a func-

[15] Another way that firms may be affected in their production is when they use intermediate inputs that were shipped through the ports that were struck. In that case we would suspect to observe a similar substitution mechanism for imports as we would see for exports. We do not control for this effect explicitly either, but since the effect would run through the same mechanism, it does not invalidate our setup.

Figure 4: Tsunami-hit and substitute ports



Note: Data on the height of the wave from the Japanese Ministry of Land, Infrastructure, Transport and Tourism (2011), the location of the earthquake from the US Geological Survey but this information is not further used in our analysis, exposure from authors' calculations. In the regression analysis Hokkaido ports are not designated as treated.

tion that gives a measure of potential substitution for an individual port as the combined distance from tsunami hit ports and the height of the waves that these were struck with. Intuitively, the color coding of the substitution ports (triangles) indicates that potential substitution may be stronger for ports in the Tohoku and Kanto regions relative to those in Hokuriku and Tokai.

The ports further south-east in Japan, starting from the region of Kinki were likely too far away to be noticeable impacted and will henceforth be designated as the counterfactuals (circles). Since we found no effect of either hit ports or from substitutes in Hokkaido these ports are designated as counter-factual as well, but we change this designation in the robustness analysis.

3.1.3 Empirical setup

We will exploit variation over time, ports, sectors and destination, and we only have one origin, Japan. Therefore we rewrite the equation as

$$\ln X_{kht} = \text{constant} + a \ln \mu_{kht} + b \ln \mu_{lht} + c \ln f_{kht} + d \ln f_{lht},$$

with subscripts as in the theoretical model, k and l for port, h for sector and t for time. The tsunami is an event that can be tracked over time and geography (and sectors only in combination with the specific ports, further discussed below), while we can control for all other factors that determine a port's export pattern, such as world demand, pre-determined industrial structure and output around the port, which are arguably uncorrelated with the Tsunami event. From this equation, port destruction will affect ports differently depending on whether the shock is on the own port k, or to another port l. The only variables in the theoretical model that vary over k or l are the internal trade costs towards the ports and the fixed cost associated with each port μ_k, μ_l, f_k and f_l (omitting subscripts i and j).

There is *a priori* no clear way to disentangle the variable from the fixed costs in our setup. On one hand infrastructure around ports and in some regions quite far inland was damaged or destroyed. In the immediate aftermath of the tsunami shortages in electricity or fuel may have been experienced by transporters. On the other hand, the destruction of ports probably dominates the effect on port exports, because alternative roads could likely be used with very little additional costs and the destruction inland was less severe than at the coast line. Therefore we need to assume that the outcome that we measure on trade is the sum of the effect that the tsunami had on the variable and the fixed costs, i.e. $a + c$ for the ports hit by the tsunami, and $b + d$ for the substitutes.

How does it matter for the research question? If we are interested in the effect of port *construction* or upgrades on exports we imagine that it it does not only affect the location of the port itself but also its direct surroundings. In order to make the port function efficiently additional road and supply routes may be part of the port construction. Therefore, in the case of port construction one would also expect that the local transport costs and the port's fixed costs are also affected simultaneously. What we are estimating therefore is the average aggregate effect of such changes.[16]

Although the comparative statics of the theoretical model are such that positive and negative shocks have the same elasticity, we do admit that analysing port destruction may not directly translate to answers on the effect of port upgrades. The destruction of ports does allow to look at the effect of major change in fixed costs that seems more suitable from an empirical point of view relative to a gradual infrastructure process. What also matters here is that ports were rebuild after the disaster and we take that period into account. So just as much as we can analyse the immediate impact, we can analyse the two year reconstruction phase to give backing on the mechanism that we have in mind.

[16]Additionally, we acknowledge that the tsunami destruction and recovery period may have been perceived by some firms to be shock of a temporary nature, rather than a permanent change that would be more closely comparable to the construction of whole new ports or other infrastrure. A temporary shock may have allowed them to use inventory measures over the reconstruction phase, rather than reroute their goods to new ports, and therefore would reduce total exports. The use of inventory might be dependent on the specific categories of products and we find some evidence of this below.

The model we will estimate is

$$y_{k,g,t} = \sum_{\tau=\text{Jan 2011}}^{\text{Dec 2012}} \beta_{1,\tau} \text{I}(\text{hit}_k) + \sum_{\tau=\text{Jan 2011}}^{\text{Dec 2012}} \beta_{2,\tau} \text{I}(\text{sub}_{k,g}) + x_{k,g,t} + \theta_{k,g} + \alpha_{g,t} + \epsilon_{k,g,t} \quad (12)$$
$$k = 1, \ldots, 119;\ g = \text{sectors/destinations};\ t = \text{Jan 2009,}\ldots\text{,Dec 2012}$$

keeping with the notation of the theoretical model, k for port, g for group, such as sectors h or destinations m, and finally time t. Our main analysis will be done at the port-sector level, rather than port-destination, so in following we will refer to sectors for exposition. The left hand side variable $y_{k,g,t}$ will be any trade variable of interest. The indicator functions $\text{I}(\text{hit}_k)$ and $\text{I}(\text{sub}_{k,g})$ designate those port-sector combinations that are treated by the tsunami or as substitute. For the tsunami hit ports the indicator varies only at the port level since all products will be affected. However, for the substitute ports assume treatment takes place at the port-sector level. For instance, only products belonging to the sectors that were exported from a tsunami hit port will be treated as substitute, with others unaffected. Geographically, the designation for substitute is defined as being located in one of the four regions where ports have the highest potential exposure (while not being hit by a tsunami themselves). We can add control variables to the regression, represented by $x_{p,g}$, such as local industrial production levels, further discussed below. The baseline results will contain no control variables. Fixed effects are summarised by $\theta_{p,g}$ for the port-by-sector, and $\alpha_{g,t}$ for sector-by-time.[17] The first will capture port's specialization into certain sectors, the second will capture nation-wide sector development. For instance, the second would capture nation-wide energy supply shock on (energy intensive) sectors following the earthquake. We note that in the case that certain sectors would be concentrated in the tsunami hit area this set of fixed effect could absorb some of the actual impact from the earthquake.

The parameters of interest are collected in the $\beta_{1,\tau}$'s and $\beta_{2,\tau}$'s. Given the reduced form structural equation above we have the following relationship between the parameters that we estimate and those that come from the theoretical model: $\beta_{1,\tau} = a + c$ and $\beta_{2,\tau} = b + d$. In combination with the indicator functions $\text{I}(\text{hit}_k)$ and $\text{I}(\text{sub}_{k,g})$, the estimated coefficients essentially indicate the evolution of the outcome variables over the 24 months time for the ports that are hit by the tsunami and those that we designated as potentially exposed to substitution. Through this setup, the effect of interest is estimated as the performance of a port relative to all other ports that were neither hit by the tsunami nor close enough to the hit port to be potentially treated as substitute ports, i.e. the counterfactuals, or in short 'others'. What we obtain through this setup is an average group effect for the two groups of ports relative to the rest.

The issue with the substitute ports is that there are potentially two effects working on

[17] These greek letters are not related to the ones in the theoretical model.

them. The substitution part will only play a role if firms are located near a port that was hit, but the firm itself was not affected by the disaster. In case the firm itself was affected by the tsunami, total production will have decreased and there will be no substitution taking place. We showed above that the number of firms directly affected by the tsunami is likely to be a small percentage of the total. Nevertheless, we provide robustness result where we control for monthly industrial production at the prefecture level.

We cluster standard errors at the regional level. This cluster-level would relate specifically to the suspicion that ports within the same region will be supplied by firms that are similarly affected by the disaster and cause correlation between those firms, but not so when moving further away to other regions.[18]

3.1.4 A measure for the heterogenous shock size.

We can control for some variation in the shock that will be evident among both the tsunami-hit and the substitute ports. For the hit ports we have the recorded height of the wave that reached the individual ports, while for the substitute ports we can assume a function that approximates the potential exposure to additional exports from nearby ports. Here we assume the following structure for the measure of exposure,

$$\text{exposure}_k = \sum_l \frac{\text{I}(\text{hit}_l) \times \text{wave}_l}{\text{dist}_{k,l}}.$$

So for every port k not hit by a tsunami we measure the distance to all ports l that were hit by the tsunami. We assume that the effect diminishes with distance. Here we expect that the height of the weight is a measure of the destruction that took place and therefore increased the costs of exporting through such a port. In relation to the theoretical model, the wave height will capture the heterogenous size of the shock to the ports. The distance is measured as the distance between two ports. In the theoretical model what matters really is the distance from ports to a firm. So our measure can only serve as an approximation to the underlying mechanism. Using these measures we can augment model (12) to obtain

$$\begin{aligned} y_{k,g,t} = &\sum_{\tau=\text{Jan 2011}}^{\text{Dec 2012}} \beta_{1,\tau}\text{I}(\text{hit}_{k,g,\tau}) \times \text{wave}_k + \sum_{\tau=\text{Jan 2011}}^{\text{Dec 2012}} \beta_{2,\tau}\text{I}(\text{sub}_{k,g,\tau}) \times \text{exposure}_{k,g} + \\ &+ \theta_{k,g} + \alpha_{g,t} + \epsilon_{k,g,t}. \end{aligned} \tag{13}$$

[18]There are 10 regions in Japan, of which four (Kanto, Tohoku, Hokuriku and Tokai) are considered 'treated' in our empirical setup. At the prefecture level we have 39 (coastal) prefectures, 6 of these have one or more hit ports, 13 have one or more substitute ports. There are 133 ports, 15 were hit, 17 serve as substitute as noted in the Table 4 with the Descriptive statistics.

We can test the relevance of adding these interactions by inspecting whether the exposure measure improves the inference of the coefficients relative to model (12).

Finally, a note on the definition of group g, which we referred to as 'sector' in the above discussion. In line with the theory model we can empirically distinguish all effects by sector, h. However, the use of g in the empirical set up is more general than that, since we also know the destination of each product category from each port. So we can redefine g to denote (groups of) destinations, m rather than sectors. The method of estimation remains unchanged, but the demeaning process will always take the group level into account. We will present results on both below.[19] Additionally we can let the β_1's and β_2's be varying over the group rather than estimating one average effect, in effect subscripting the β's with g. We will present also these results.

