Examining the Impact of the 2011 Japanese Earthquake on Japanese Production Networks in the Republic of Korea: A Firm-level Data Analysis

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Abstract: *This paper examines the impact of the 2011 Japanese earthquake on the sales and purchases of firms that have an intra-firm network with Japan. Using unique firm-level data of the Republic of Korea (henceforth, Korea) and applying a difference-in-differences model, we find two results. First, following the 2011 Japanese earthquake, Japanese subsidiaries in Korea switched their intra-firm sales patterns with a reduction in intra-firm export and an increase in intra-firm domestic sales, compared to non-Japan foreign subsidiaries in Korea. Second, however, the sales or purchases of Korean mother firms with subsidiaries in Japan were negatively affected, compared to either non-foreign direct investment (FDI) firms or FDI firms without subsidiaries in Japan. The results imply that the Japanese subsidiaries in Korea had a relatively resilient and flexible intra-firm network, whilst the Korean firms with subsidiaries in Japan did not.*

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1. Introduction

The Covid-19 pandemic has taught us an invaluable lesson: global supply chains are fragile and vulnerable to unexpected shocks originating from any country in the world economy. Consequently, understanding the existing structure of global supply chains, their resilience, and the potential consequences of sudden disruptions has become a paramount objective for numerous countries worldwide. In this regard, this study aims to enhance overall understanding by conducting a specific case study of the aftermath of the devastating 2011 Tohoku earthquake in Japan.

The earthquake that struck Japan in 2011 left a lasting impact on the economy, causing significant disruptions to both domestic and global supply chains. Given this, we will examine how Japanese firms responded to this unforeseen and tragic event. Specifically, this project seeks to explore the extent to which these shocks influenced their subsidiaries located in the Republic of Korea (hereafter, Korea), which serves as the closest link in Japan's global supply chains. By doing so, we can emphasise the significant role that Korea plays in Japan's global supply chains, and understanding these relationships will contribute to strengthening the supply chain and enhancing crisis response capabilities.

Our study is based on two strands of studies. First, it is associated with the literature on how multinational firms manage their manufacturing plants, both domestically and internationally. Boehm et al. (2019) find a positive correlation between the outputs of multinational firms and their foreign subsidiaries. Similarly, Cravino and Levchenko (2017) demonstrate a positive association between domestic and foreign sales for both domestic parent firms and foreign subsidiaries. These studies imply that the larger the global production network within a multinational firm, the more severe the propagation of an external shock within the network. However, some economists have argued that a more thorough investigation is needed (Chun et al., 2017; Ramondo et al., 2016). Specifically speaking, they found weak evidence of intra-firm trade, even between a domestic parent firm and its foreign subsidiaries. Therefore, our project aims to contribute to this literature by examining whether an external shock could spill over through the ownership structure of multinational firms.

Second, this project is in line with the literature on the international propagation of natural disasters. MacKenzie et al. (2012) examined the world input-output table and found a significant reduction in output for some countries due to the decrease in Japanese input production caused by the 2011 Japanese earthquake. Carvalho (2014) emphasised the importance of production network characteristics in understanding how external shocks

spread throughout the economy via a network. He argued that the impact of a shock depends on the elasticity of substitution between inputs within a production network. Furthermore, Barrot and Sauvagnat (2016) theoretically demonstrated that the spillover impact of a shock can be amplified when there is high complementarity between inputs within a production network.

Our project focuses on a semi-natural experimental case, the 2011 Japanese earthquake, and examines how such an unforeseen natural disaster disrupted the production network of Japanese firms established in Korea. Specifically, in this project, we are investigating the following questions:

(1) How did the sales network of Japanese subsidiaries in Korea change as a result of the 2011 Japanese earthquake?

(2) What changes occurred in the input purchase network of Japanese subsidiaries in Korea due to the 2011 Japanese earthquake?

