Natural Disasters and the Reshaping of Global Value Chains

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Abstract

To understand the longer term consequences of natural disasters for global value chains, this paper examines trade in the automobile and electronic sectors after the 2011 earthquake in Japan. Contrary to widespread expectations, the analysis shows that the shock did not lead to reshoring, nearshoring, or diversification; and trade in intermediate products was disrupted less than trade in final goods.

Imports did shift to new suppliers, especially where dependence on Japan was greater. But production relocated to developing countries rather than to other top exporters. Despite important differences, the observed pattern of switching may be relevant to disasters like the COVID-19 pandemic.

Natural Disasters and the Reshaping of Global Value Chains[1]

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1. Introduction

COVID-19 has exposed the risks associated with the interconnected nature of global trade. The reliance on foreign input producers can lead to a disruption of production when source countries experience a negative shock. A view shared by many observers is that firms will respond to this shock reconsidering the balance between efficiency and resilience in production, leading to long term changes in the structure of global value chains (GVCs) in the form of reshoring, nearshoring and diversification (e.g. Javorcik, 2020; Kilic and Marin, 2020; Lund et al., 2020; UNCTAD, 2020). In contrast, others have argued that the same technological and institutional factors that have underpinned the international fragmentation of production in the past decades would make a retrenchment of GVCs post-COVID-19 unlikely, unless there is a radical change in the policy environment (Antràs, 2021; Baldwin, 2020).[2] Ultimately, the long-term impact of natural disasters on global value chains and their organization is an empirical question.

To understand how firms behave when faced with new risks, we examine the 2011 earthquake in Japan. The earthquake off the Pacific coast of Tōhoku was the most powerful ever recorded in Japan. It triggered a tsunami that swept the Japanese mainland, causing devastation of physical infrastructure and approximately 16,000 deaths. The earthquake also severely disrupted supply chains. For example, a shortage of over 100 parts left Toyota's North American operations operating at 30 percent capacity for several weeks (Canis, 2011). Boehm et al. (2019) show that Japanese multinationals in the United States lost access to intermediate inputs and experienced severe reductions in production as a result. In the short run, the effects were highly disruptive because there were few substitutes for Japanese suppliers. For Japanese firms operating in the US, the elasticity of substitution across material inputs was estimated to be only 0.2 in the short run.

Most of the existing literature on natural disasters focuses on how GVCs transmit shocks, domestically (Carvalho et al., 2016) or internationally (Boehm et al., 2019).[3] In this paper, we study instead the longer-

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[2] For an analysis of the long-term evolution of global value chains, see Constantinescu et al. (2020) and World Bank (2020).

[3] An exception is Zhu et al. (2016) which uses Japanese firm-level data from 2010-2013, to show that the earthquake increased manufacturing offshoring from Japan among firms in the prefectures most affected by the disaster.

term impact of the 2011 earthquake in Japan on trade patterns. We focus on the automobile and electronics industries, for which Japan is a key supplier, especially of parts and components. For instance, as the shock severely affected production of Japanese automotive equipment, it had cascading effects on global auto producers such as Honda, Opel, Nissan, and General Motors which froze production lines in several factories worldwide (Automotive News, 2011). In electronics, the problems were similar, as many specialized inputs such as connectors, microphones, and sensors were produced in Japan and had few or no substitutes (World Bank, 2020).

To motivate the analysis, we identify certain patterns in the data. We examine imports of auto and electronics in the 15 largest auto producing countries as of 2010 and in the 15 largest exporters of final electronics products to gauge the longer term effect of the earthquake on suppliers.[4] The left panel of Figure 1 shows the average shares of products imported from Japan for importers where Japan is not a prominent supplier (less than 15 percent of total imports of that product by the country). The right panel focuses on importers largely dependent on Japanese suppliers (more than 15 percent of total imports in a product line). The figure shows that reliance on Japan dropped sharply following the 2011 earthquake for the countries most dependent on Japan. The drop was more than 10 percentage points for the auto industry, while in the case of electronics the earthquake appeared to accelerate pre-existing declining trends. This is prima facie evidence that large shocks do lead to a partial reconfiguration of supply chains: while less exposed importers return to near pre-crisis operations after the shock, it is the more dependent producers that tend to change production structures.

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[4] See Table A1 in the Appendix for the list of countries. While we have data for automobile production by countries, we do not have similar data for electronics and therefore rely on export data.

Figure 1: Country share of imports from Japan in auto and electronics (average)
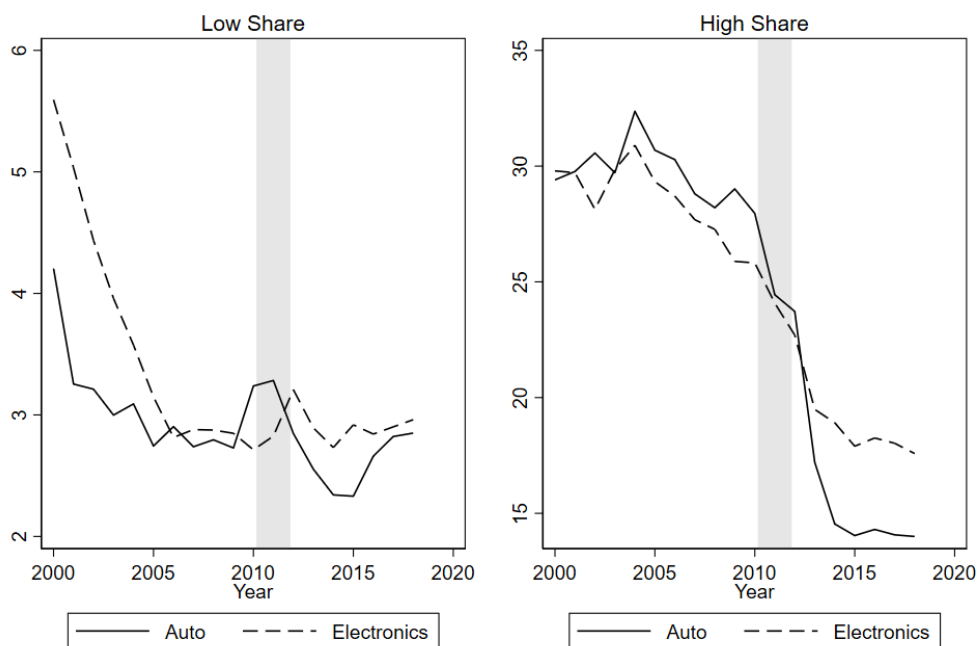
Source: 6-digit HS 1988/92 import data from United Nations Comtrade.

Notes: The figures plot Japan's average market share for auto and electronics for country-products in which Japan had an average market share below 15 percent (left panel "Low Share") and in country-products in which Japan had an average market share greater than 15 percent (right panel "High Share") calculated over the 2004-2010 period. The sample for auto is restricted to the 15 largest auto producers and for electronics to the 15 largest exporters of final electronics; in both cases Japan is excluded.