3.2 Data

Monthly export statistics for each customs office in Japan with details on destination, value, quantity, at the 9-digit (6-digit HS codes with 3-digit Japanese specific addition) product level was obtained from the Japanese Ministry of Trade website and is freely available. The values are represented as F.O.B. Customs are located both at sea and airports, we limit ourselves to seaports.[20] Road distances between ports were obtained from an route project based on OpenStreetMaps.[21]

Besides the export value (by sector and port) we calculate the empirical margins of trade following Hummels and Klenow (2005). Using k for each (Japanese) port with reference port J representing the sum of all Japanese ports, h for sector, m for destination, I for the product set with individual product code i, and x for the export value, the margins are defined as,

$$\begin{aligned}
\text{extensive margin: } EM_{k,h,m} &= \frac{\sum_{i\in I_{k,h,m}}\sum_{k\in J} x_{k,m,i}}{\sum_{k\in J}\sum_{i\in I_{k,h,m}} x_{k,m,i}}\times 100,\\
\text{trade share: } TS_{k,h,m} &= \frac{\sum_{i\in I_{h,m}} x_{k,m,i}}{\sum_{k\in J}\sum_{i\in I_{k,h,m}} x_{k,m,i}}\times 100,\\
\text{intensive margin: } IM_{k,h,m} = TS_{k,h,m}/EM_{k,h,m} &= \frac{\sum_{i\in I_{h,m}} x_{k,m,i}}{\sum_{i\in I_{k,h,m}}\sum_{k\in J} x_{k,m,i}}\times 100.
\end{aligned}$$

The margins are calculated for each period independently. The empirical intensive margin as defined here is the sum of the intensive margin and compositional margin from the theoretical model. Destination m can be either the rest of the world or country specific,

[19] The interaction of sector and destination is also possible in principle, but the 'bins' from which the margins would be calculated would become very small and potentially less reliable.

[20] Further information on the location of the ports was obtained from the website http://www.searates.com

[21] See http://router.project-osrm.org

similarly, sector h can be represented at various levels of detail including the least disaggregated level of a single sector. Our main analysis will be with a single destination (the world) over a set of 19 sectors, which are defined in Appendix B.4.

As we are looking for a substitution effect we need to focus on those goods that were exported from ports that were hit by the tsunami. For this reason we restrict the sample to all goods that had non-zero exports during the entire year of 2010 from at least one of the ports that were hit in March 2011. This restricted sample represents 77% in terms of the total Japanese export value in 2010. We drop ports that have less than ¥100M (≈ US$1M) of exports in 2010. Furthermore, all ports will have margins for all sectors in which they exported somewhere during the sample. So sector margins are included in all time periods, even if there are no exports recorded in certain time periods. The corresponding margins would then simply have the value zero.[22] This makes sure that we do not create a bias due to missing exports in tsunami hit ports after the Tsunami, nor of missing sector exports pre-tsunami in substitute ports.

3.3 Descriptive statistics

First we will look at the four measures of trade, the intensive margin (which includes the compositional margin), extensive margin, log(export value) and trade share. Each of these measures can be calculated for each port-sector level.. Table 4 presents some descriptive statistics for the variables of interest over the three groups of ports, but without distinction of sectors for brevity. The full period includes the entire sample period from 2009 to 2014. The pre- and post-periods present the data for Dec 2010–Feb 2011, and Mar 2011–Apr 2011 respectively, with the last column presenting a simple t-test on the means. As is evident from the extensive margin, trade share and number of varieties, the tsunami-hit ports are considerably smaller than the national average, while the substitute, given that these include the ports around Tokyo, are considerably larger than the average. Only for the trade share of tsunami-hit ports does the t-test indicate a significant drop in exports at the 5% level. What this means is mainly that the data series have a large variation and unconditional tests are not able to pick up the major shock, not even for the export value of the tsunami hit ports. This is interesting because it is clear that these ports were severely affected.[23]

[22]For the log of export values this creates a minor problem because the log of zero will create missing observations.

[23] Density and distribution plots for the ports are presented in Appendix B.1. These plots are informative for the inspection that the tsunami-hit ports and substitution ports, although quite different in their characteristics, are not extraordinary relative to the entire collection of ports of Japan.

Table 4: Descriptive Statistics

measure	group	n. ports	full mean	full sd	mean pre	sd pre	mean post	sd post	test
EM	Other	84	12.77	21.78	12.70	22.16	12.98	22.21	0.54
	Tsunami hit	15	7.54	12.93	8.63	14.45	5.19	10.38	0.00
	Substitute	17	24.45	30.56	23.47	30.45	23.78	30.27	0.82
	all	116	14.01	23.13	13.93	23.37	13.78	23.24	0.71
IM	Other	84	3.76	9.31	3.71	9.22	3.90	9.49	0.33
	Tsunami hit	15	3.82	10.95	3.81	10.54	2.95	10.16	0.11
	Substitute	17	4.69	9.37	4.64	9.49	4.43	9.11	0.59
	all	116	3.91	9.53	3.87	9.43	3.87	9.52	0.99
lValue	Other	84	11.23	2.97	11.20	2.98	11.27	2.98	0.39
	Tsunami hit	15	11.04	2.65	11.27	2.61	10.59	2.66	0.00
	Substitute	17	12.19	3.15	12.11	3.22	12.07	3.17	0.79
	all	116	11.38	2.99	11.37	3.00	11.35	3.01	0.80
nvar	Other	84	23.91	53.87	23.90	54.39	23.94	54.35	0.97
	Tsunami hit	15	11.29	23.03	11.12	22.74	9.89	21.94	0.29
	Substitute	17	51.68	82.70	49.59	81.98	49.58	81.71	1.00
	all	116	26.85	58.16	26.49	58.20	26.37	58.11	0.91
TS	Other	84	0.92	3.22	0.92	3.20	0.97	3.32	0.47
	Tsunami hit	15	0.39	1.55	0.40	1.13	0.22	0.80	0.00
	Substitute	17	2.26	5.04	2.27	5.22	2.18	5.05	0.69
	all	116	1.07	3.48	1.07	3.49	1.07	3.52	1.00

Statistics, averaged over sectors, for extensive margin (EM), intensive margin (IM), log export value, number of product categories/varieties (n. var) and trade share (TS), calculated as defined in the text. 'n. ports' is the number of ports, 'full mean' and 'full sd' give the mean and standard deviation of the respective statistic over the entire sample period (2009-2014). The columns for 'pre' and 'post' indicate the same statistics based on the pre-tsunami and post-tsunami periods. The final column present the p-value of a simple t-test on the differences between the two periods for each statistic.

3.4 Results

The regression models (12) and (13) estimate the difference of the two types of treated ports *relative to the counterfactual*, while controlling for sector and time fixed effects. Before presenting these results we first show the graphically the time pattern of the average for each type. This is useful to discern whether the counterfactual ports were actually affected in any way by the Great Japanese Earthquake. Figure 5 present these plots for each of the four trade measures. All measures are demeaned with the means at the port-sector level, in panel (a) we used the full sample to estimate these means, for panel (b) we only use the sample from before March 2011. The dots represent the average value for each month by port type. The smooth-line represents a polynomial fit based on all (demeaned) observations for a port type in a period. In order words, this line is estimated separately for each type and for two periods, before and from March 2011. The shaded bands represent 95% confidence intervals.

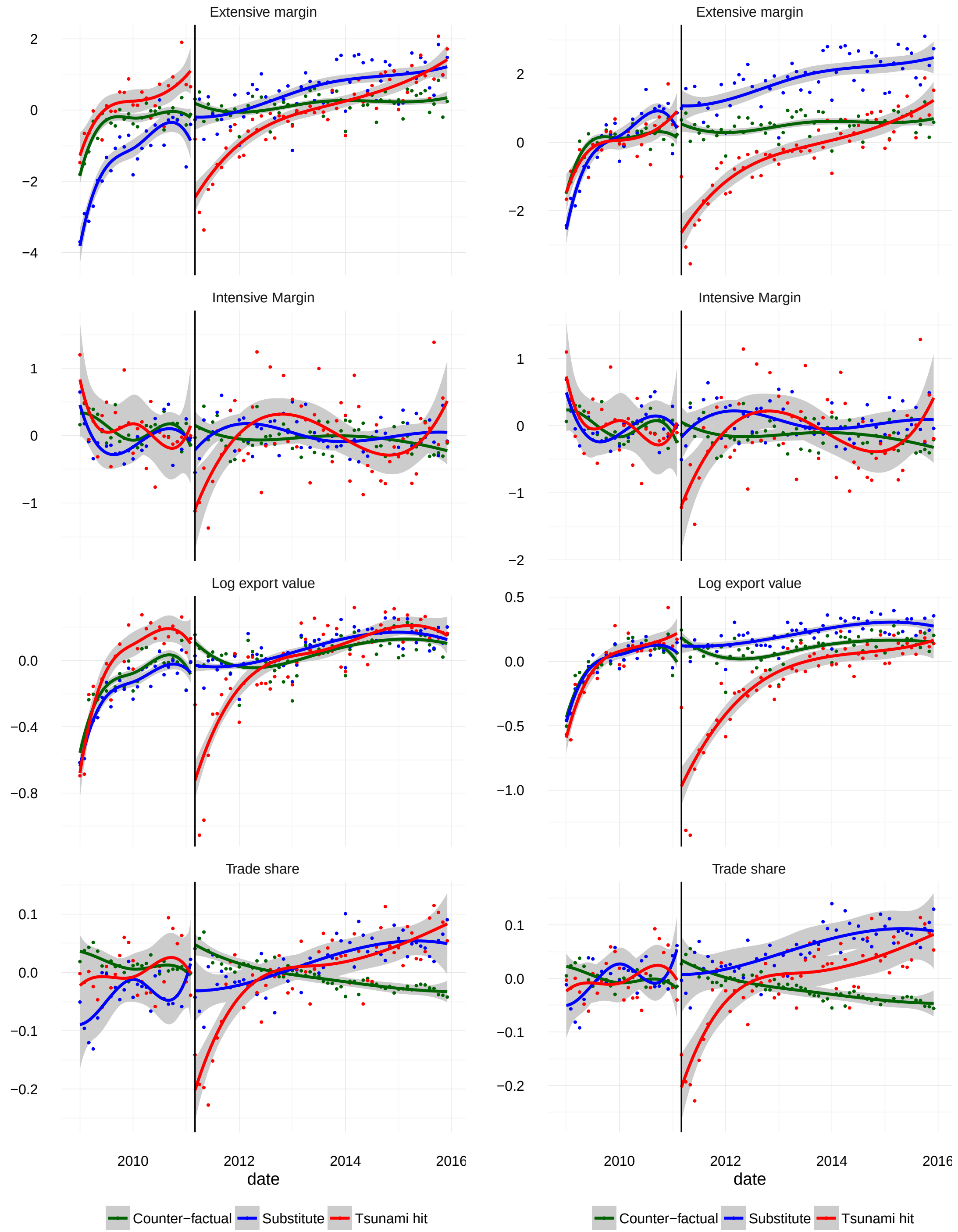
Unlike in the table of the descriptive statistics, in these plots the different patterns between the groups pre- and post-tsunami are clearly visible. In both panels, the effect of the tsunami is mostly visible for the ports hit by the tsunami and the substitution ports, for all measures except the intensive margin. As a first result this seems to be in line with our theoretical predictions. Specifically for the extensive margin and the log of total exports we find that the tsunami hit port significantly under perform after the tsunami, and the substitution port obtain higher values after the tsunami relative to the counter-factuals.