In fact, we can observe preliminary evidence that the Japanese subsidiaries in Korea were affected by the 2011 Japanese earthquake. Following the 2011 disaster, Japanese subsidiaries in Korea switched their sales and purchases towards domestic (i.e. Korean) markets and away from foreign markets. Similar behaviour can be found for their intra-network sales and purchases, where intra-network is defined as a Japanese subsidiary's internal network with its own subsidiaries in Korea and the world and its own mother firm in Japan.
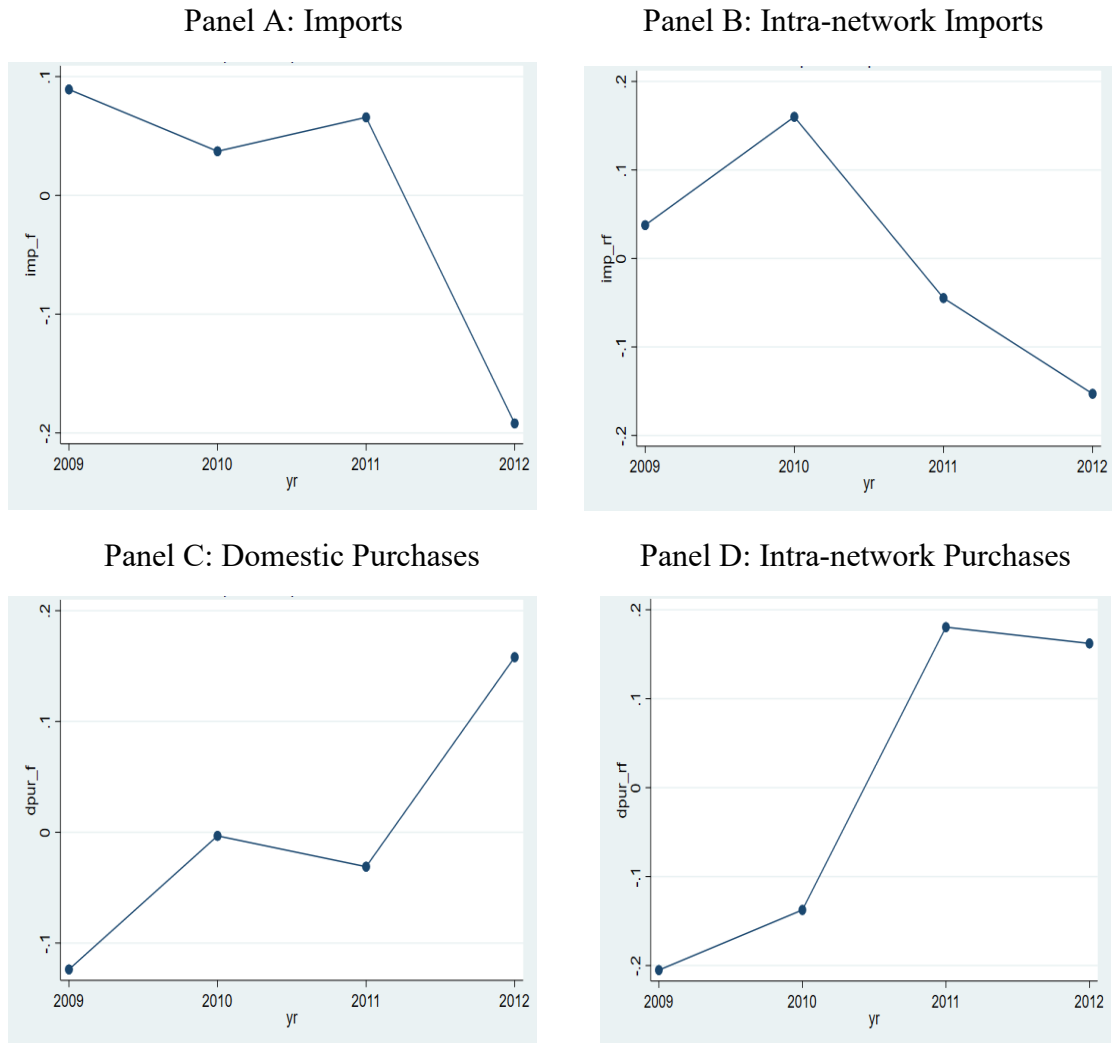
Figure 1: Exports and Domestic Sales of Japanese Subsidiaries in Korea
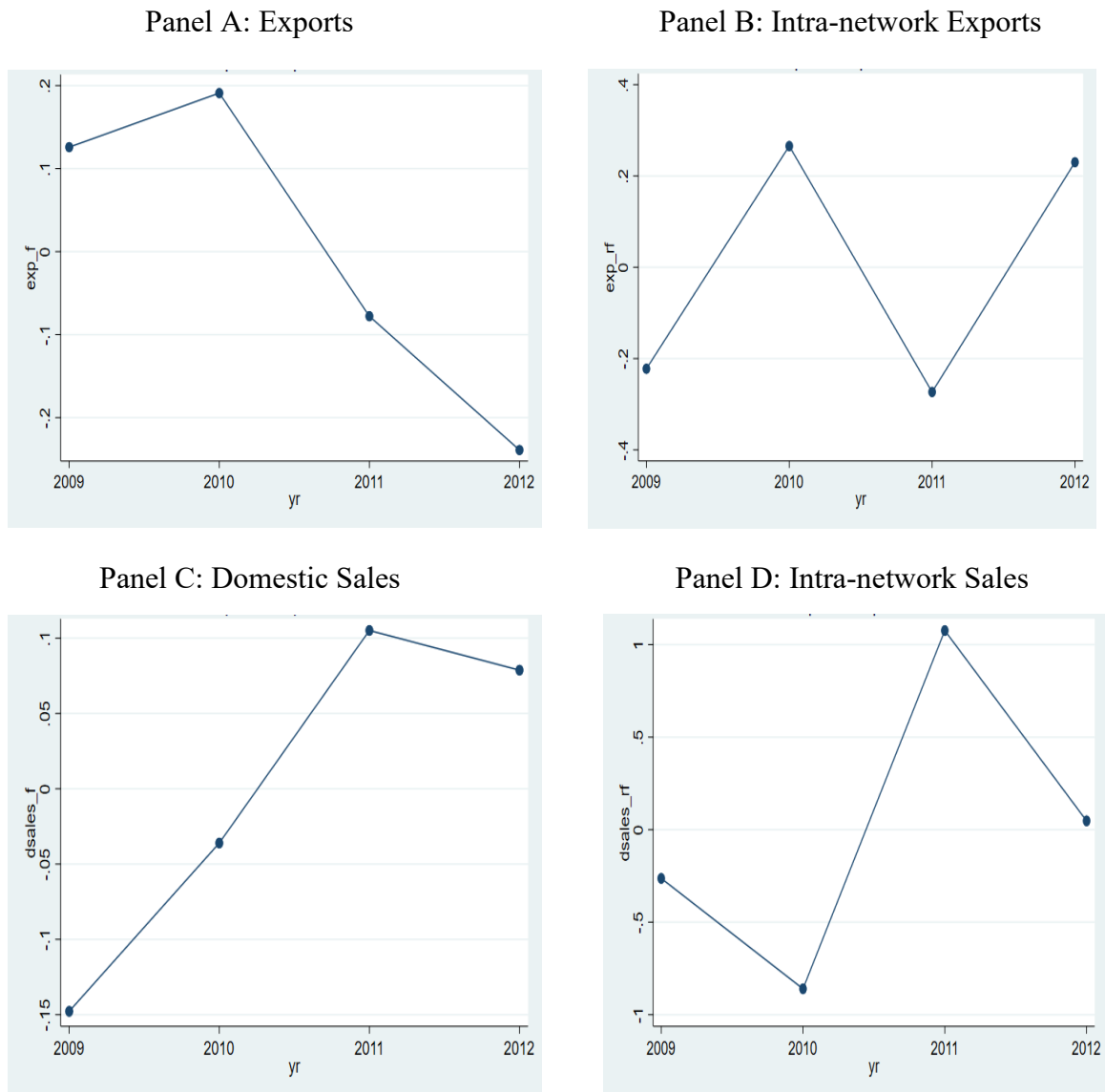
Panel A: Exports