The analysis relies on a simple identification strategy. We use detailed international trade data for automobile and electronics components and final goods to study whether in the aftermath of the 2011 earthquake, importers more dependent on Japan before the earthquake behaved differently from importers less dependent on Japan. Apart from the change in imports from Japan, we also investigate whether the 2011 earthquake led to a diversification of imports away from Japan and to reshoring or nearshoring of production by more dependent importers.

We find that the earthquake led to a sharp decline in imports from Japan of auto parts and finished vehicles of countries more dependent on Japan before the shock. Electronics shows a similar pattern to the auto industry, but the decline was less pronounced. For both auto and electronics, intermediate imports were less affected than final imports. Using a continuous measure of dependence, we find that

the decline in imports for both auto and electronics is more severe the higher the importers' dependence on Japanese suppliers in the period preceding the earthquake. We find, somewhat surprisingly, that importers more exposed to Japan before the 2011 earthquake did not increase import diversification in either auto or electronics. There is also no evidence that countries re-shored production. In fact, importers more exposed to Japan before the 2011 earthquake *increased* total imports, which is consistent with an intensification of offshoring rather than reshoring.

An important question relates to which countries picked up the slack as supply chains reorganized in the aftermath of the 2011 earthquake. We perform a difference-in-differences analysis, comparing shifts in trade patterns of high Japan-dependent products with other products while controlling for importer and product specific time-varying shocks. We find that in the years following the shock, production relocation decisions were largely driven by fundamentals rather than policy. Developing countries, rather than top exporters, were the primary beneficiaries and production tended to relocate in larger countries. There is no evidence that supply chains were increasingly regionalized or that importers sought nearby suppliers, except for final autos where transport costs are especially high.

The rest of the paper is organized as follows. Section 2 provides a simple framework to think of the effects of natural disasters and the reshaping of supply chains. Section 3 studies the impact of the Japanese earthquake on the reconfiguration of supply chains. Section 4 takes a closer look at where production moved after the shock. Section 5 concludes.

2. Natural disasters and supply chain reconfiguration

To guide the empirical analysis, we propose a simple framework to think of the impact of natural disasters on the reconfiguration of supply chains. To begin with, consider the choice from the perspective of a multinational firm that imports from a subsidiary located in Japan.[5] A disaster that destroys fixed assets like factories will accelerate the reallocation of production to production hubs where average costs are lower. Note that in normal circumstances, a firm would move to another location if the sum of the cost and insurance savings in the new location were larger than the fixed costs of relocation. Specifically, we

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[5] As noted in the introduction, Boehm et al. (2019) found that Japanese multinationals abroad lost access to auto intermediates and experienced severe reductions in production of final goods. The case of arm's length trade is also considered below.

define the cost of relocation, C = F + S, as the sum of the cost of building a factory, F, and the cost of establishing new relationships in the new production location, S. The benefit of relocation, B = (c + i) q, depends on the scale of production, q (assumed for simplicity to be the same in the two locations), the per-unit cost difference, c, and the per unit insurance premium difference, i, in the new location. For parsimony, we use a static example, in a dynamic setting the cost savings would compound overtime, without changing the qualitative results. A firm would relocate if

$$(c + i) q > F + S.$$

Before a natural disaster, small differences in unit costs would not induce a relocation – the sunk costs in the existing location create inertia. The event has two implications for the decision to relocate production. First, if the factory is destroyed as a consequence of the disaster, the cost of building a new factory, F, is no longer relevant because it is truly sunk. It disappears from the inequality because it must now be paid in both the old and new locations. Although the cost of building new relationships, S, must still be incurred in the new location, firms will now be more sensitive to cost differences between the old and new locations than if the factory were intact. If the same factors that affect production cost also affect cost of building a new factory (for example, exchange rate undervaluation), that will enhance this effect. Second, the natural disaster may affect the differential on the insurance premium between locations. As the old location is riskier, relocating to a new low-risk location becomes more attractive.

Figure 2 provides an illustration of the forces at play. Note that finding new production locations in the aftermath of a natural disaster has larger benefits the higher the dependence on production and hence imports from the exporting country (Japan). To see why, note that the expected costs of exposure to a specific source for imports are related to the relative importance and riskiness of that source. The larger the imports, the greater the disruption caused by a cut off in production in that source. The benefits of relocating production can be seen as the inverse of the expected costs from the disruption associated with a natural disaster. Accordingly, in Figure 2, B^{PRE} = (c + i) q shows the benefits of switching away from the risky source before the realization of the event as increasing in exposure (i.e. quantity imported from Japan). This benefit must be compared with the costs which depend on the costs of relocating production and the costs of investing in a new relationship, captured by the schedule C^{PRE} = F + S. Before the realization of the natural disaster, country-sectors with exposure higher than q*(PRE) would have switched away from Japan.

A first question that this framework helps to address is whether to continue sourcing from a country that experiences a natural disaster. Following the recent empirical literature on behavioral economics—see Bourdeau-Brien and Kryzanowski (2020) for the US and Cameron and Shah (2015) for Indonesia—we assume that for any given level of dependence, an increase in the perceived riskiness of the source increases the expected loss and, hence, the benefit from switching away from it. The schedule $B^{POST} = (c + i^{POST})$ q depicts the upward shift in benefits due to the upward revision in perceived riskiness, and hence the insurance premium differential, after a shock. These benefits are compared with the costs, now captured by $C^{POST} = S$.

The model indicates that (a) an increase in perceived riskiness and the destruction of physical capital lower the threshold at which firms would choose to switch suppliers (from q*(PRE) to q*(POST) in Figure 2); and (b) importers that are more dependent on the source (i.e. those with imports higher than q*(POST)) are more likely to switch to a different supplier. Note that sectors where the fixed costs of building a factory, F, are relatively higher (e.g. auto) would display more inertia even in presence of larger unit costs differential before a natural disaster. In the figure, the shift in C is greater when the fixed cost is larger. The model thus indicates that these sectors would experience a larger relocation of production after a natural disaster relative to sectors with lower fixed costs (e.g. electronics).

While our analysis has focused on the imports of a multinational firm with a production base in Japan, the analysis of an arms-length importer can be considered a special case. The reduced inertia due to the destruction of a factory is not relevant, and so the impulse to switch sources is primarily due to the increase in the risk premium following the natural disaster—though the cost differential may also rise if factories are not rebuilt. Note, in particular, that the benefits of relocation are again positively related to the extent of import dependence on Japan.