The two types of demeaning presented between the two panels of the Figure are also relevant for the consideration the interpretation of the regressions later. In general the overlap between the three port groups pre-earthquake is better (showing no significant difference) for panel (b). In panel (a) the calculation of port-sector fixed effects uses the entire sample period, including post-earthquake months. Since there is a persistent effect of the tsunami for the treated ports and the pre-tsunami period relatively short, part of the response of the tsunami will be captured by the fixed effects. We can see this in the first panels. Especially the tsunami hit ports appear to be outperforming the other two ports before March 2011. This is an artifact of the differencing procedure. For the substitution ports this effect is causing an under-estimation of the substitution effect, which can be seen by comparing the two panels, especially for the extensive margin and the log of total exports. In the estimation results presented below we will use the standard fixed effect estimation, noting that this likely underestimates the effect for both the tsunami hit and substitution ports.

Additionally, we can see that counter-factual ports do not indicate a clear change of pattern between the two periods. Nevertheless, for the extensive margin and the log export value there appears an immediate positive effect for the counterfactuals, which is

Figure 5: Average trade measures by port-group and time

(a) demeaned using full sample (b) demeaned using pre-2011 data



The dots represent the average of the trade measures after demeaning at the port-sector level. The smoothed line represents a polynomial fit based on all underlying sector-port observations. This polynomial is fitted separately for each port-group (Counter factual, Tsunami hit and substitute) and period (pre and post-tsunami). The shaded areas represent 95% confidence intervals. Panel (a) uses a de-meaning procedure where the means are based on the entire sample period. Panel (b) bases the means on the pre-tsunami period only. The vertical axes represent percentage points in the case of the extensive and intensive margins and trade share. The log export value the interpretation is closer to $\exp(scale) - 1$. Standard errors are not clustered in this representation.

not apparent for the substitution ports. This pattern could potentially limit our ability to estimate a clear substitution effect for the first few months after the tsunami. For the trade share variable we see a declining pattern over time for the counter-factuals before and after the tsunami, but a shift upwards following the earthquake.

In summary, we find some underlying patterns for the counter-factual ports, but these are minor relative to the variation observed in the other two types, and if anything indicate that some of the substitution might have been occurring in the counterfactual ports too. Together with a fixed effects approach we are likely to produce conservative estimates of the substitution effect in the regression analysis.

3.4.1 The effect of the tsunami on port-sector margins of trade

The estimation of regressions (12) and (13) results in 48 coefficients for each outcome variable (24 months for tsunami-hit and substitute ports). Therefore, we present the coefficients graphically as a time plot, allowing to observe clear time-patterns. The 95% confidence bands are based on clustered standard errors at the regional level.

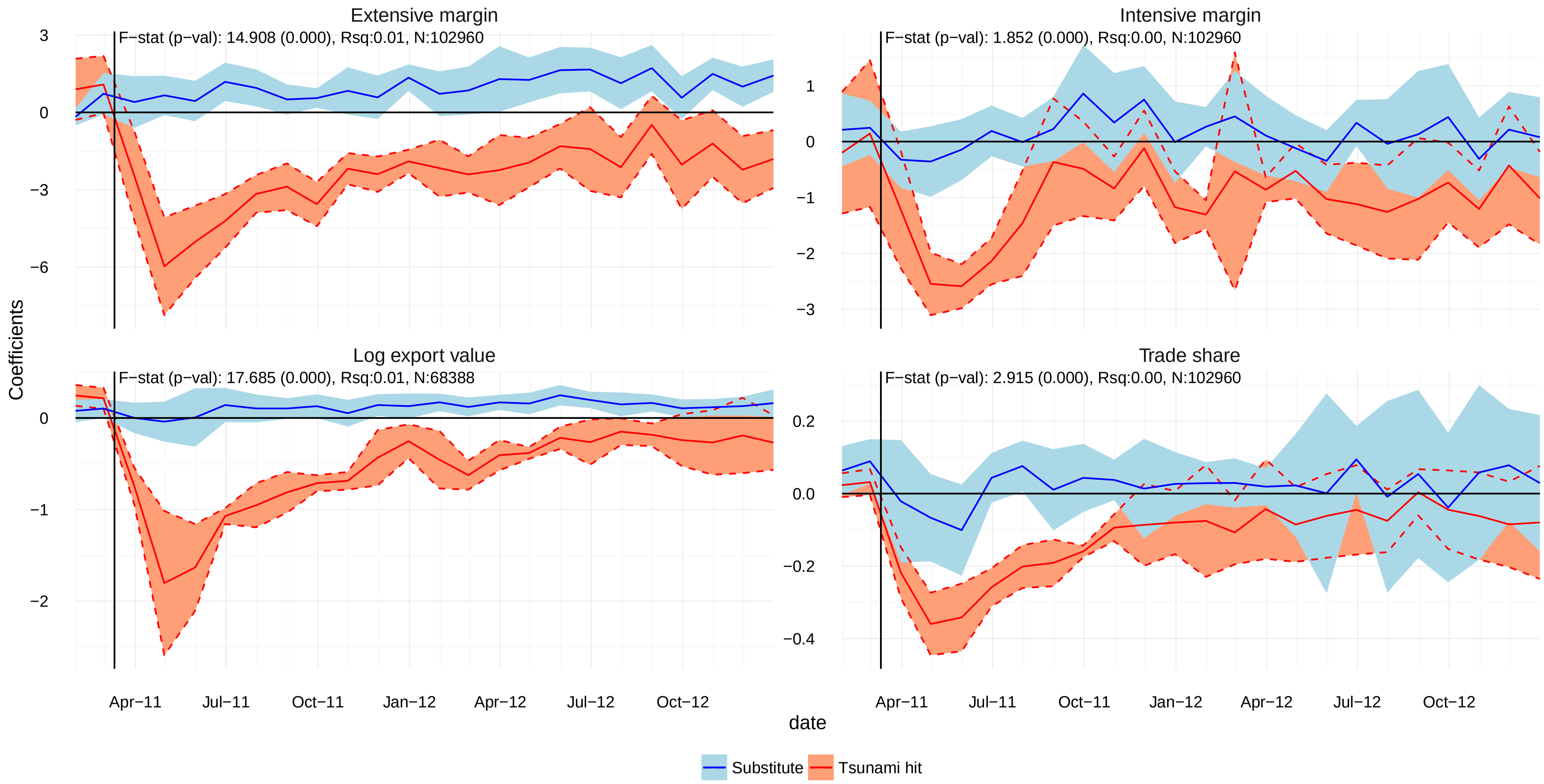
Figure 6 presents the first results based on model (12). On the horizontal axes time is indicated from January 2011 to December 2012. The vertical black line indicates the date of 11 March 2011. Since the monthly measures are plotted at the last day of the month, the first month in which the data should show an effect from the tsunami would be March 2011. In contrast to Figure 5, these results aim to indicate the difference between the two types of treated ports relative the the counterfactuals. The horizontal zero-axis is accentuated to aid on the inspection of this difference. In this way the plots allow for a range of comparisons, notably, at every point in time while controlling for all fixed effects,

1. for each type (tsunami-hit ports and substitutes) relative to the counterfactual ,
2. relative to the two months before the tsunami, and
3. relative to each other.

Each plot represents one regression and some additional statistics of the estimation are indicated. The F-statistic is calculated as the difference between the estimated model and the projected model with no additional regressors.

While one may discern a time pattern in the various plots we have not employed a smoothing technique or inter-month time dependence to gain some statistical efficiency from the time patterns. Every coefficient is calculated as the average difference relative to the counter-factual for a given month. The dramatic shock of the tsunami for the tsunami-hit ports is clearly visible. The drop is bigger for April 2011 relative to March as it accounts for the fact that exports were normal during the month until the earthquake of 11 March. The recovery took a few months, but there is a difference between the various measures. The extensive margin and the log of export value indicate the largest,

Figure 6: The effect of the tsunami relative to counter-factuals, model (12)



Each of the four plots presents the coefficients of a regression of the corresponding trade margins on time dummies interacted with an indicator variable for tsunami hit and substitute ports. The shaded area represents the 95% confidence interval using a clustered covariance matrix (clustered at the regional level). The vertical line indicates the day of the Great East Japan Earthquake and tsunami, 11 March 2011. For each regression some summary statistics of the regression estimation are indicated at the top of the plots.

statistically most significant and most persistent effects. While the intensive margin and trade share appear to recover within a few months, but indicate overall smaller absolute impacts.

Focusing on the substitute ports we note that the response is much less dramatic relative to the fall of the tsunami-hit ports. This is not surprising overall. As was evident from the descriptive statistics, and indeed our simulations, there are more substitute ports and each of these are on average larger relative to the substitute ports. If there is any trade substitution the effect will be smaller than the shock from the destructed ports. Moreover, any substitution effect will be diminished by the potential that firms reduced output following the earthquake. Still we find that the extensive margin receives a significant boost at the same time as the the tsunami-hit ports start to return to pre-tsunami levels from the summer of 2011 onwards. For the intensive margin the response is much smaller overall and statistically indistinguishable from zero. For the log export value we find a significant increase, in particular from January of 2012 onwards. Finally for the trade share we also find no statically significant effect.