Panel B: Intra-network Exports

Panel C: Domestic Sales

Panel D: Intra-network Sales

Source: Authors, using data from the Survey of Business Activity, Statistics Korea.

Panels A and C in Figure 1 show the trend of total exports and domestic sales of Japanese subsidiaries in Korea from 2009 to 2012. As shown, exports decreased whilst domestic sales within Korea increased. Panels B and D reveal a weak but similar fact that the intra-network exports of Japanese subsidiaries in Korea dropped in 2011, whilst intra-network domestic sales increased in 2011. Overall, the sales pattern of Japanese subsidiaries in Korea seems to have been contemporaneously reversed by the shock of the 2011 Japanese earthquake by focusing on more domestic market sales within Korea.

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Figure 2: Input Imports and Domestic Input Purchases of Japanese Subsidiaries in Korea

Panel A: Imports

Panel B: Intra-network Imports

Panel C: Domestic Purchases

Panel D: Intra-network Purchases

Source: Authors, using data from the Survey of Business Activity, Statistics Korea.

Panels A and C in Figure 2 demonstrate the annual total imports and domestic purchases of Japanese subsidiaries in Korea from 2009 to 2012. Just like exports and domestic sales, we can observe a downward trend of total imports and an upward trend of domestic purchases within the Korean market. Panels B and D illustrate similar patterns: a decreasing trend of intra-network imports and an increasing trend of the intra-network domestic purchases of Japanese subsidiaries in Korea. Overall, the input purchase pattern of Japanese subsidiaries in Korea seems to have switched from the foreign market to domestic markets.

Now, we are going to empirically investigate the impact of the 2011 Japanese earthquake on the sales and purchase patterns in Korea.

2.   Data and Empirical Analysis

2.1.   Data source

The main firm-level database we will utilise is the Survey of Business Activities (SBA), which is provided by Statistics Korea, the official government authority for national statistics in Korea.

The SBA contains comprehensive firm-specific variables as outlined in the methodology section, covering the period from 2006 to 2020. Importantly, the SBA is a unique firm-level survey dataset in Korea that provides information on Korean firms' ownership and transaction relationships with their parent firms and subsidiaries both domestically and abroad. This information is accessible only in person at the Research Data Center of Statistics Korea after an application process for the use of the data.

2.2.   Industry distribution of Japanese subsidiaries in Korea

Given our focus on intra-firm trade for multinational firms, our analysis will concentrate on manufacturing firms within the SBA. Here, we will summarise the characteristics of the industry distribution of the Japanese subsidiaries located in Korea for the year 2009, which is the starting year of our sample period that we examine for the 2011 Japanese earthquake.