Figure 2: Benefits and costs of switching import sources before and after a natural disaster
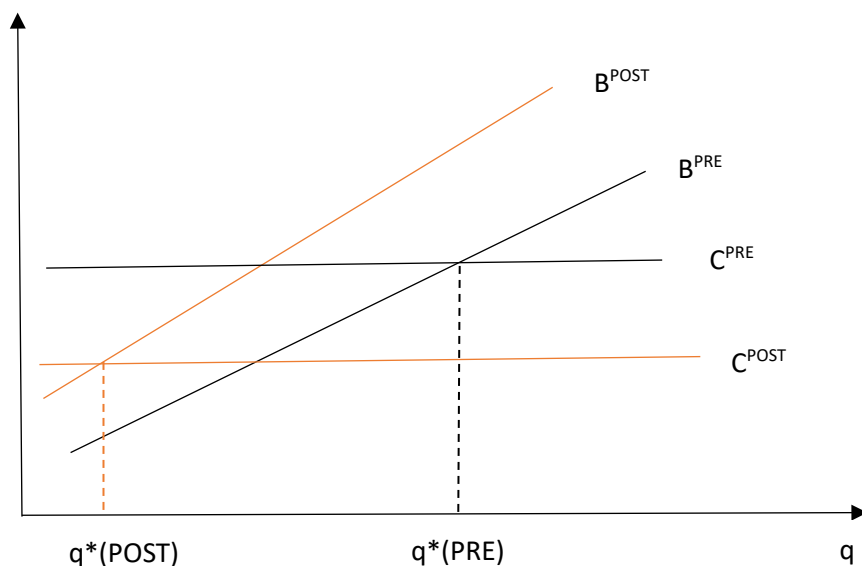
Consider now possible differences between intermediate and final goods. The costs of switching suppliers, S, is likely to be relatively larger for relationship-specific intermediate products relative to final goods due to higher search and customizing costs (Antràs and Chor, 2013). Indeed, the data on relationship stickiness in trade (Martin et al., 2021) show that auto and electronics parts are stickier than final autos and electronics, respectively.[6] In the model, this implies that S is relatively more important than F in the switching costs for intermediate goods as compared with final goods. Thus, the shift down of the C curve will be less pronounced, resulting in more inertia. In other words, relationship-specific investments in intermediates relative to final goods will tend to depress the ability to switch trade partners subsequent to shocks, assuming those relationships remain intact.

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[6] See Figure A1 in Annex for the distribution of relationship stickiness across industries and types of products.

3. Impact of the Japanese earthquake on supply chain reconfiguration

In this section, we study how the 2011 earthquake impacted imports from Japan and whether it led to more diversification or reshoring of production.

3.1 *Impact on imports from Japan*

As a first exercise, we investigate whether importers less dependent on Japan as a source behaved differently from importers more dependent on Japan in the aftermath of the 2011 earthquake. Specifically, we rely on the following specification:

$$\ln\left(Y_{ikt}^{JPN}\right) = \alpha_{ik} + \theta_{it} + \sigma_{kt} + \beta\, I(High\, Share\, JPN\, 2011_{ikt}) + \varepsilon_{ikt} \qquad (1)$$

where Y_{ikt}^{JPN} are country i's imports of HS 6-digit product k from Japan for the 15 largest auto producing countries or the 15 largest exporters of final electronics.[7,8] The analysis focuses on the largest auto producing countries as those are the countries where lead firms located their production facilities. The countries are selected based on 2010 motor vehicle production data from the Organisation Internationale des Constructeurs d'Automobiles (OICA). As there is no comparable production data for electronics, we select the largest exporting countries of final electronics based on the 2004-2010 data.[9] $I(High\, Share\, JPN\, 2011_{ikt})$ is an indicator variable taking value 1 if the importer is dependent on Japanese suppliers in the period preceding the earthquake (more than x percent of total imports in a product line between 2004-2010, where x can take value of 15, 10 and 5). The specification also includes α_{ik}, θ_{it} and σ_{kt}, which are respectively the importer-sector, importer-time and sector-time fixed effects. We expect the coefficient of interest, β, to be negative if the shock led to a greater drop in reliance on

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[7] See Table A1 in Annex for the list of countries in the sample.

[8] We use product level bilateral trade data from WITS (UN Comtrade) reported at the 6-digit level in the HS 1988/92 classification for the period 2004-2018.

[9] Results are robust to alternative selection methods. See Table A2 in Annex for results for the auto industry based on exports of final auto and selection based on imports of intermediates.

Japan following the 2011 earthquake for the producers most dependent on Japan. This finding would suggest that global value chains reconfigured after the shock.

Table 1: Impact on imports from Japan

Panel A: All

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Auto				Electronics			
	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports
(Dummy share 2004-2010 > 15)	-0.814***			-0.576***	-0.386***			-0.108
	(0.165)			(0.181)	(0.057)			(0.069)
(Dummy share 2004-2010 > 10)		-0.694***		-0.140		-0.469***		-0.221***
		(0.140)		(0.158)		(0.050)		(0.064)
(Dummy share 2004-2010 > 5)			-0.594***	-0.345**			-0.508***	-0.387***
			(0.128)	(0.138)			(0.047)	(0.051)
Observations	5,336	5,336	5,336	5,336	50,194	50,194	50,194	50,194
R-squared	0.903	0.903	0.902	0.904	0.912	0.913	0.913	0.913
Treated	74	109	177	177	683	1024	1708	1708
Total country-products	405	405	405	405	3971	3971	3971	3971
Auto-Electronics >15	0.428**			0.468**				
Auto-Electronics >10		0.226		-0.081				
Auto-Electronics >5			0.085	-0.042				

Panel B: Auto

	Intermediate auto				Final auto			
	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports
(Dummy share 2004-2010 > 15)	-0.748***			-0.560***	-0.723*			-0.171
	(0.160)			(0.178)	(0.433)			(0.511)
(Dummy share 2004-2010 > 10)		-0.606***		-0.249		-0.752**		-0.035
		(0.146)		(0.165)		(0.334)		(0.346)
(Dummy share 2004-2010 > 5)			-0.340**	-0.114			-1.121***	-1.035***
			(0.152)	(0.155)			(0.312)	(0.319)
Observations	3,749	3,749	3,749	3,749	1,587	1,587	1,587	1,587
R-squared	0.918	0.918	0.917	0.919	0.896	0.897	0.899	0.899
Treated	49	75	121	121	25	34	56	56
Total country-products	285	285	285	285	120	120	120	120
Intermediate-Final >15	0.025			0.389				
Intermediate-Final >10		-0.147		0.213				
Intermediate-Final >5			-0.781**	-0.921***				

Panel C: Electronics

	Intermediate electronics				Final electronics			
	log of imports	log of imports	log of imports		log of imports	log of imports	log of imports	log of imports
(Dummy share 2004-2010 > 15)	-0.228**			-0.092	-0.453***			-0.122
	(0.099)			(0.126)	(0.070)			(0.081)
(Dummy share 2004-2010 > 10)		-0.263***		-0.069		-0.549***		-0.277***
		(0.086)		(0.114)		(0.061)		(0.077)
(Dummy share 2004-2010 > 5)			-0.386***	-0.336***			-0.548***	-0.400***

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
			(0.094)	(0.098)			(0.055)	(0.059)
Observations	13,857	13,857	13,857	13,857	36,337	36,337	36,337	36,337
R-squared	0.928	0.928	0.929	0.929	0.904	0.905	0.905	0.905
Treated	208	315	537	537	475	709	1171	1171
Total country-products	1034	1034	1034	1034	2937	2937	2937	2937
Intermediate-Final >15	-0.225*			-0.030				
Intermediate-Final >10		-0.286***		-0.207				
Intermediate-Final >5			-0.162	-0.063				

Note: Robust standard errors clustered at the cluster importer-product level are in parentheses. All specifications include importer-year, importer-product, and product-year fixed effects. The samples include the top 15 producers of automobile or top 15 exporters of final electronics other than Japan. The last three rows of each panel report the difference between coefficients for auto and electronics in Panel A and intermediate and final in Panel B and C.