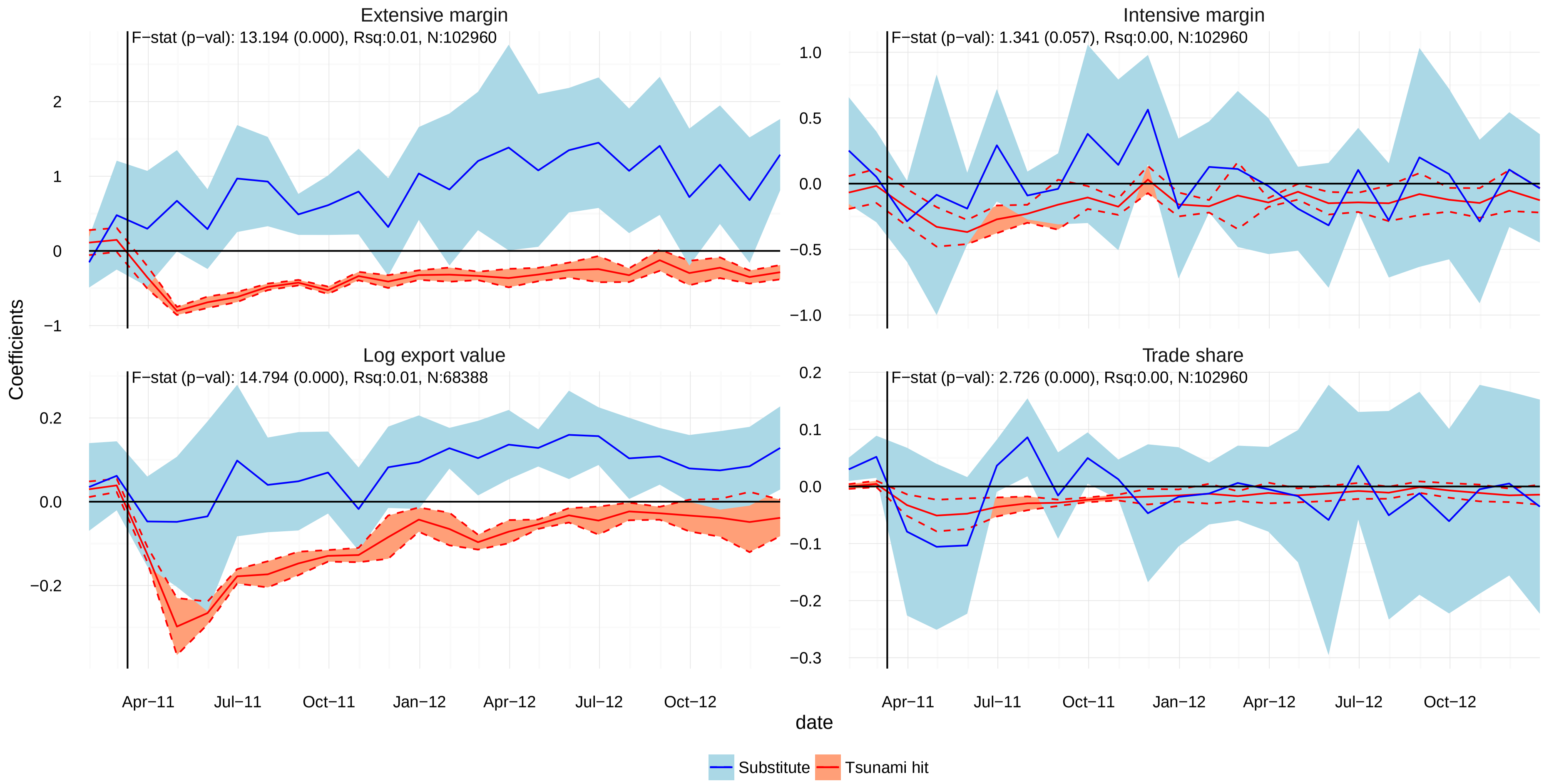
The size of the effects can be read directly from the vertical axes. We can see for the extensive margin that the negative shock for the tsunami-hit ports were around 5 percentage points decline while there is a 2 percentage points increase for the substitutes at their respective peaks. Given the average extensive margin of tsunami hit ports of 23.47 (see Table 4, EM section, column 'mean pre') for the tsunami-hit ports this means 69% ($= -5.97/8.63 \times 100$) decline. For the substitute ports the effect is smaller, presenting about a 7.3% ($=1.72/23.47 \times 100$) increase. The effect in percentage terms of the log export value can be read directly from the vertical axis. The plot indicates a dramatic drop in exports value, with values so large these basically indicate a complete stop on exports for the first 2-3 months, which is otherwise not surprising. What is interesting is the relatively quick recovery, while the substitute ports on average at their peaks in May 2012 would have gained around 28.1% ($= (e^{0.248} - 1) \times 100$) in additional exports. The combination of the descriptive statistics with summarised regression statistics explain in Section 3.4.3 below, while taking these estimates as representative and credible, allows us to perform a back-of-the-envelope calculation to get an idea of the share of exports that was substituted to other ports. We find that on average at the port-sector level, for the period March 2011 to February 2012, about 48.8% of exports was substituted to other ports.[24]

From this first set of results we can gain further insights by varying our analysis in various directions. Firstly we will show model (13) using the same margins. Results

[24] Using the statistics of log exports for substitute and tsunami hit in the pre-earthquake period, and multiplying these with the summary statistics in the first line of Table 6, the calculation is,

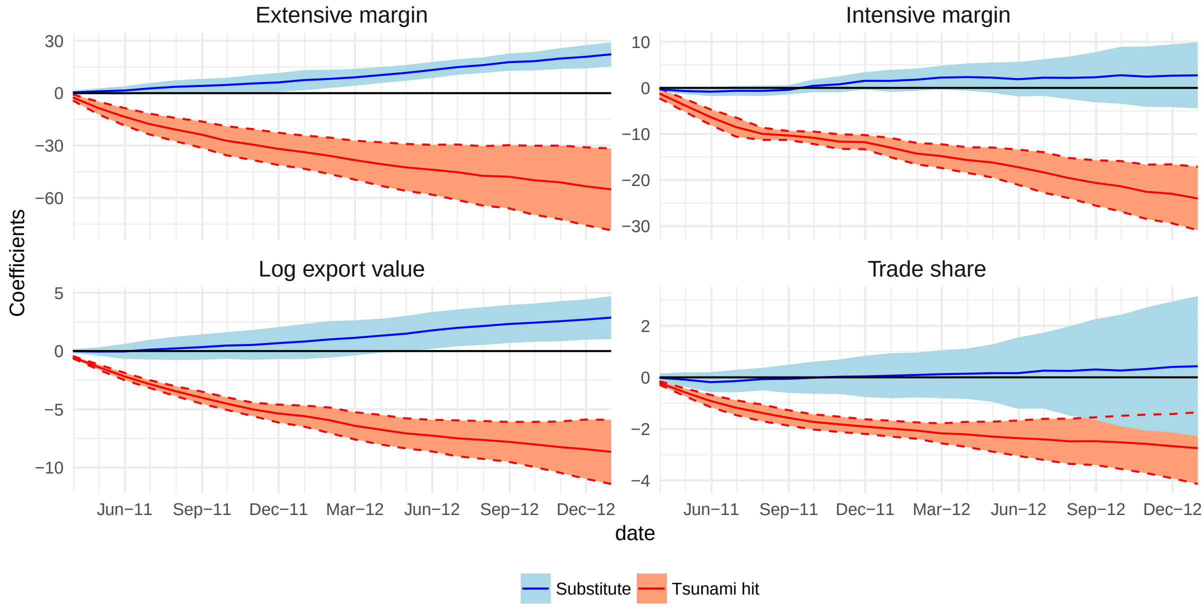
$$(1.488 \times \exp(12.11))/(7.059 \times \exp(11.27)) = 0.488$$

Figure 7: Overall margins of trade, model (13)



The vertical axes now takes into account the unit of measurement of the right-hand-side variables, which is wave height in meters for the tsunami-hit ports and the exposure measure as wave height/distance between ports (m/km) for the substitute ports. The coefficients for the latter have been scaled by 10 for readability. Further see note of Figure 6

Figure 8: Cummulative effects



Each of the four plots presents cumulative effects of results are presented in Figure 6. The shaded area represent the 95% confidence intervals calculated using the delta method.

are presented in Figure 7. There are two major differences, 1) the interpretation for the coefficients now takes into account the unit of measurement, which is in meters of the wave height for the tsunami-hit ports and exposure in terms of wave height meters/distance in km $\times$ 10 (using tens of kilometers scales the measures to comparable amplitudes), 2) the confidence interval for the tsunami-hit ports are much tighter (especially for the extensive margin), but for the substitute ports the precision of the estimates appears not affected as much. As before we find the most significant effects for the extensive margin and the log export value, while the intensive margin and trade share show no statistically significant result.

3.4.2 Cummulative effects

Figure 8 presents a similar graph as above, but the coefficients from March 2011 are presented cumulatively, and the corresponding standard errors are calculated using the delta method. The graph can be interpreted as indicated the cumulative loss or gain over the period. These graphs make it even more clear that the main export subsitution effect goes through the extensive margin. This effect also indicates the persistance of the shock, with very little flattening of the curves, or indeed reversal, over time. Moreover, whereas we see that the standard errors increase progressively with time for the intensive margin and trade share, we do not see this to be case for the other two measures.

This cumulative measure also allows us to derive an informative summary measure that we can use to compare various estimation methods; we simply take the level of the

Table 5: Summary robustness results

Model		Stat	EM	IM	lValue	TS
Benchmark	hit	$\sum \beta$	−38.342	−14.786	−6.408	−2.171
		cse	5.669***	1.313***	0.595***	0.197***
		rse	2.147***	2.601***	0.254***	0.198***
	sub	$\sum \beta$	9.043	2.235	1.132	0.121
		cse	2.481***	1.304*	0.771	0.476
		rse	1.390***	1.463	0.231***	0.203
+ cluster at port instead of region	hit	cse	14.180***	5.709***	1.449***	1.011**
	sub	cse	3.471***	1.948	0.653*	0.639
+ add prefecture production as control	hit	$\sum \beta$	−25.369	−12.936	−5.143	−1.159
		cse	2.608***	2.414***	0.620***	0.305***
	sub	$\sum \beta$	11.137	3.072	2.005	−0.033
		cse	2.640***	1.605*	0.878**	0.367
+ pre-differencing instead of F.E.	hit	$\sum \beta$	−35.860	−15.216	−6.903	−2.034
		cse	5.409***	0.968***	0.819***	0.095***
	sub	$\sum \beta$	12.355	1.585	1.376	0.207
		cse	2.290***	0.658**	0.697**	0.463
Exposure	hit	$\sum \beta$	−5.624	−2.211	−1.587	−0.332
		rse	0.320***	0.372***	0.099***	0.029***
		cse	0.172***	0.147***	0.124***	0.041***
	sub	$\sum \beta$	84.379	7.349	9.836	−1.904
		rse	12.406***	11.972	3.334***	1.945
		cse	18.155***	10.771	8.184	4.102
+ cluster at port instead of region	hit	cse	2.343**	1.097**	0.677**	0.173*
	sub	cse	39.387**	18.861	8.487	4.866

Statistics are the sum of the first twelve months from March 2011 onwards. Standard errors (cse for clustered and rse for robust) are calculated using the delta method. For the log export value, coefficients were transformed using $\exp(\beta) - 1$. Benchmark estimated following (12) and Exposure following (13) with variations to the Benchmark and Exposure models as indicated. Clustering is at the regional level unless otherwise indicated. $p < 0.01$ ***, $p < 0.05$ **, $p < 0.1$ *

effect at 12 months after the tsunami. In this way we can compare models using a single statistic, which saves on plotting all the results.