Table 1: Industry Distribution of Japanese Subsidiaries in Korea (2009)

IND	No.	Share
10	1	0.9%
11	1	0.9%
14	2	1.8%
17	1	0.9%
19	1	0.9%
20	16	14.4%
21	2	1.8%
22	8	7.2%
23	7	6.3%
24	2	1.8%
25	6	5.4%
26	13	11.7%
27	5	4.5%
28	8	7.2%
29	17	15.3%
30	20	18.0%
33	1	0.9%
Total	111	100%

Note: IND refers to the Korean Standard Industry Classification (KSIC), and the numbers indicate 24 different manufacturing industries, which are summarised in the Appendix.
Source: Survey of Business Activities (SBA), Statistics Korea.

According to the 2009 SBA, the total number of Japanese subsidiaries is 111, as shown in Table 1. The Japanese subsidiaries are concentrated in the Chemicals (16), Electronics (13), Other Machinery (17), and Motor Vehicles (20) industries. These are 60% of the total number. The industry distribution of sales and purchases is slightly different.

Table 2: Industry Distribution of Sales and Purchases of Japanese Subsidiaries in Korea (2009)

IND	Imp	Imp_r	Exp	Exp_r	Dpur	Dpur_r	Dsales	Dsales_r
10	0.2%	0.0%	0.6%	0.0%	0.6%	0.1%	0.4%	0.0%
11	0.1%	0.1%	0.0%	0.0%	0.8%	0.1%	1.4%	0.0%
14	0.1%	0.1%	0.0%	0.0%	0.4%	0.1%	2.1%	0.1%
17	0.1%	0.1%	0.3%	0.0%	0.3%	0.1%	0.5%	0.0%
19	0.0%	0.0%	0.1%	0.0%	1.0%	0.0%	1.6%	9.3%
20	19.4%	11.5%	16.5%	11.7%	22.8%	11.9%	24.5%	1.4%
21	0.2%	0.4%	0.4%	1.8%	0.5%	0.4%	1.2%	0.0%
22	9.3%	17.2%	9.0%	2.5%	11.7%	16.6%	14.1%	1.1%
23	21.5%	39.4%	4.6%	6.3%	15.3%	37.9%	19.2%	65.2%
24	0.0%	0.0%	0.1%	0.0%	0.2%	0.0%	0.5%	0.0%
25	0.6%	0.5%	0.7%	1.0%	0.9%	0.5%	1.4%	0.0%
26	35.3%	12.6%	53.1%	33.5%	25.9%	12.1%	5.8%	2.4%
27	0.4%	0.5%	0.7%	3.4%	0.9%	2.0%	1.4%	0.4%
28	2.9%	4.9%	1.2%	2.0%	3.7%	5.2%	6.3%	8.1%
29	4.1%	6.6%	3.7%	6.6%	4.5%	7.0%	7.2%	10.5%
30	5.1%	5.2%	9.0%	31.3%	9.9%	5.2%	11.5%	1.4%
33	0.7%	0.6%	0.1%	0.0%	0.6%	0.6%	1.0%	0.0%

Notes: IND refers to the Korean Standard Industry Classification (KSIC), and the numbers indicate 24 different manufacturing industries, which are summarised in the Appendix. Imp = imports, Imp_r = imports from related firms, Exp = exports, Exp_r = exports to related firms, Dpur = domestic purchases, Dpur = domestic purchases from related firms, Dsales = domestic sales, Dsales_r = domestic sales to related firms. Related firms are defined as subsidiaries (and/or a mother firm) of Japanese subsidiaries.
Source: Survey of Business Activities (SBA), Statistics Korea.

The largest share of exports of Japanese subsidiaries is found in Electronics (53.1%), followed by Chemicals (16.5%), Motor Vehicles (9.0%) and Rubber and Plastics (9.0%). However, their imports are slightly different – Electronics (35.3%), Non-metal Minerals (21.5%), Chemicals (19.4%), and Rubber and Plastics (9.3%). Since Korea is not endowed with many natural resources such as non-metal mineral products, Japanese firms tend to rely on importing them from other countries. This is clearer for their intra-firm trade. The shares of intra-firm exports of Japanese subsidiaries are found in Electronics (33.5%), Motor Vehicles (31.3%), and Chemicals (11.7%), in order, whilst their intra-imports are observed in Non-metal Minerals (39.4%), Rubber and Plastics (17.2%), Electronics (12.6%), and

Chemicals (11.5%). So, we can see that the reliance on their intra-firm supply chain for procuring natural resources is stronger than that on their inter-firm supply chain abroad.

The subsidiaries' domestic sales and purchase patterns are quite different from their international trade. The majority of domestic sales are found in Chemicals (24.5%), Non-metal Minerals (19.2%), Rubber and Plastics (14.1%), and Motor Vehicles (11.5%), whilst domestic purchases are from Electronics (25.9%), Chemicals (22.8%), Non-metal Minerals (15.3%), and Rubber and Plastics (11.7%). As such, their domestic sales and purchases are mostly production materials and natural resources. Also, their intra-firm domestic sales and purchases are mostly in Non-metal Minerals. The largest share of domestic intra-firm sales is Non-metal Minerals (65.2%), followed by Other Machinery and Equipment (10.5%). The majority of the domestic intra-firm purchases are from Non-metal Minerals (35.3%), Rubber and Plastics (16.6%), Electronics (12.1%), and Chemicals (11.9%). Again, the dependence on the domestic intra-firm supply chain for natural resources and production materials is stronger than their dependence on domestic inter-firm supply chains.