*** p<0.01, ** p<0.05, * p<0.1

Table 1 presents the estimates of Equation (1) for the impact of the 2011 earthquake on imports from Japan. The results show that importers who are more dependent on Japan are more likely to reduce imports. The coefficient in columns 1-3 and 5-7 consider highly dependent imports versus less dependent as defined by the indicated threshold (5, 10, or 15). For example, column 1 shows that importers who relied on Japan for 15 percent or more of the product reduced exports of autos by 56 percent (exp(-.814)=.44), as compared with those that relied on them for 15 percent or less. When the variables for all of the thresholds are included, in columns 4 and 8, results show that the declines in imports for both auto and electronics were stronger for higher thresholds of dependence on Japan.[10] The estimated negative impact on imports from Japan varies between around 32 percent for electronics and 56 percent for auto— the coefficients for auto are statistically different from those for electronics when using the 15 percent threshold. The stronger effects for the auto industry may reflect the higher fixed costs of building a factory in this sector relative to electronics. As shown in Section 2, sectors with higher fixed costs would experience larger relocation of production after a natural disaster that destroyed the factory. Alternatively, the industry may be more sensitive to cost savings--a flatter benefits curve or face more elevated insurance costs.

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[10] For instance, to gauge the impact for country-products with a Japan share above 15 percent, we would need to sum the coefficients of all the dummy variables (i.e., 5 percent, 10 percent, and 15 percent) as these variables are not mutually exclusive. Note that the coefficients in columns 1-3 and 5-7 cannot be directly compared since the control groups are different. In columns 4 and 8 they are additive and relative to less than 5 percent.

Results in Panels B and C confirm the negative impacts for both intermediates and final products. Results in Panel B for auto parts, columns 1-4, and final vehicles, columns 5-8, show that intermediate auto declined between around 50 and 30 percent, while imports of final auto dropped by around 50 to 70 percent. The impact is stronger for final auto and statistically different from auto parts at the 5 percent threshold. Results in Panel C show a similar pattern for electronics—we observe a stronger, and statistically different, decrease for final electronics than for intermediate products—but the decline is less severe than the drop for the auto industry. As discussed in section 2, the higher search costs associated to finding new suppliers of auto and electronics parts led to lower switching relative to final products, at least for the case of the 2011 Japanese earthquake.

3.2 *Impact on diversification*

Economic intuition would suggest that importers exposed to risk may seek to diversify their supplier base. From the model, reduce q in any one location so as to reduce risk. However, the literature on supply chains stresses the importance of firm-to-firm relationships and customized products, suggesting diversification is costly (Antràs, 2019). The relative strengths of these two forces in the aftermath of a natural disaster is not obvious. In this subsection, we investigate whether the 2011 earthquake led to a diversification of imports from suppliers other than Japan.[11] Specifically, we modify Equation (1) as follows:

$$\ln(HHI_{ikt}) = \alpha_{ik} + \theta_{it} + \sigma_{kt} + \beta \, I(High \, Share \, JPN \, 2011_{ikt}) + \varepsilon_{ikt} \quad (2)$$

where HHI_{ikt} is the Herfindahl–Hirschman Index (HHI), a measure of concentration, for importer *i* in product *k* at time *t*.[12] The set of fixed effects and the indicator variable are as in Equation (1). The results from table 1 showed that importers reduced exposure to Japan in those products where there was high dependence, this regressions tests whether those imports were replaced with less concentrated suppliers.

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[11] We exclude Japan from the calculation because imports from Japan decreased and this could mechanically drive the diversification index. Also, the index allows us to test if importer replaced Japan with several suppliers.

[12] The formula used to calculate the concentration index is equal to the sum of all the import shares, Japan excluded: $HHI_{ikt} = \sum_{j=1}^{N} Import \, Share_{jt}$. The index varies between 1, which indicates that there is only one supplier, to 1/N when all suppliers have the same market share.

A negative sign on the coefficient of interest, β, would indicate that the 2011 earthquake led to a diversification of imports away from Japan in those formerly high dependence products after the shock.

Table 2: Diversification Herfindahl–Hirschman Index (HHI)

	(1)	(2)	(3)		(4)	(5)		(6)
Panel A: All		Auto				Electronics		
	HHI	HHI	HHI	HHI	HHI	HHI	HHI	HHI
(Dummy share 2004-2010 > 15)	-0.007			-0.021	0.017***			0.013**
	(0.013)			(0.019)	(0.005)			(0.006)
(Dummy share 2004-2010 > 10)		0.005		0.022		0.013***		-0.000
		(0.013)		(0.020)		(0.005)		(0.006)
(Dummy share 2004-2010 > 5)			-0.001	-0.006			0.015***	0.012**
			(0.014)	(0.015)			(0.005)	(0.005)
Observations	5,562	5,562	5,562	5,562	52,584	52,584	52,584	52,584
R-squared	0.847	0.847	0.847	0.847	0.799	0.799	0.799	0.799

Panel B: Auto		Intermediate auto				Final auto		
	HHI	HHI	HHI	HHI	HHI	HHI	HHI	HHI
(Dummy share 2004-2010 > 15)	0.000			-0.019	0.003			-0.073
	(0.015)			(0.022)	(0.031)			(0.046)
(Dummy share 2004-2010 > 10)		0.019		0.035		0.014		0.031
		(0.016)		(0.022)		(0.026)		(0.043)
(Dummy share 2004-2010 > 5)			-0.001	-0.012			0.036	0.039
			(0.017)	(0.017)			(0.025)	(0.033)
Observations	3,818	3,818	3,818	3,818	1,744	1,744	1,744	1,744
R-squared	0.899	0.900	0.899	0.900	0.783	0.783	0.783	0.773