Table 5 presents these resuts. The first few lines give the coefficient with the by-region-clustered standard errors as presented in the figures above for the purpose of providing a baseline against which to evaluate variations on our main specification.

The cumulative statistics are presented in the rows indicates by $\sum \beta$, with directly underneath the relevant standard errors (s.e.), *cse* for clustered and *rse* for robust s.e. The stars immediately to the right of the s.e. represent the statistical significance at the usual levels. The statistics indicate that for our benchmark model we have a statistical significant substitution effect for the extensive margin and the log of export value, but not for the intensive margin and trade share, in line what the graphical representations already indicated.

The robust s.e. are smaller than the clustered ones, which may be expected. We then present by-port clustered s.e., where the coefficients are naturally identical to those of the benchmark. These s.e. are slightly larger compared to the by-region clustered s.e., but qualitatively do not affect our conclusions.

The next set of results adds the log of prefecture industrial production as additional controls. We add both the monthly aggregate industrial production for the prefecture in which a port is located, $\log(production_{k,t})$, as the cumulative industrial production of the treated or non-treated region (excluding the production of a port's own prefecture), $\log(\sum_{l=-k} production_{l,t})$.[25] Controlling for local output could affect both set of ports. Our estimates of hit ports would be confounded by the damaging consequence of the earthquake to both the ports and local firms. Since both effects would plausibly exert a negative effects on exports, we would overestimate the effect of the port damage. For the substitute ports the effect is in the opposite direction, since the relevant variation comes from the regional output. If firms in neighboring prefectures would be significantly affected by the earthquake, their reduced output would lower exports in surrounding ports, making it less likely for us to find a substitution effect.

The fourth set of results present estimates where we estimate a version of model (12), but the fixed-effects are replaced with left-hand-side variables that are demeaned at the port-sector levels, as presented in the Figure 5 panel (b). The idea again is that the usual fixed effects absorb some of the actual impact of the shock.[26] We find indeed that the estimated point estimate have increased for substitute ports, and that this is in particular relevant for the Extensive margin and the Log of exports values and their standard errors. However, the difference with our benchmark is not very large for these estimations, further supporting the general robustness of our empirical setup.

The last set of results present variations for model (13) with respect to the estimation of the variance-covariance matrix and derived standard errors. Note that the point estimates

[25] Data from the Japanese Ministry of Industry website.To be precise, the 'treated or non-treated' for certain ports is defined based on the treatment area. For ports in Tohoku, Kanto, Hokoriku and Tokai it is the sum of all prefectures in this area, for prefectures outside of those four regions the surrounding prefectures are the sum of all except in those four.

[26] Our model can be summarized in a standard panel framework,

$$y_{i,t} = x'_{i,t}\beta + c_i + e_{i,t}.$$

The tsunami and substitution dummies are summarized in the column vector $x_{i,t}$, while c_i represent individual i (e.g. port×sector) unobserved time-constant effects. Therefore, c_i can be estimated using only data from before March 2011; $\bar{y}_i = c_i + v_i$, where $\bar{y}_i = \frac{1}{26}\sum_{t=\text{Jan 2009}}^{\text{Feb 2011}} y_{i,t}$, which excludes x' since it contains no variation for the first 24 months in the sample. Subtracting, this equation from structural model, gives

$$\ddot{y}_{i,t} = x'_{i,t}\beta + \epsilon_{i,t},$$

where $\ddot{y}_{i,t} = y_{i,t} - \bar{y}_{i,t}$, and $\epsilon_{i,t}$ is the transformed model error. This procedure relies on the assumption that $\bar{y}_i$ is a consistent estimator of c_i. A fixed effects estimator would follow the same approach, but will use the entire time sample available including the period after March 2011 to estimate c_i. Note that a specific time trend is not included in this case. Alternatively, one could estimate the equation using 1 year differences. This would not be ideal in our case since the effect we are after can possibly be measured over the a period longer than one year and we would not want to compare the impact in April in 2012 against April 2011. Instead what we are after is to demean all effects from 2011 onwards against the average port-sector level of the year 2009 and 2011 such that the estimated parameters show a difference-in-difference effect relative to the the counter-factual ports.

of coefficients should be interpreted again with the unit of account of the interaction variable, wave height for the tsunami hit ports, wave height/10 km for the substitutes.

3.4.3 Margins of trade by sectors

Next we allow the effect of each sector to be estimated independently (as if our β's are subscripted by h). Rather than presenting this graphically we calculated again the sum over the 12 month period from March 2011 onwards. Table 6 presents results where each row represents a separate regression.[27] The results are ordered descending by the extensive margin. What we find is that fresh and unprocessed sea products and high-tech products included in the optical/photography and machinery categories have the largest substitution effect. On the other extreme we find bulk industry goods and material that can likely be stored for an extended period. The negative effects of the extensive margins for the hit ports does not show a similar pattern, but we can note that the shocks is represented among all sectors, in contrast to the substitution effect. In terms of the log export value, we find a negative shock among most sectors again, but for the substitution effect we cannot detect a statistically significant effect for most ports.

In the simulations we presented with varying levels of the elasticity of substitution σ. Different values of σ for different sectors could provide an explanation for this result. Additionally, as suggested by Todo et al. (2015), the supply chain may be critical here for the technology goods that are included in the categories of the first to sixth row. Freshness of products, given the unprocessed sea products, also appears to be a strong driver to divert products to other ports. In contrast, goods that can be easily stored, do not expire or perish quickly or are more costly to transport domestically are least substituted. This intuitive relation between product characteristics and substitution supports the findings in the before mentioned studies that supply chains are important for the understanding of trade dynamics.[28] Finally, the negative effect of the extensive margin of iron and steel could be further motivated from increased domestic demand for reconstruction purposes.

3.5 Margins of trade by destination

As a final exploration we look at the effects by destination regions (similarly as before, as if our β are subscripted by m for destinations).[29] Note that the destination groups replace

[27] Not all sectors are present. We estimate or model where at least nine of the 15 tsunami hit ports had positive exports for each period from March 2011 to December 2012. Plots from individual sectors are available on request. The fixed effects exclude the sector subscripts as well, resulting in time and port fixed effects for each regression.

[28] Cole et al. (2015a), using a sample of surveyed firms, find that most firms that experienced significant damage are across all sectors, but with specific concentration in a sector called 'Production Machinery'.

[29] Following the Japanese trade statistics we group destinations over North America, Middle and South America, Asia, Western Europe, Central and Eastern Europe (incl. Russia), Middle East, Africa, and Oceania.

Table 6: Differentiated effects over sectors

Sector	stat	EM hit	EM sub	lValue hit	lValue sub
unprocessed fish and other sea animals and plants	$\sum\beta$	−113.291***	42.858*	−3.431***	4.258
	cse	29.041	22.756	0.732	4.919
Optical and photographic	$\sum\beta$	−3.882	38.687***	−3.909*	5.427
	cse	3.799	9.964	2.065	4.754
Machinery and mechanical appliances	$\sum\beta$	−34.556***	24.763***	−1.520	2.496
	cse	12.317	9.241	1.353	4.134
Products of stone and glass	$\sum\beta$	−34.257***	19.532*	−3.563***	5.572
	cse	8.938	9.978	1.127	3.812
Plastics	$\sum\beta$	−50.267***	18.522**	−7.506***	0.114
	cse	13.637	8.520	2.202	0.435
Electrical machinery and appliances	$\sum\beta$	−50.205***	16.485***	−2.357	−0.388
	cse	12.735	6.009	1.799	2.366
Other metals and articles thereof	$\sum\beta$	−46.987***	7.597	−8.326***	0.431
	cse	10.367	6.173	2.078	1.325
Articles of iron and steel	$\sum\beta$	−11.721***	6.701	−1.222	2.967
	cse	3.282	5.757	1.792	2.527
Other vehicles	$\sum\beta$	−19.499	4.878	−6.542**	1.754
	cse	31.102	22.842	3.008	2.975
Chemical products	$\sum\beta$	−47.021***	4.035	−9.247***	0.489
	cse	11.861	4.076	0.163	1.170
Paper and printed	$\sum\beta$	−52.613***	3.924	−8.385***	2.623
	cse	13.496	10.495	0.636	1.773
Processed agricultural products	$\sum\beta$	−33.316***	2.902	−3.397***	0.188
	cse	6.152	13.068	1.279	1.694
Other organic based products	$\sum\beta$	−57.831***	1.867	−5.840***	−1.561
	cse	17.560	6.286	0.961	1.323
Other craft products	$\sum\beta$	−14.508***	1.472	−9.563***	0.314
	cse	2.504	7.825	1.268	1.505
Intermediate textiles	$\sum\beta$	−3.856**	−3.686	−8.240***	6.538
	cse	1.756	11.138	0.934	4.577
Iron and steel	$\sum\beta$	−10.459*	−5.538	−3.331***	1.949
	cse	6.273	6.186	1.041	2.040

Calculations based on model (12) for each sector separately. Statistics are the sum of the coefficients for the first twelve months from March 2011 onwards. Clustered standard errors are calculated using the delta method. For the log export value, coefficients were transformed using $\exp(\beta) - 1$.

Table 7: Differentiated effects over destination regions

		EM		lValue	
Region	stat	hit	sub	hit	sub
Middle and South America	$\sum\beta$	-31.377^{**}	26.646^{***}	-3.524^{***}	1.448
	cse	13.332	5.228	0.860	1.123
Asia	$\sum\beta$	-30.508^{***}	12.455^{***}	-2.757^{***}	2.382^{**}
	cse	4.310	4.593	0.840	1.196
North America	$\sum\beta$	-12.320	8.279	-4.319^{***}	3.563^{**}
	cse	18.570	16.349	1.234	1.758
Central and East Europe, incl. Russia	$\sum\beta$	-42.343^{**}	6.627	-5.270^{***}	1.018
	cse	17.503	8.532	0.830	1.664
Western Europe	$\sum\beta$	-28.442^{***}	6.417	-2.068^{**}	2.352
	cse	8.549	7.986	0.927	1.634
Oceania	$\sum\beta$	-23.711^{***}	3.852	-4.979^{***}	1.441
	cse	4.096	10.567	1.118	1.029
Middle East	$\sum\beta$	-7.046	3.469	-4.803^{***}	0.724
	cse	18.506	22.091	0.757	0.973
Africa	$\sum\beta$	-53.237^{***}	-8.901	-3.290^{***}	2.997^{**}
	cse	6.475	14.944	1.171	1.279

Calculations based on model (12) for each destination region separately. 'Groups' are defined as country-destinations rather than sectors. A group is than defined as the countries belonging to the geographical region. Statistics are the sum of the coefficients for the first twelve months from March 2011 onwards. Clustered standard errors are calculated using the delta method. For the log export value, coefficients were transformed using $\exp(\beta) - 1$.

the sectoral definitions such that we calculate a single margin for each port-destination-month. If these destination groups can be seen as an approximation for the international trade costs and market size, these estimations would give insight into whether destinations are treated differently. Again we present the results in a table with the sum over the first 12 months from March 2011, see Table 7.