2.3. Empirical model

Our main analysis strategy involves estimating a difference-in-differences (DID) model to examine the impact of the 2011 Japanese earthquake on the sales and purchases of Japanese subsidiaries located in Korea. To do this, we will begin by defining treated (T_{it}=1) and non-treated ($T_{it} = 0$) firm groups, and the event dummy of the 2011 Japanese earthquake (S_t) as follows.

$T_{it} = 1$ if firm i is a Japanese subsidiary located in Korea;

     $= 0$ if firm i is another foreign country's subsidiary located in Korea

$S_t = 1$ if the year is 2011 or 2012

     $= 0$ if the year is 2009 or 2010

With T_{it} and S_t, we propose the following DID regression model:

$$Y_{it} = \beta_0 + \beta_1 T_{it} + \beta_2 S_t + \beta_3 (T_{it} \times S_t) + \gamma_i + \theta_j + \varepsilon_{it}$$

Y_{it} represents the Japanese subsidiary-level sales and purchases variable as follows.

- Sales part: total sales (s), total sales to related firms (sr), exports (e), exports to related firms (er), domestic sales (ds), domestic sales to related firms (dsr).

- Purchase part: total purchases (p), total purchases from related firms (pr), imports (i), imports from related firms (ir), domestic purchases (dp), domestic purchases from related firms (dpr).

The relationship between those sales and purchases can be simply explained by the following equations.

- Total sales (s) = exports (e) + domestic sales (ds)
- Total sales to related firms (sr) = exports to related firms (er) + domestic sales to related firms (dsr)
- Total purchases (p) = imports (i) + domestic purchases (di)
- Total purchases to related firms (pr) = imports from related firms (ir) + domestic purchases to related firms (isr)

Also, γ_i and θ_j are the firm-specific dummy and 2-digit level manufacturing dummy, to control for unobserved firm and industry characteristics. The main estimator of interest is β_3, which represents the causal effect of the 2011 Japanese earthquake on the sales and purchase patterns of Japanese subsidiaries. The results are summarised in Tables 3 and 4.

Table 3: Sales of Japanese Subsidiaries in Korea

Dependent Variable	(1) Ln(s)	(2) Ln(sr)	(3) Ln(e)	(4) Ln(er)	(5) Ln(ds)	(6) Ln(dsr)
T_{it}	0.008	-0.147	0.357	-0.379	-0.415	1.159
	(0.073)	(0.813)	(0.603)	(0.732)	(0.375)	(0.755)
S_t	0.105***	-0.423	-0.345	-0.575**	0.212	0.339
	(0.019)	(0.287)	(0.233)	(0.276)	(0.139)	(0.237)
T_{it} x S_t	0.107	-0.182	-0.106	-1.544**	0.185	2.480***
	(0.073)	(0.714)	(0.572)	(0.680)	(0.378)	(0.749)
Industry Fixed Effects	YES	YES	YES	YES	YES	YES
Firm Fixed Effects	YES	YES	YES	YES	YES	YES
Observations	1,424	1,424	1,424	1,424	1,424	1,424
R-squared	0.059	0.008	0.010	0.033	0.016	0.034

Notes: Ln() refers to a logarithmic value. The variables in Ln() are as follows: total sales (s), total sales to related firms (sr), exports (e), exports to related firms (er), domestic sales (ds), domestic sales to related firms (dsr). All regressions are clustered at the firm level. The values in parentheses are the heteroscedasticity and multicollinearity robust standard errors. $T_{it} = 1$ if i is a Japanese subsidiary in Korea, and $T_{it} = 0$ if i is a non-Japanese foreign subsidiary in Korea. $S_t = 1$ if t is the year 2011 or 2012, and $S_t = 0$ if the year is 2009 or 2010.
Source: Authors' regression results using data from the Survey of Business Activities (SBA), Statistics Korea.

Table 4: Purchases of Japanese Subsidiaries in Korea

Dependent Variable	(1) Ln(p)	(2) Ln(pr)	(3) Ln(i)	(4) Ln(ir)	(5) Ln(dp)	(6) Ln(dpr)
T_{it}	0.278	0.603	-0.052	-0.427	0.386	0.971
	(0.682)	(0.910)	(1.021)	(0.816)	(0.608)	(0.782)
S_t	-0.154	-0.743**	-0.448	-0.780***	-0.280	-0.714***
	(0.186)	(0.292)	(0.281)	(0.278)	(0.182)	(0.259)
T_{it} x S_t	0.668	-0.312	-0.515	-1.790**	0.763	0.114
	(0.652)	(0.878)	(0.963)	(0.836)	(0.586)	(0.753)
Industry Fixed Effects	YES	YES	YES	YES	YES	YES
Firm Fixed Effects	YES	YES	YES	YES	YES	YES
Observations	1,424	1,424	1,424	1,424	1,424	1,424
R-squared	0.014	0.022	0.020	0.042	0.016	0.026