Panel C: Electronics		Intermediate electronics				Final electronics		
	HHI	HHI	HHI	HHI	HHI	HHI	HHI	HHI
(Dummy share 2004-2010 > 15)	0.025**			0.016	0.014**			0.013*
	(0.010)			(0.012)	(0.006)			(0.007)
(Dummy share 2004-2010 > 10)		0.022**		0.011		0.009*		-0.006
		(0.009)		(0.012)		(0.005)		(0.007)
(Dummy share 2004-2010 > 5)			0.012	0.003			0.016***	0.016***
			(0.010)	(0.010)			(0.005)	(0.005)
Observations	14,320	14,320	14,320	14,320	38,264	38,264	38,264	38,264
R-squared	0.791	0.791	0.790	0.791	0.804	0.804	0.804	0.804

Note: Robust standard errors clustered at the cluster importer-product level are in parentheses. All specifications include importer-year, importer-product, and product-year fixed effects. The samples include the top 15 producers of automobile or top 15 exporters of final electronics other than Japan.
*** p<0.01, ** p<0.05, * p<0.1

The results in Table 2 suggest that importers more exposed to the 2011 earthquake, those with higher shares of imports sourced from Japan in the pre-shock period, did not increase import diversification as a

result of the shock. If anything, the results for electronics suggest an increase in import concentration for the more affected country-products. That is consistent with a post-shock change in risk perceptions that is limited to Japan and does not affect other sources.[13] Overall, there is no evidence of a systematic increase in diversification following the negative shock which suggests that Japan was replaced by other suppliers that did not have large market shares.

The finding that the shock leads to switching rather than widening sources may be because the required relationship-specific investments discourage firms from diversifying. For instance, many auto parts are customized and need to meet safety standards and other regulatory requirements, making it cost effective to limit the number of key suppliers. A complementary explanation relates to the characteristics of the industries we are analyzing. For example, it could be that all the conditions for producing and exporting vehicles—skills, scale, connectivity, contiguity to large markets—are only available in few countries which may limit the scope for import diversification.

3.3 *Impact on* reshoring

Another possibility is that affected producers moved production home in the aftermath of the natural disaster. If this were the case, we would expect to see importers dependent on supplies from Japan reduce total imports of the product in subsequent years. To test this hypothesis, we rely on the following specification

$$\ln\left(Y_{ikt}^{TOT}\right) = \alpha_{ik} + \theta_{it} + \sigma_{kt} + \beta\,I(High\,Share\,JPN\,2011_{ikt}) + \varepsilon_{ikt} \qquad (3)$$

where Y_{ikt}^{TOT} are total imports of country i in HS 6-digit product k at time t. The set of fixed effects and the indicator variable are again as in Equation (1). A negative sign of the coefficient of interest, β, would indicate a fall in imports of high dependence products, consistently with the view that the 2011 earthquake led to a reshoring of production.

Table 3: Impact on total imports

	(1)	(2)	(3)	(4)	(5)	(6)

[13] Table A3 in Annex reports the results when constructing the HHI which includes Japan as well. Regression results show that post shock import sources are less concentrated which is consistent with a switching away from Japan.

Panel A: All

	Auto				Electronics			
	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports
(Dummy share 2004-2010 > 15)	0.018			-0.115	0.105**			0.115**
	(0.108)			(0.129)	(0.043)			(0.052)
(Dummy share 2004-2010 > 10)		0.108		0.129		0.050		-0.007
		(0.103)		(0.145)		(0.038)		(0.048)
(Dummy share 2004-2010 > 5)			0.125	0.092			0.006	-0.017
			(0.105)	(0.124)			(0.034)	(0.036)
Observations	5,562	5,562	5,562	5,562	52,597	52,597	52,597	52,597
R-squared	0.947	0.947	0.947	0.947	0.962	0.962	0.962	0.962
Treated	74	109	177	177	683	1024	1708	1708
Total country-products	405	405	405	405	3971	3971	3971	3971

Panel B: Auto

	Intermediate auto				Final auto			
	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports
(Dummy share 2004-2010 > 15)	-0.030			-0.058	0.366			0.099
	(0.076)			(0.093)	(0.284)			(0.508)
(Dummy share 2004-2010 > 10)		0.017		0.008		0.369		0.321
		(0.067)		(0.108)		(0.244)		(0.487)
(Dummy share 2004-2010 > 5)			0.076	0.085			0.191	-0.032
			(0.096)	(0.119)			(0.213)	(0.278)
Observations	3,818	3,818	3,818	3,818	1,744	1,744	1,744	1,744
R-squared	0.973	0.973	0.973	0.973	0.935	0.936	0.935	0.936
Treated	49	75	121	121	25	34	56	56
Total country-products	285	285	285	285	120	120	120	120

Panel B: Electronics

	Intermediate electronics				Final electronics			
	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports
(Dummy share 2004-2010 > 15)	0.214***			0.132	0.054			0.104*
	(0.079)			(0.095)	(0.051)			(0.061)
(Dummy share 2004-2010 > 10)		0.197***		0.082		-0.013		-0.045
		(0.075)		(0.095)		(0.043)		(0.055)
(Dummy share 2004-2010 > 5)			0.152**	0.086			-0.046	-0.050
			(0.071)	(0.075)			(0.038)	(0.041)
Observations	14,323	14,323	14,323	14,323	38,274	38,274	38,274	38,274
R-squared	0.962	0.962	0.962	0.963	0.961	0.961	0.961	0.961
Treated	208	315	537	537	475	709	1171	1171
Total country-products	1034	1034	1034	1034	2937	2937	2937	2937

Note: Robust standard errors clustered at the cluster importer-product level are in parentheses. All specifications include importer-year, importer-product, and product-year fixed effects. The samples include the top 15 producers of automobile or top 15 exporters of final electronics other than Japan.

*** p<0.01, ** p<0.05, * p<0.1

The results for the impact of the shock on total imports are reported in Table 3. There is no evidence that in the aftermath of the shock countries with high dependence on Japan re-shored those activities. The results are robust to the use of different thresholds and consistent across industries and intermediate and final products. Results in Panel A, column 4, and Panel C, columns 1-3, suggest that for electronics overall imports increased after the Japan shock which could indicate an intensification of offshoring of some activities instead reshoring for intermediate electronics.