The results indicate that the substitution effect is the biggest for the closest markets, Asia, and Middle and South America. Therefore, trade distance and market size seems to be the relevant driver of the size of the substitution effect given that these regions represent Japan's biggest export markets. The other regions have both smaller coefficients which are statistically not different from zero at the usual significance levels. For Africa we even find a negative substitution effect, much like we found negative coefficients for some sectors. This would indicate that there might be some further replacement going on, for instance where the counter-factual ports are taking over some of the trade to Africa while the substitute ports concentrate on the main markets.

3.6 Robustness

In Appendix B.3 we present further robustness results. First, We estimated the effect for each of the four Japanese treatment regions separately. These results indicate that it is not one region that drives the result but the effect is present for all regions although estimating parameters for each region separately results in a loss of precision. For good measure we estimated the effects for Hokkaido as well.

Second, we vary the distance at which ports are assumed to be exposed to treatment, add Hokkaido as a treated region with hit and substitute ports and perform a placebo analysis by designating some of the counter factual ports as substitute (while excluding substitute ports from the treated regions). All these function as a test on our selection of substitute ports. None of these results alter the conclusions we can draw from the main results.

We have also performed all the above analysis on the trade measures computed at the port level, rather than by port-sector, with qualitatively similar results.[30]

4 Conclusion

In this paper, we develop a new general equilibrium model with multiple ports and heterogeneous firms. Exporting requires local transportation costs and port specific fixed costs as well as international bilateral trade costs. Based on these two port specific costs a port is characterised by its comparative advantage relative to other ports. Multiple ports are in action in equilibrium in the presence of port comparative advantage. We then establish a gravity equation with multiple ports and show that gravity distortions due to heterogeneous firms is conditional on both forms of internal trade costs. We analytically present comparative statistics results for each margin of trade and show how the switch of exports from one port to the another can be accounted for by exogenous variation in both port specific local transportation costs and port specific fixed export costs. Finally, we test the prediction of the model with Japanese customs data and find a supportive evidence for a port substitution following the 2011 Great Japanese Earthquake. We find a significant and economically meaningful substitution effect. Back-of-the-envelope calculations suggest that about 50% of exports was substituted to other ports. Reversing this argument for the case of investments into the infrastructure around ports would suggest that gains will be spread over new trade due to lowering of export costs as well as replacement, and therefore a loss to other ports, due to a change in the comparative advantage relative to these other ports. Naturally, this division of exports between these two channels will be highly dependent on the specific local circumstances.

Therefore, the implication of this article is that internal barriers to trade are to a large extent mitigated by the ability of firms to choose among a number of route options to bring their products to international markets, which helps during unexpected events such as the one we exploited in this paper. The substitution effect is most evident for product varieties that we know to play a big role in the supply chain networks of technology products, while products that are too bulky to transport domestically while storable for a longer period

[30]Results available on request and also in an earlier working paper Hamano and Vermeulen (2017)

appear not to be substituted to other ports. Again, reversing the argument, we expect that infrastructure investments for new or existing ports could potentially facilitate new trade for product that were previously too costly to transport internally, while product categories that are part of a international supply chain might switch between ports but would not affect aggregate export volumes.

Inevitably we left some dimensions unexplored. As our empirical results indicate that the intial shock of the natural disaster has a diminishing impact over time for some ports and sectors, one could imagine that firms are forward looking and anticipate such adjustments, and thereby introduce a dynamic aspect to decision of firms to trade. Additionally, we took firms' locations to with respect to ports as given, which was appropriate for the empirical setup, but both the location of firms and the number of ports could be thought of to be endogenous when thinking about policy on infrastructure. We leave such extensions to future research.

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A Proof of Proposition 1

First we look the ranking condition of cutoff productivity levels. From (4) and taking the ratio of ZCP of two ports k and s with $k > s$,

$$\left(\frac{\overline{\varphi}_{ijs}}{\overline{\varphi}_{ijk}}\right)^{\sigma-1} = \left(\frac{\mu_k}{\mu_s}\right)^{1-\sigma}\frac{f_{ijs}}{f_{ijk}}.$$

We have $\overline{\varphi}_{ijk} < \overline{\varphi}_{ijs}$ when $f_{ijs}/f_{ijk} > (\mu_{ijs}/\mu_{ijk})^{1-\sigma}$. Also dividing (6) by profits for port s,

$$\left(\frac{\overline{\varphi}_{ijks}}{\overline{\varphi}_{ijs}}\right)^{\sigma-1} = \frac{\mu_s^{-(\sigma-1)}}{\mu_s^{-(\sigma-1)} - \mu_k^{-(\sigma-1)}}\left(\frac{f_{ijs} - f_{ijk}}{f_{ijs}}\right) = \frac{1 - \frac{f_{ijk}}{f_{ijs}}}{1 - \left(\frac{\mu_k}{\mu_s}\right)^{1-\sigma}}$$

Thus when $f_{ijs}/f_{ijk} > (\mu_{ijs}/\mu_{ijk})^{1-\sigma}$, we have $\overline{\varphi}_{ijs} < \overline{\varphi}_{ijks}$ simultaneously.

Next we look for the condition with which a marginal increase in productivity $\varphi^{\sigma-1}$ induces higher dividends for port s than port k. Namely,

$$\frac{\partial d_{ijs}(\varphi)}{\partial \varphi^{\sigma-1}} > \frac{\partial d_{ijk}(\varphi)}{\partial \varphi^{\sigma-1}} \tag{A-1}$$

From (3) and (2), we can express profits in exporting from port k as

$$d_{ijk}(\varphi) = \frac{1}{\sigma}\left(\frac{\sigma}{\sigma-1}\frac{w_i\mu_k\tau_{ij}}{\varphi q_{ij}P_j}\right)^{1-\sigma}\alpha Y_j - f_{ijk}$$

The similar expression holds for port s. Deriving these expressions with respect to $\varphi^{\sigma-1}$ for each port, we have $(\mu_k/\mu_s)^{\sigma-1} > 1$ so that (A-1) holds. On the other hand, when $(\mu_k/\mu_s)^{\sigma-1} < 1$, for a marginal rise in productivity level, exporters prefer to export from port k. In such a case, all firms prefer to export from port k.

Finally, having established $C(K_n, 2)$ number of even profit cutoff productivity levels for any combination of two ports, provided the ranking of zero profit cutoff productivity levels for each port as (5), the firm with φ eventually chooses to export from one specific port k^* that maximizes its exporting profits $d_{ijk^*}(\varphi)$, specifically by solving the following problem.

$$\max_{d_{ijk^*}(\varphi)}\left[d_{ijK_n}(\varphi), d_{ijK_n-1}(\varphi), ..., d_{ij2}(\varphi), d_{ij1}(\varphi)\right]$$

Together with the specific preference of firms with respect to exporting port as defined previously, the above condition establishes the proposition 1.