Notes: Ln() refers to a logarithmic value. The variables in Ln() are as follows: total purchases (p), total purchases from related firms (pr), imports (i), imports from related firms (ir), domestic purchases (dp), and domestic purchases from related firms (dpr). All regressions are clustered at the firm level. The values in parentheses are the heteroscedasticity and multicollinearity robust standard errors. T_{it} = 1 if i is a Japanese subsidiary in Korea, and T_{it} = 0 if i is a non-Japanese foreign subsidiary in Korea. S_t = 1 if t is the year 2011 or 2012, and S_t = 0 if   the year is 2009 or 2010.
Source: Authors' regression results using data from the Survey of Business Activities (SBA), Statistics Korea.

The estimates of interest are the interaction terms between T_{it} and S_t. The results in columns (1), (2), (3), and (5) in Table 3 and Table 4 show statistically insignificant estimates. This implies that the 2011 Japanese earthquake did not have a transmission effect to Japanese subsidiaries in Korea. From (1), they did not have reduced total sales or total input purchases. Also, from (2), they did not have reduced intra-firm total sales or input purchases. From (3), they did not have reduced total exports or imports. Lastly, from (5), they did not reduce their total domestic sales or domestic input purchases.

However, columns (4) and (6) of Table 3 show interesting results for the impact on the sales of Japanese subsidiaries in Korea. The estimated coefficient of the interaction term in (4), where the dependent variable is intra-firm exports, is significantly significant and negative (-1.544), whilst that in (6), where the dependent variable is domestic intra-firm sales, is significantly significant and positive (2.480). This implies that following the 2011 Japanese earthquake, the Japanese subsidiaries in Korea switched their intra-network sales from intra-firm exports towards domestic (i.e. in Korean markets) intra-firm sales.

However, columns (4) and (6) of Table 4 reveal different results. The coefficient of the interaction term in (4), where the dependent variable is intra-firm imports, is significantly negative (-1.790), whilst that in (6), when the dependent variable is domestic intra-firm purchases, is not statistically significant. Unlike the case of exports and sales, the 2011 disaster in Japan did not make the Japanese subsidiaries switch their intra-network purchases from intra-firm imports to domestic intra-firm purchases. They simply reduced their imports from their intra-firm network. Also, it is evident from column (5) that they suffered from a lack of domestic input outsourcing – the coefficient of the interaction terms in (5) is not statistically significant at all.

In sum, we find that the 2011 Japanese Earthquake influenced negatively only the intra-firm network of the Japanese subsidiaries located in Korea. First, the intra-firm sales connections shifted away from external firm-networks and increasingly focused on internal firm-networks. Second, intra-firm input procurement did not work well, i.e. there was a reduction in intra-firm imports with no domestic input outsourcing.

This result is different from the findings by Boehm et al. (2019), who found a drop in the US output of Japanese multinationals and a Leontief-like response for their imported and domestic inputs, i.e. a reduction in input purchases. First, unlike Boehm et al. (2019), we do not find any spillover or transmission effect of the 2011 Japanese earthquake to the Korean economy. That is, there was no drop in the total sales or total input purchases of the Japanese subsidiaries. Furthermore, we did not see a reduction in their total exports or total imports. Second, our empirical analysis further disaggregates the Japanese subsidiaries' sales and purchases to intra-firm network transactions. Interestingly, we find that the Japanese subsidiaries switched their intra-firm exports to domestic intra-firm sales, and as a result, their total intra-firm sales (intra-firm exports + domestic intra-firm sales) were not affected at all. Third, the fact that they reduced their intra-firm imports but did not increase domestic outsourcing (neither internally nor externally) implies a low elasticity of substitution between inputs within the production network.

2.4. Korean firms owning subsidiaries in Japan

If the 2011 Japanese Earthquake could affect Japanese subsidiaries in Korea, then it is also likely that Korean mother firms owning subsidiaries in Japan could be affected. To check this, we redefine the treated and non-treated firms as follows.

$$T_{it}^K = 1 \quad \text{if firm } i \text{ is a Korean mother firm located in Korea and owns}$$

subsidiaries located in Japan;

$$= 0 \quad \text{if firm } i \text{ is a Korean mother firm located in Korea and owns}$$

subsidiaries located in other foreign countries.

The total number of Korean firms with subsidiaries in Japan is 135, as shown in Table 5. The majority of these are in industries such as Electronics (38), Metal (15), Medical (15), and Other Machinery (10). Table 6 summarises the shares of sales and purchases of the Korean firms with subsidiaries in Japan across different manufacturing industries.

Table 5: Industry Distribution of Korean Mother Firms with Subsidiaries in Japan (2009)

IND	No.	Share
10	5	3.7%
11	3	2.2%
13	2	1.5%
14	2	1.5%
15	2	1.5%
19	1	0.7%
20	10	7.4%
21	1	0.7%
22	5	3.7%
23	2	1.5%
24	15	11.1%
25	7	5.2%
26	38	28.1%
27	15	11.1%
28	8	5.9%
29	13	9.6%
30	4	3.0%
32	1	0.7%
33	1	0.7%
Total	135	100%

Note: IND refers to the Korean Standard Industry Classification (KSIC), and the numbers indicate 24 different manufacturing industries, which are summarised in the Appendix.
Source: Survey of Business Activities (SBA), Statistics Korea.