4.   To which countries did importers switch?

In this section, we study where importers chose to source from in the aftermath of the 2011 earthquake. We perform a difference-in-differences analysis, comparing shifts in trade patterns of high Japan-dependent products with other products, and allow for heterogenous impacts of the shock depending on country characteristics. This method in effect asks what would trade patterns have looked like had the shock not happened, using unaffected products (countries with limited imports in the product from Japan) as a control group.[14] To investigate for differential impacts we estimate the following equation:

$$\ln(Y_{ijkt}) = \alpha_{ijk} + \theta_{it} + \mu_{jt} + \beta_1\, I(High\ Share\ JPN\ 2011_{ikt}) + \\ \beta_2\, I(High\ Share\ JPN\ 2011_{ikt}) * Char_{(i)j(k)t} + \varepsilon_{ikt} \quad (4)$$

where Y_{ijkt} are bilateral imports, Japan excluded, at time t and $Char_{(i)j(k)t}$ are a set of relevant country characteristics such as level of income and population size or country-pair characteristics such as geographic distance, whether countries belong to the same region, or share the border. We also control for bilateral-sector, importer-time and exporter-time fixed effects. The indicator variable $I(High\ Share\ JPN\ 2011_{ikt})$ is equal to 1 for importer i in a product line k if Japan's share exceeded 10 percent during the 2004-2010 period.[15] A significant coefficient, β_2, would indicate a differential impact on imports along the $Char_{(i)j(k)t}$ dimension. For instance, a positive coefficient on the interaction term

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[14] The results above on imports from Japan, diversification, and total imports are significant using the difference-in-differences approach as well.

[15] Results are robust to the use of alternative thresholds (i.e., 15 and 10 percent).

$I(High\ Share\ JPN\ 2011_{ikt}) * \ln(population\ pre_j)$ would indicate a stronger increase in imports from countries with larger population size in the pre-earthquake period.

Information on country and country-pair characteristics come from different sources. Bilateral distance in kilometers and an indicator variable that captures if two countries share a border are from the CEPII's GeoDist database (Mayer and Zignago, 2011). Country characteristics related to population and GDP per capita are from the World Bank World Developments Indicators (WDI). Countries' vulnerability to natural disasters is constructed based on the World Risk Index (Bündnis Entwicklung Hilft, 2011) and it is defined equal to one if the index is greater than 63.3 (i.e., very high risk). The real exchange rate is constructed based on data from the Penn World Tables version 9.1 (Feenstra et al., 2015).[16] We use trade data from WITS to construct an indicator variable equal to one if the exporter was among the top 4 suppliers of importer i in HS 6-digit product k in the pre-shock period and to compute exporter's revealed comparative advantage (RCA) index. Data on Free Trade Areas (FTA) are from Mario Larch's Regional Trade Agreements Database from Egger and Larch (2008). Finally, we use World Bank's regional classification to construct an indicator variable equal to one if two countries are located in the same region.[17] To reduce potential endogeneity concerns, we use averages based on the pre-shock period for all the time varying variables, except for the real exchange rate which is lagged.

Table 4: Country-specific fundamentals

	(1)	(2)	(3)	(4)	(5)	(6)
	All		Auto		Electronics	
	Auto	Electronics	Intermediate	Final	Intermediate	Final
	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports
(Dummy share 2004-2010 > 10)	0.188***	0.103***	0.135***	0.119	0.197***	0.079***
	(0.033)	(0.010)	(0.038)	(0.074)	(0.019)	(0.012)
(Dummy share) * …						
… (log GDP pc pre)	-0.061***	-0.063***	-0.065***	-0.007	-0.069***	-0.060***
	(0.015)	(0.006)	(0.016)	(0.029)	(0.011)	(0.007)
… (log of pop. Pre)	0.019**	0.019***	0.030***	0.006	0.018***	0.017***
	(0.009)	(0.004)	(0.010)	(0.021)	(0.007)	(0.004)

[16] We follow Rodrik (2008) and define the log of the real effective rate as $\ln(RER_{it}) = \ln(XRAT_{it}/PPP_{it})$. Data on exchange rates ($XRAT$) and power parity conversion factors (PPP) come from the Penn World Tables.

[17] We modify World Bank's regional classification and classify Mexico as part of North America.

	(1)	(2)	(3)	(4)	(5)	(6)
… (log of distance)	0.036*	0.049***	0.032	-0.024	0.046***	0.053***
	(0.020)	(0.008)	(0.021)	(0.049)	(0.014)	(0.009)
Observations	449,922	3,275,053	333,842	116,066	952,400	2,322,653
R-squared	0.865	0.821	0.872	0.821	0.831	0.817

Note: Robust standard errors clustered at the cluster exporter-importer-product level are in parentheses. All specifications include importer-exporter-product, importer-year, and exporter-year fixed effects. The samples include the top 15 producers of automobile or top 15 exporters of final electronics other than Japan.
*** p<0.01, ** p<0.05, * p<0.1

Table 4 presents the estimates of Equation (4) focusing on fundamentals: distance, size and level of development. The negative and significant effect on GDP per capita indicates that in the years following the shock, developing countries were more likely to be the new destinations for imports of auto and electronics. For instance, results in columns 1 and 2 suggest that an increase in GDP per capita from the level of the median upper-middle income to the median high income country decreases exports by around 10 percent.[18] Similarly, imports tended to relocate to larger countries, especially for auto parts (column 3) and electronics (columns 5 and 6), perhaps to take advantage of economies of scale. The results do not indicate that closer countries benefited from the relocation. For electronics, imports tended to relocate to more distant suppliers reflecting relatively low trade and transport costs.

Table 5: Other country-specific characteristics

	(1)	(2)	(3)	(4)	(5)	(6)
	All		Auto		Electronics	
	Auto	Electronics	Intermediate	Final	Intermediate	Final
	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports
(Dummy share 2004-2010 > 10)	0.177***	0.098***	0.123***	0.087	0.197***	0.073***
	(0.035)	(0.011)	(0.040)	(0.080)	(0.021)	(0.012)
(Dummy share) * …						
… (log GDP pc pre)	-0.024	-0.051***	-0.037*	-0.004	-0.061***	-0.047***
	(0.018)	(0.008)	(0.021)	(0.038)	(0.014)	(0.009)
… (log of pop. Pre)	0.050***	0.026***	0.060***	0.010	0.029***	0.024***
	(0.011)	(0.005)	(0.012)	(0.026)	(0.009)	(0.005)
… (log of distance)	-0.061**	0.025**	-0.052*	-0.041	0.020	0.029**
	(0.026)	(0.012)	(0.029)	(0.060)	(0.022)	(0.014)
… I(Contiguity)	0.082	0.053	-0.003	0.456**	0.106	0.020
	(0.095)	(0.036)	(0.100)	(0.215)	(0.073)	(0.042)
… I(Same Region)	-0.318***	0.008	-0.196**	-0.071	-0.005	-0.003
	(0.076)	(0.031)	(0.085)	(0.167)	(0.058)	(0.036)
… I(High Vulnerability to Natural Disasters)	0.026	0.043	0.011	0.096	0.054	0.025
	(0.061)	(0.027)	(0.072)	(0.110)	(0.052)	(0.031)
… I(Top 4 supplier pre)	-0.911***	-0.440***	-0.950***	-0.811***	-0.398***	-0.465***
	(0.097)	(0.033)	(0.105)	(0.206)	(0.059)	(0.039)
… (RCA pre)	0.250***	-0.066***	0.303***	0.158*	-0.139***	-0.036

[18] In 2010, the median GDP per capita for upper-middle income economies was USD 5,789 versus USD 33,700 for high income countries.