B Additional empirical results

B.1 Additional statistics on ports

Figure B-1: Density plot - port level

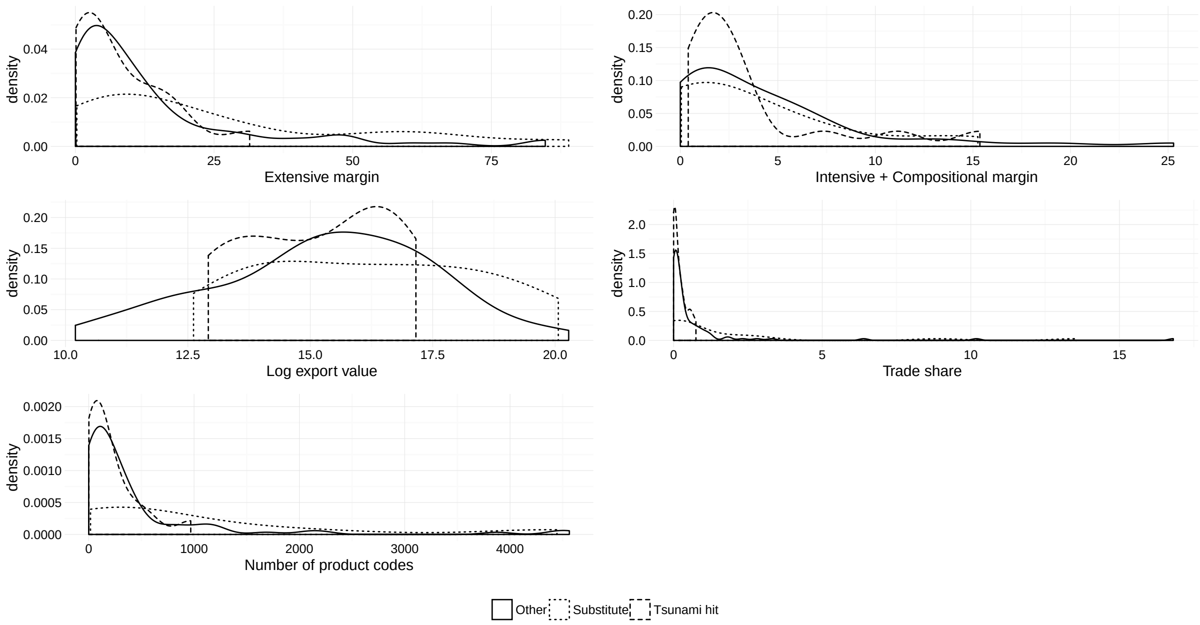


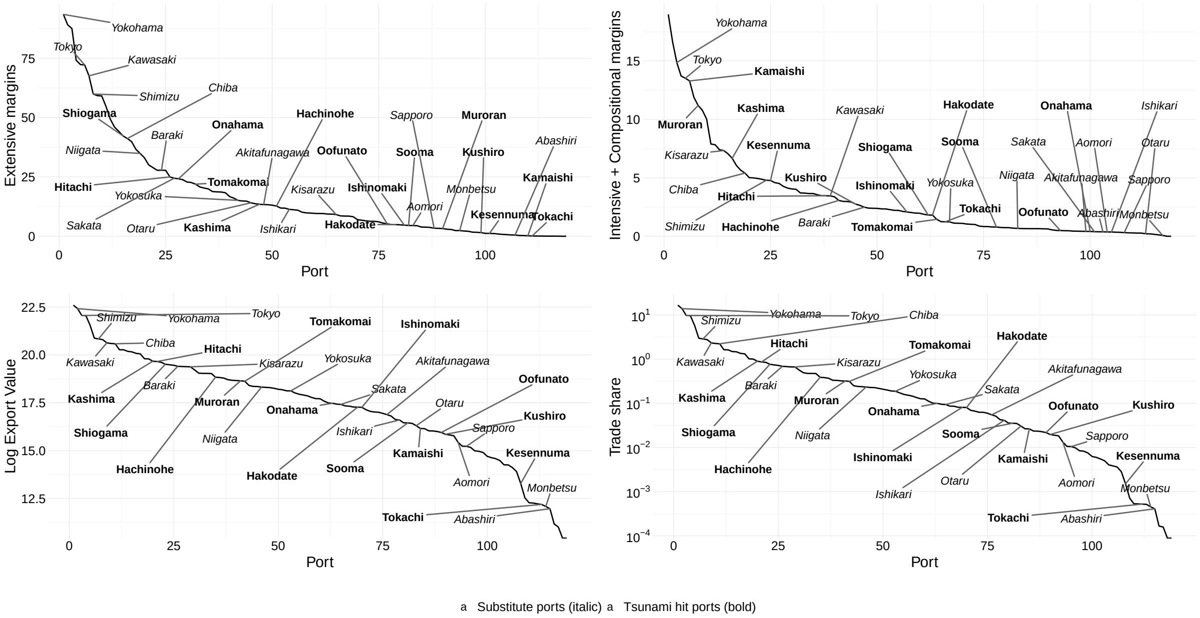
Figure B-1 gives a representation of the distributions of the four key variables, grouped as tsunami hit ports, substitutes and other. The plots are based calculated using the average margins or values over 2009-2010 (i.e. pre-tsunami), without sector definitions. The density plots are calculated for each group separately, allowing to see the range of the available observations for each group. What is evident is that the substitute ports are relatively larger in terms of export value, and their extensive and intensive margin. The substitute ports are skewed towards the low end of the trade margins, but in terms of export value appear centered relative to the other ports.

B.2 Direct flood impact

In order to substantiate that the tsunami primarily hit ports in the Tohuku and Kanto region, but not the wider economy around it we provide statistics on the affected region using two different datasets. Figure B-3 gives an overview of the two underlying data of the approaches, zoomed in around the Sendai port area, one of the worst hit areas.

We obtained a shape files of the flooded region from Geospatial Information Authority of Japan (GSI Japan, part of the Ministry of Land, Infrastructure, Tourism and Transport), which contains a number of polygons that indicate the maximum flood extend. These were created using arial images during the crisis and continuously updated as new

Figure B-2: Ports ranked by trade measures (2010)

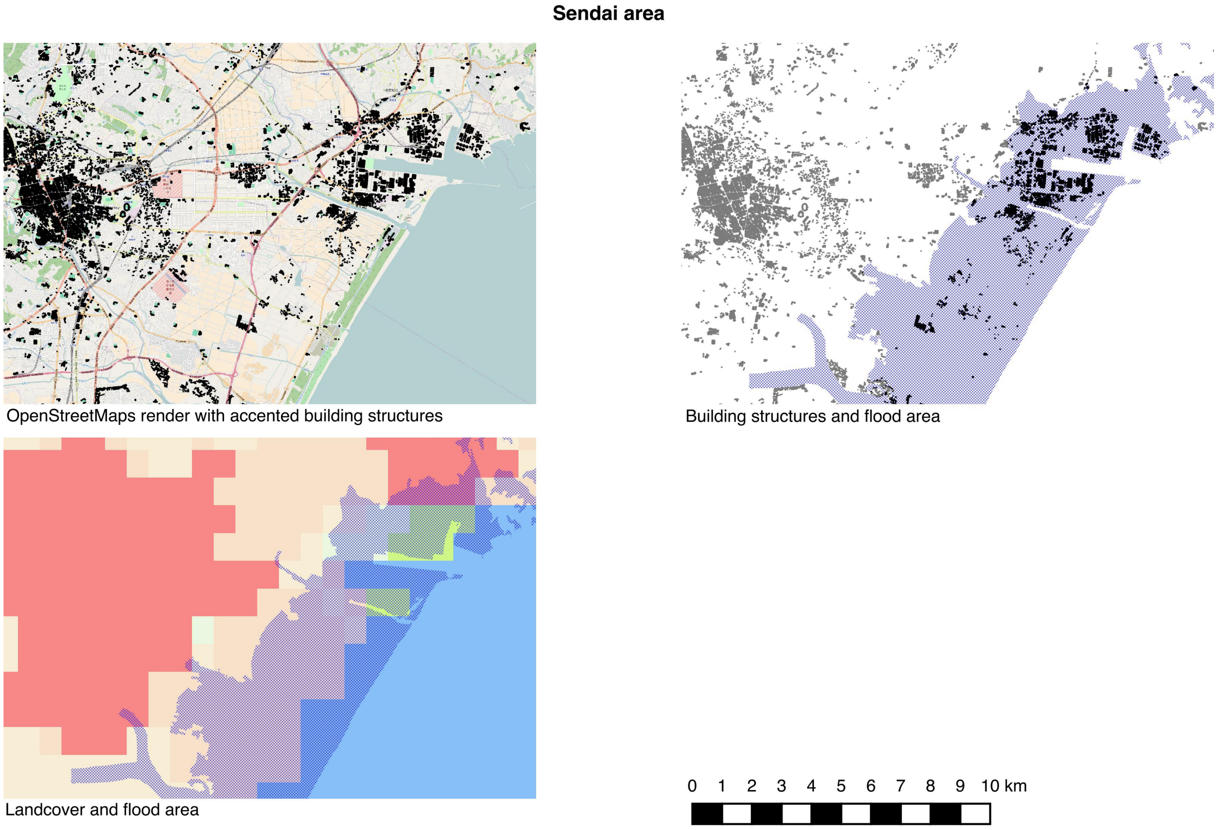


information came on the actual reach of the water (Nakajima and Koarai, 2011). We spatially interacted these polygons with two data sources.

Firstly, using OpenStreetMaps (OSM) we extracted all building structures in Tohoku and Kanto, and counted the number inside and outside the flood extend. The second panel showcases this method. The OpenStreetMaps (OSM) data is from 2016, but it is impossible to exactly date all information contained. It is therefore possible that buildings that were destroyed and not rebuild are not in the data set. In general, the building structures contained in the dataset are larger structures in city centers, industrial, commercial and military structures, but not residential housing. For our purpose of highlighting the effect on businesses this might not be very problematic. We find that 0.12% of the buildings in Kanto, and 5.48% in Tohoku were flooded.

Secondly, we used a raster file on landcover from the GSI Japan. We took the raster data of 2006 (Global Map Japan version 1.1 Raster data). Only one value of the raster band relates to build-up area. Panel 3 showcases this data, build-up are is light-red and concentrated around the city centre and north of the port area. In this case the data does not appear very accurate in placing the industrial area around the port. On the other hand, the area north of the port is considered build-up whereas relatively few structures are identified at that place in the OSM data. Each cell in the raster presents a certain area. We calculated the total area of all cells that touch the flood region, independent of how much of the cell is covered by the flood region. This should give us a conservative figure. We find that 0.01% in Kanto and 4.67% in Tohoku of build-up area was affected by the floods.

Figure B-3: Measures of direct physical impact of the tsunami



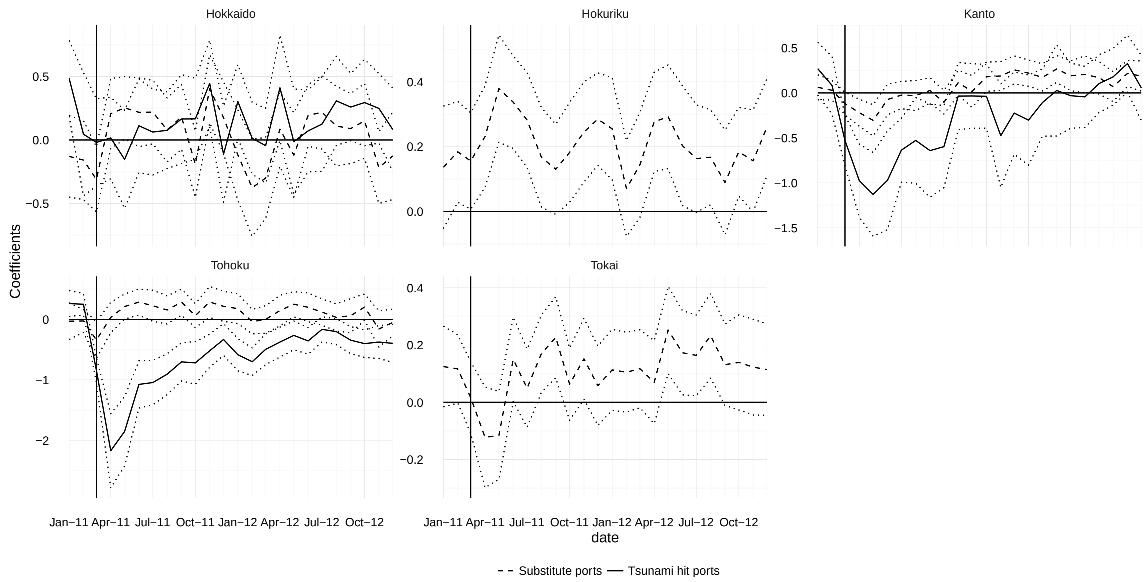
In conclusion, neither of the two datasets is perfect for giving a measure of the number of business directly affected by the Tsunami. For the Tohoku region the two measures give a rather similar figure of around 5% of industrial and commercial land being affected, while the relevant number for the Kanto region is much lower.