Table 6: Industry Distribution of Sales and Purchases of Korean Mother Firms with Subsidiaries in Japan (2009)

IND	Imp	Imp_r	Exp	Exp_r	Dpur	Dpur_r	Dsales	Dsales_r
10	1.8%	0.2%	0.3%	0.1%	2.2%	2.3%	6.1%	0.6%
11	0.0%	0.0%	0.0%	0.0%	0.2%	0.1%	1.0%	0.0%
13	0.7%	1.2%	2.4%	1.5%	1.6%	1.4%	2.4%	0.2%
14	0.1%	0.0%	0.0%	0.0%	0.1%	0.0%	0.4%	0.0%
15	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
19	0.0%	0.0%	0.2%	0.0%	0.2%	0.1%	0.1%	0.4%
20	0.4%	0.3%	0.2%	0.2%	0.7%	0.3%	2.3%	0.1%
21	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.5%	0.0%
22	1.4%	2.4%	1.1%	2.4%	3.0%	1.2%	2.9%	0.0%
23	0.1%	0.1%	0.0%	0.0%	0.1%	0.0%	0.3%	0.1%
24	24.2%	12.7%	9.6%	0.8%	13.8%	10.2%	28.3%	8.2%
25	0.5%	0.5%	0.3%	0.2%	0.4%	0.3%	0.5%	0.0%
26	25.8%	9.8%	29.0%	12.8%	22.7%	23.8%	12.2%	61.8%
27	0.1%	0.1%	0.2%	0.1%	0.1%	0.1%	0.3%	0.0%
28	42.5%	72.4%	40.9%	61.1%	33.1%	53.0%	17.9%	3.6%
29	1.8%	0.2%	1.0%	1.4%	1.7%	0.1%	1.8%	0.3%
30	0.3%	0.0%	14.6%	19.3%	19.8%	6.9%	22.8%	24.6%
32	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
33	0.1%	0.1%	0.0%	0.0%	0.0%	0.1%	0.1%	0.0%

Notes: IND refers to the Korean Standard Industry Classification (KSIC), and the numbers indicate 24 different manufacturing industries, which are summarised in the Appendix. Imp = imports, Imp_r = imports from related firms, Exp = exports, Exp_r = exports to related firms, Dpur = domestic purchases, Dpur = domestic purchases from related firms, Dsales = domestic sales, and Dsales_r = domestic sales to related firms. Related firms are defined as subsidiaries (and/or a mother firm) of Japanese subsidiaries.

Source: Survey of Business Activities (SBA), Statistics Korea.

According to Table 6, the largest share of exports of the Korean firms is found in Electric (40.9%), followed by Electronics (29.0%) and Motor Vehicles (14.6%), whilst the majority of imports are found in Electric (42.5%), Metal (24.2%), and Electronics (25.8%). Their trades are highly concentrated in these few industries, comprising 84.5% of total exports and 92.5% of total imports of the Korean firms with subsidiaries in Japan. The intra-firm trade (both

export and imports) of the firms shows similar industrial concentration but is more skewed towards Electric. The largest share of intra-firm exports of the Korean firms amongst different industries is 61.1% in Electrical, and that of intra-firm imports is 72.4%.

The industry distribution of the firms' domestic sales and purchases is noteworthy. The largest industry share of domestic sales of the Korean firms with subsidiaries in Japan is for Metals at 28.3%, followed by Motor Vehicles (22.8%), Electric (17.9%), and Electronic (12.2%). The major shares of domestic purchases of the firms are in Electric (33.1%), Electronic (22.7%), Motor Vehicles (19.8%), and Metal (13.8%). Compared to their exports and imports, their domestic sales and purchases are relatively evenly distributed. The domestic intra-firm sales are highly concentrated in Electronic (61.8%) and Motor Vehicles (24.6%). The domestic intra-firm purchases are also highly concentrated in Electric (53.0%), Electronic (23.8%), and Metal (10.2%).

Whilst the sales and purchases of the Japanese subsidiaries in Korea are concentrated heavily in resources and materials-related upstream industries, such as Chemicals, Non-Metal Minerals, and Rubber and Plastics, the sales of purchases of the Korean firms with subsidiaries in Japan are highly agglomerated in final goods-related downstream industries, such as Electric, Electronic, Motor Vehicles.

Now, we attempt to check whether the shock transmission effect exists for the Korean mother firms with subsidiaries in Japan following the 2011 Japanese Earthquake, using the same empirical DID model. The results are summarised in Tables 7 and 8.