	(0.055)	(0.020)	(0.067)	(0.095)	(0.040)	(0.023)
… FTA	0.070	0.045*	-0.043	0.171	0.049	0.056*
	(0.066)	(0.025)	(0.079)	(0.116)	(0.045)	(0.030)
… lag(ln RER t-(t-1))	0.166***	0.119***	0.199***	0.029	0.111***	0.123***
	(0.051)	(0.022)	(0.057)	(0.115)	(0.042)	(0.026)
Observations	424,452	3,086,669	314,506	109,944	901,307	2,185,362
R-squared	0.864	0.821	0.873	0.821	0.830	0.818

Note: Robust standard errors clustered at the cluster exporter-importer-product level are in parentheses. All specifications include importer-exporter-product, importer-year, and exporter-year fixed effects. The samples include the top 15 producers of automobile or top 15 exporters of final electronics other than Japan.
*** p<0.01, ** p<0.05, * p<0.1

Table 5 explores the effect of additional country characteristics on exports. There is no evidence that firms shun countries at a higher risk of natural disasters. Production did not relocate to previous top exporters. Contiguity to the export market appears to be a very important determinant of final auto exports (column 4), which may be due to the high transport costs of final autos. For auto parts and electronics, there is however no evidence that supply chains were increasingly regionalized. The presence of a Free Trade Area (FTA) appears to matter for final electronics. As tariffs tend to be higher on final than on intermediate imports, firms might seek to relocate final production in FTA members because of tariff escalation. A depreciating exchange rate in the preceding period may have also served to attract production in electronics and auto parts. While auto production relocated to countries with a revealed comparative advantage in the years preceding the shock, this was not the case for electronics. It is possible that these countries had a latent comparative advantage in electronics, but the presence of fixed costs of building a factory created inertia that prevented production relocation (Section 2). The earthquake, with its physical destruction and the need to rebuild, thus allowed these countries' comparative advantage to emerge.

5. Conclusion

This paper investigates the long-term consequences of natural disasters on the reconfiguration of global value chains. Focusing on the 2011 earthquake off the Pacific coast of Tōhoku in Japan, the largest ever recorded, we study how the shock affected trade in automobiles and electronics –two sectors that rely heavily on Japanese suppliers.

We find that countries more dependent on Japanese suppliers before the shock experienced larger declines in imports from Japan. But the decrease for intermediate auto and electronics was less

pronounced than for final products. We find no evidence that firms re-shored or nearshored production and increased import diversification to mitigate risk. They also did not switch to other top suppliers. Rather firms replaced suppliers from Japan with suppliers from developing countries and larger countries where scale economies could be realized. We also find that in the years following the shock, production relocation decisions were largely driven by fundamentals rather than policy.

While COVID-19 is a global shock unlike any other in recent times,[19] the evidence on the long-term consequences of the 2011 earthquake may help understand if and how firms may reset their supply chains after a large shock. Our results—in line with intuition by Antràs (2021) and Baldwin (2020)—suggest that the reshaping of GVCs in the post-COVID-19 world may be less pronounced than expected by many observers. A major difference between the current shock and the one studied here is that physical capital has not been destroyed. Capital in place coupled with established relationships will tend to reduce the extent of reconfiguration as compared to the Japan shock. Some producers dependent on risky suppliers may reassess their location decisions in the aftermath of the pandemic--but this is likely to be gradual, given capital in place. Sectors and stages of production where search frictions are lower may continue to relocate where economic fundamentals are more attractive, creating opportunities for developing countries. But broader trends towards reshoring, nearshoring or diversification are unlikely to result from firms' decisions to reconsider the balance between efficiency and resilience in light of COVID-19, unless supported by pronounced government intervention.

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[19] See Espitia et al. (2021) for an analysis of the trade impact of COVID-19 during the first six months of the pandemic.

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Annex A: Additional figures and tables

Figure A1:Relationship stickiness
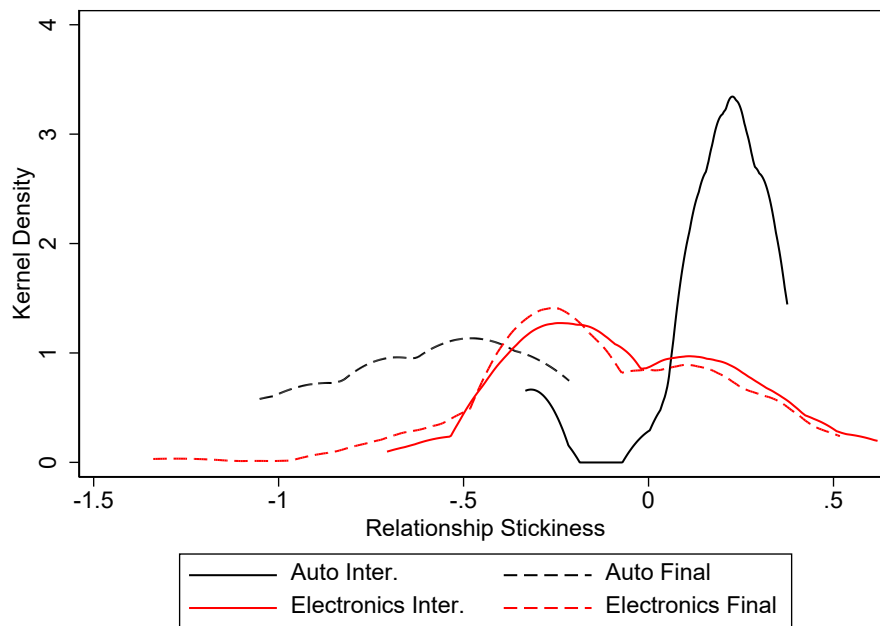
Source: Martin et al. (2021).