B.3 Additional regression results

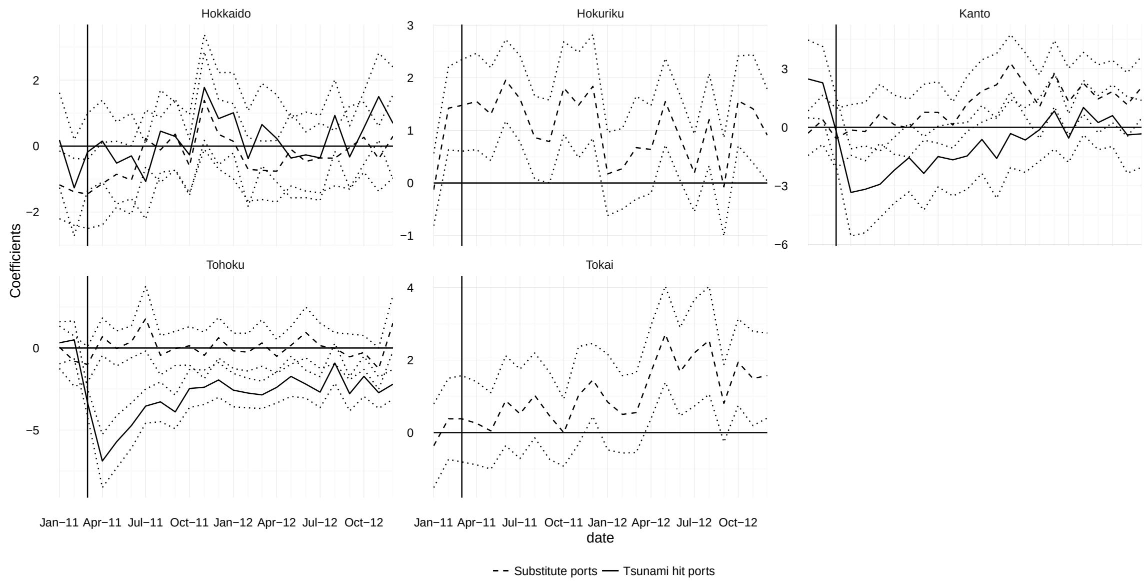
B.3.1 By Japanese region

Figure B-4: Results of Log export value and Extensive margin by Japanese regions

(a) Log export value



(b) Extensive margin



B.3.2 Varying substitute distance and selection

We present summary statistics of further robustness regressions in Table B-1. Figures that that belong to these regressions are available on request to the authors. The first three sets limit progressively the distance a port can be away from a tsunami hit port to be able to function as substitute. In effect this limits the number of substitution ports as well as decreasing their level of exposure, while adding to the counter-factuals some ports that may be affected. What we see is that the coefficients on the substitution ports tend to increase the more we limit the distance range. This effect is due to the decreasing level of the exposure, which is compensated for through the increase of the coefficient. The second observation is that the trade margins for which we did not find a result thus far, the intensive margin and the trade share become statistically significant in the more restricted settings. These results further underline the conservative nature of our main estimates.

Adding Hokkaido as a treated region, rather designating its ports as counter-factual, changes little to our conclusions. On inspection we that including Hokkaido increases the standard errors of the coefficients for each period, indicating that it does not serve well to identify the main effect we are after.

Finally, we performed a placebo analysis. We designate at random 10 ports from the counter-factuals as substitute, while removing all ports from the other regions that were not hit by the tsunami. We then estimate the same model. We repeat this 100 times. The results we present are the means and standard deviations of the estimated (12 month sum of) the coefficients over these 100 repetitions. The estimates for the placebo substitute ports should show little or no effect with no statistical significance, which is what we find.[31]

[31]The estimations for the tsunami hit ports are not relevant since we do not change these ports over each repetitions.

Table B-1: Summary robustness results

Model		Stat	EM	IM	lValue	TS
Exposure limited to 500km	hit	$\sum \beta$	-5.751^{***}	-2.248^{***}	-1.608^{***}	-0.335^{***}
		cse	0.204	0.143	0.131	0.040
	sub	$\sum \beta$	79.957^{***}	-3.500	5.502	-4.327
		cse	18.684	9.948	5.674	4.318
Exposure limited to 300km	hit	$\sum \beta$	-5.803^{***}	-2.250^{***}	-1.618^{***}	-0.337^{***}
		cse	0.221	0.139	0.135	0.040
	sub	$\sum \beta$	106.264^{***}	-7.733	4.275	-9.040
		cse	30.913	12.842	6.643	6.701
Exposure limited to 100km	hit	$\sum \beta$	-5.855^{***}	-2.253^{***}	-1.620^{***}	-0.325^{***}
		cse	0.239	0.128	0.141	0.034
	sub	$\sum \beta$	551.075^{***}	-76.303^{**}	534.685	-6.435
		cse	96.292	32.824	779.484	4.177
Add Hokkaido as treated	hit	$\sum \beta$	-24.603^{*}	-4.618	-4.568^{**}	-1.324^{*}
		cse	14.042	8.702	2.131	0.782
	sub	$\sum \beta$	7.267^{**}	2.487^{**}	1.217^{*}	0.144
		cse	2.836	1.229	0.698	0.426
Placebo analysis	hit	$\sum \beta$	-25.677^{***}	-4.672^{***}	-6.574^{***}	-1.347^{***}
		bse	0.623	0.455	0.151	0.075
	sub	$\sum \beta$	0.691	0.009	-0.017	-0.008
		bse	4.786	3.499	1.101	0.568

Statistics are the sum of the first twelve months from March 2011 onwards. Standard errors are calculated using the delta method. For the log export value, coefficients were transformed using $\exp(\beta) - 1$. For the placebo analysis the coefficient and standard errors reperesent the mean and standard deviation over 500 repetitions $p < 0.01^{***}$, $p < 0.05^{**}$, $p < 0.1^{*}$

B.4 Definition of sectors

We aggregate various HS-2-digits together to slightly reduce the number of sectors and create a more homogenous distributions on the number of product categories for each sector. The results are given in Table B-2. Doing makes sure that most sectors are represented in most ports in most time periods.

Table B-2: Sector definitions

HS code	HS name	n var	new sector	new n.var
01	Live animals; animal products	14	unprocessed animal and plants	265
02	Meat and edible meat offal	27		
04	Dairy produce; birds' eggs; na...	33		
05	Products of animal origin	14		
06	Live trees and other plants; b...	18		
07	Edible vegetables and certain ...	51		
08	Edible fruit and nuts; peel of...	55		
09	Coffee, tea, maté and spices	40		
10	Cereals	13		
03	Fish and crustaceans, molluscs...	242	unprocessed fish and other sea animals and plants	242
11	Products of the milling indust...	24	Processed agricultural products	366
12	Oil seeds and oleaginous fruit...	42		
13	Lac; gums, resins and other ve...	9		
14	Vegetable plaiting materials; ...	5		
15	Animal or vegetable fats and o...	51		
16	Preparations of meat, of fish ...	60		
17	Sugars and sugar confectionery	19		
18	Cocoa and cocoa preparations	11		
19	Preparations of cereals, flour...	21		
20	Preparations of vegetables, fr...	50		
21	Miscellaneous edible preparati...	20		
22	Beverages, spirits and vinegar	24		
23	Residues and waste from the fo...	20		
24	Tobacco and manufactured tobac...	10		
25	Salt; sulphur; earths and ston...	70	Solid minerals	167
26	Ores, slag and ash	34		
27	Mineral fuels, mineral oils an...	63		
28	Inorganic chemicals; organic o...	178	Inorganic chemicals	178
29	Organic chemicals	360	Organic chemicals	360
30	Pharmaceutical products	33	Chemical products	307
31	Fertilisers	21		
32	Tanning or dyeing extracts; ta...	53		
33	Essential oils and resinoids; ...	31		
34	Soap, organic surface-active a...	23		
35	Albuminoidal substances; modif...	16		
36	Explosives; pyrotechnic produc...	9		
37	Photographic or cinematographi...	38		
38	Miscellaneous chemical product...	83		
39	Plastics and articles thereof	188	Plastics	188
40	Rubber and articles thereof	87	Other organic based products	280
41	Raw hides and skins(other than...	46		
42	Articles of leather; saddlery ...	21		
43	Furskins and artificial fur; m...	10		
44	Wood and articles of wood; woo...	77		
45	Cork and articles of cork	7		
46	Manufactures of straw, of espa...	11		
47	Pulp of wood or of other fibro...	21		

Table B-2: Sector definitions, *continued*

HS code	HS name	n var	new sector	new n.var
48	Paper and paperboard; articles...	121	Paper and printed	140
49	Printed books, newspapers, pic...	19		
50	Silk	15	Textiles	491
51	Wool, fine or coarse animal ha...	41		
52	Cotton	168		
53	Other vegetable textile fibres...	23		
54	Man-made filaments; strip and ...	133		
55	Man-made staple fibres	111		
56	Wadding, felt and nonwovens; s...	51	Intermediate textiles	205
57	Carpets and other textile floo...	21		
58	Special woven fabrics; tufted ...	51		
59	Impregnated, coated, covered o...	25		
60	Knitted or crocheted fabrics	57		
61	Articles of apparel and clothi...	119	Final clothing and other worn products	340
62	Articles of apparel and clothi...	114		
63	Other made up textile articles...	53		
64	Footwear, gaiters and the like...	30		
65	Headgear and parts thereof	10		
66	Umbrella, sun umbrellas, walki...	6		
67	Prepared feathers and down and...	8		
68	Articles of stone, plaster, ce...	57	Products of stone and glass	224
69	Ceramic products	38		
70	Glass and glassware	66		
71	Natural or cultured pearls, pr...	63		
72	Iron and steel	416	Iron and steel	416
73	Articles of iron or steel	169	Articles of iron and steel	169
74	Copper and articles thereof	55	Other metals and articles thereof	313
75	Nickel and articles thereof	17		
76	Aluminum and articles thereof	41		
78	Lead and articles thereof	8		
79	Zinc and articles thereof	9		
80	Tin and articles thereof	6		
81	Other base metals; cermets; ar...	49		
82	Tools, implements, cutlery, sp...	88		
83	Miscellaneous articles of base...	40		
84	Nuclear reactors, boilers, mac...	662	Machinery and mechanical appliances	662
85	Electrical machinery and equip...	370	Electrical machinery and appliances	370
86	Railway or tramway locomotives...	22	Railway, aircraft and ships	54
88	Aircraft, spacecraft, and part...	14		
89	Ships, boats and floating stru...	18		
87	Vehicles other than railway or...	144	Other vehicles	144
90	Optical, photographic, cinemat...	209	Optical and photographic	209
91	Clocks and watches and parts t...	52	Other craft products	240
92	Musical instruments; parts and...	19		
93	Arms and ammunition; parts and...	19		
94	Furniture; bedding, mattresses...	44		
95	Toys, games and sports requisi...	45		
96	Miscellaneous manufactured art...	54		
97	Works of art, collectors' piec...	7		