Table A1: Top 15 producers (2010), final exporters (2004-2010), and intermediate importers (2004-2010) of auto and electronics

	Auto			Electronics	
Rank	Production	Final Exports	Intermediate Imports	Final Exports	Intermediate Imports
1	China	Germany	United States	China	China
2	United States	United States	Germany	United States	Hong Kong
3	Germany	United Kingdom	France	Germany	United States
4	South Korea	France	Canada	Netherlands	Singapore
5	Brazil	Canada	Spain	United Kingdom	Germany
6	India	Spain	United Kingdom	Hong Kong	South Korea
7	Spain	Italy	Mexico	South Korea	Malaysia
8	Mexico	Belgium	China	France	Netherlands
9	France	South Korea	Italy	Mexico	United Kingdom
10	Canada	Mexico	Belgium	Canada	Mexico
11	Thailand	Netherlands	South Korea	Malaysia	Philippines
12	Iran	China	Poland	Singapore	France
13	Russia	Russia	Czech Republic	Italy	Thailand
14	United Kingdom	Australia	Sweden	Switzerland	Canada
15	Turkey	Sweden	Austria	Thailand	Italy

Table A2: Robustness Alternative Selection Methods, Imports from Japan

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Panel A: Auto (Selection intermediate imports)	Auto				Intermediate auto				Final auto			
	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports
(Dummy share 2004-2010 > 15)	-0.529***			-0.041	-0.369*			0.030	-0.827**			-0.211
	(0.174)			(0.223)	(0.193)			(0.283)	(0.383)			(0.444)
(Dummy share 2004-2010 > 10)		-0.645***		-0.394**		-0.534***		-0.434		-0.857***		-0.367
		(0.143)		(0.196)		(0.165)		(0.280)		(0.295)		(0.335)
(Dummy share 2004-2010 > 5)			-0.520***	-0.359***			-0.380***	-0.277*			-0.825***	-0.608**
			(0.116)	(0.124)			(0.144)	(0.157)			(0.259)	(0.258)
Observations	5,538	5,538	5,538	5,538	3,825	3,825	3,825	3,825	1,713	1,713	1,713	1,713
R-squared	0.924	0.924	0.925	0.925	0.933	0.933	0.933	0.934	0.912	0.913	0.914	0.914
Treated	40	60	125	125	26	36	72	72	14	24	53	53
Total country-products	405	405	405	405	285	285	285	285	120	120	120	120
Panel B: Auto (Selection final exports)	Auto				Intermediate auto				Final auto			
	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports
(Dummy share 2004-2010 > 15)	-0.763***			-0.289	-0.586***			-0.239	-1.024**			-0.166
	(0.177)			(0.212)	(0.188)			(0.219)	(0.396)			(0.488)
(Dummy share 2004-2010 > 10)		-0.824***		-0.469**		-0.653***		-0.460**		-1.090***		-0.527
		(0.150)		(0.188)		(0.159)		(0.190)		(0.315)		(0.387)
(Dummy share 2004-2010 > 5)			-0.586***	-0.294**			-0.319**	-0.098			-1.081***	-0.763**
			(0.128)	(0.127)			(0.156)	(0.153)			(0.292)	(0.299)
Observations	5,573	5,573	5,573	5,573	3,863	3,863	3,863	3,863	1,710	1,710	1,710	1,710
R-squared	0.913	0.913	0.913	0.914	0.931	0.931	0.930	0.931	0.897	0.899	0.899	0.900
Treated	65	93	158	158	38	57	98	98	27	36	60	60
Total country-products	405	405	405	405	285	285	285	285	120	120	120	120

Panel C: Electronics (Selection intermediate imports)

	Electronics				Intermediate electronics				Final electronics			
	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports	log of imports
(Dummy share 2004-2010 > 15)	-0.413***			-0.127*	-0.238**			-0.113	-0.491***			-0.139*
	(0.058)			(0.068)	(0.104)			(0.127)	(0.069)			(0.079)
(Dummy share 2004-2010 > 10)		-0.500***		-0.241***		-0.262***		-0.062		-0.598***		-0.308***
		(0.051)		(0.065)		(0.093)		(0.119)		(0.061)		(0.077)
(Dummy share 2004-2010 > 5)			-0.536***	-0.394***			-0.380***	-0.326***			-0.598***	-0.420***
			(0.050)	(0.054)			(0.099)	(0.104)			(0.058)	(0.063)
Observations	49,933	49,933	49,933	49,933	13,836	13,836	13,836	13,836	36,097	36,097	36,097	36,097
R-squared	0.910	0.910	0.910	0.911	0.922	0.922	0.922	0.922	0.903	0.903	0.903	0.904
Treated	789	1158	1838	1838	241	358	583	583	548	800	1255	1255
Total country-products	3970	3970	3970	3970	1033	1033	1033	1033	2937	2937	2937	2937

Note: Robust standard errors clustered at the cluster importer-product level are in parentheses. All specifications include importer-year, importer-product, and product-year fixed effects. The samples include the top 15 producers of automobile or top 15 exporters of final electronics other than Japan.

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table A3: Diversification Herfindahl–Hirschman Index (HHI) with Japan

Panel A: All	(1)	(2)	(3)		(4)	(5)		(6)
	Auto				Electronics			
	HHI	HHI	HHI	HHI	HHI	HHI	HHI	HHI
(Dummy share 2004-2010 > 15)	-0.007			-0.021	0.017***			0.013**
	(0.013)			(0.019)	(0.005)			(0.006)
(Dummy share 2004-2010 > 10)		0.005		0.022		0.013***		-0.000
		(0.013)		(0.020)		(0.005)		(0.006)
(Dummy share 2004-2010 > 5)			-0.001	-0.006			0.015***	0.012**
			(0.014)	(0.015)			(0.005)	(0.005)
Observations	5,562	5,562	5,562	5,562	52,584	52,584	52,584	52,584
R-squared	0.847	0.847	0.847	0.847	0.799	0.799	0.799	0.799

Panel B: Auto	Intermediate auto				Final auto			
	HHI	HHI	HHI	HHI	HHI	HHI	HHI	HHI
(Dummy share 2004-2010 > 15)	0.000			-0.019	0.003			-0.073
	(0.015)			(0.022)	(0.031)			(0.046)
(Dummy share 2004-2010 > 10)		0.019		0.035		0.014		0.031
		(0.016)		(0.022)		(0.026)		(0.043)
(Dummy share 2004-2010 > 5)			-0.001	-0.012			0.036	0.039
			(0.017)	(0.017)			(0.025)	(0.033)
Observations	3,818	3,818	3,818	3,818	1,744	1,744	1,744	1,744
R-squared	0.899	0.900	0.899	0.900	0.783	0.783	0.783	0.773

Panel C: Electronics	Intermediate electronics				Final electronics			
	HHI	HHI	HHI	HHI	HHI	HHI	HHI	HHI
(Dummy share 2004-2010 > 15)	0.025**			0.016	0.014**			0.013*
	(0.010)			(0.012)	(0.006)			(0.007)
(Dummy share 2004-2010 > 10)		0.022**		0.011		0.009*		-0.006
		(0.009)		(0.012)		(0.005)		(0.007)
(Dummy share 2004-2010 > 5)			0.012	0.003			0.016***	0.016***
			(0.010)	(0.010)			(0.005)	(0.005)
Observations	14,320	14,320	14,320	14,320	38,264	38,264	38,264	38,264
R-squared	0.791	0.791	0.790	0.791	0.804	0.804	0.804	0.804

Note: Robust standard errors clustered at the cluster importer-product level are in parentheses. All specifications include importer-year, importer-product, and product-year fixed effects. The samples include the top 15 producers of automobile or top 15 exporters of final electronics other than Japan.
*** $p<0.01$, ** $p<0.05$, * $p<0.1$