Table 7: Sales of Korean Firms with Subsidiaries in Japan

Dependent Variable	(1) Ln(s)	(2) Ln(sr)	(3) Ln(e)	(4) Ln(er)	(5) Ln(ds)	(6) Ln(dsr)
T_{it}^{K}	0.054***	-0.625***	-0.273***	-0.643***	0.158***	0.021
	(0.010)	(0.094)	(0.086)	(0.097)	(0.044)	(0.100)
S_t	0.007	0.620	-0.739	-0.379	0.298	0.939
	(0.042)	(0.563)	(0.453)	(0.602)	(0.218)	(0.632)
T_{it}^{K} x S_t	0.010	-0.111	-1.046**	-0.951	0.083	0.516
	(0.040)	(0.540)	(0.476)	(0.614)	(0.207)	(0.641)
Industry Fixed Effects	YES	YES	YES	YES	YES	YES
Firm Fixed Effects	YES	YES	YES	YES	YES	YES
Observations	6,880	6,880	6,880	6,880	6,880	6,880
R-squared	0.021	0.015	0.008	0.015	0.014	0.006

Notes: Ln() refers to a logarithmic value. The variables in Ln() are as follows: total sales (s), total sales to related firms (sr), exports (e), exports to related firms (er), domestic sales (ds), and domestic sales to related firms (dsr). All regressions are clustered at the firm level. The values in parentheses are the heteroscedasticity and multicollinearity robust standard errors. T_{it}^{K} = 1 if i is a Korean firm with subsidiaries in Japan, and T_{it}^{K} = 0 if i is a Korean firm without foreign subsidiaries. S_t = 1 if t is the year 2011 or 2012, and S_t = 0 if the year is 2009 or 2010.
Source: Authors' regression results using data from the Survey of Business Activities (SBA), Statistics Korea.

Table 8: Purchases of Korean Firms with Subsidiaries in Japan

Dependent Variable	(1) Ln(p)	(2) Ln(pr)	(3) Ln(i)	(4) Ln(ir)	(5) Ln(dp)	(6) Ln(dpr)
T_{it}^K	-0.048	-0.409***	-0.398***	-0.582***	-0.114	-0.363***
	(0.070)	(0.094)	(0.101)	(0.082)	(0.071)	(0.089)
S_t	-0.340	0.325	-0.462	-0.307	-0.323	0.393
	(0.315)	(0.642)	(0.538)	(0.515)	(0.339)	(0.621)
T_{it}^K x S_t	-0.515*	-0.561	-1.378***	-1.263**	-0.514	-0.397
	(0.308)	(0.596)	(0.463)	(0.493)	(0.325)	(0.575)
Industry Fixed Effects	YES	YES	YES	YES	YES	YES
Firm Fixed Effects	YES	YES	YES	YES	YES	YES
Observations	6,880	6,880	6,880	6,880	6,880	6,880
R-squared	0.009	0.010	0.012	0.021	0.009	0.009

Notes: Ln() refers to a logarithmic value. The variables in Ln() are as follows: total purchases (p), total purchases from related firms (pr), imports (i), imports from related firms (ir), domestic purchases (dp), and domestic purchases from related firms (dpr). All regressions are clustered at the firm level. Values in parentheses are the heteroscedasticity and multicollinearity robust standard errors. $T_{it}^K = 1$ if i is a Korean firm with subsidiaries in Japan, and $T_{it}^K = 0$ if i is a Korean firm without foreign subsidiaries. $S_t = 1$ if t is the year 2011 or 2012, and $S_t = 0$ if the year is 2009 or 2010. Source: Authors' regression results using data from the Survey of Business Activities (SBA), Statistics Korea.

The estimates for the interaction terms between T_{it}^K and S_t in Tables 7 and 8 show different results from those in Tables 3 and 4. First, the results in columns (1) and (3) in Tables 7 and 8 show the existence of a transmission impact of the 2011 disaster on the Korean mother firms with subsidiaries in Japan. From (3) in Tables 7 and 8, we can observe that the total exports and imports of the firms are reduced. Also, from (1) in Table 8, the total input purchases of the firms are reduced as well. However, from (5) in Tables 7 and 8, we can see that the impacts on the firms' domestic sales and domestic purchases are not significant. So, all of these results suggest that the negative impacts on the Korean firms are due to the reduced exports and imports.

What about their intra-firm transactions? From (2) in Tables 7 and 8, we find an insignificant effect on intra-firm sales and purchases. Furthermore, in (4) and (6) of Table 7, none of the estimates are significant. However, only (4) of Table 8 reveals a negative effect

on the firms' intra-firm imports. So, overall, the impacts on intra-firm transactions are less evident than for inter-firm transactions.

In sum, following the 2011 disaster in Japan, the Korean firms with subsidiaries in Japan experienced a negative transmissive effect of the shock, mainly through a drop in both total exports and total imports. In particular, the effect is clearer on the input side. That is, the Korean firms reduced their imports of inputs from related firms abroad and, thus, reduced their total imports and total purchases without a drop in domestic input outsourcing. Although inconclusive, this may have affected their reduction in total exports as well.

One reason why the Japanese multinationals in Korea and the Korean multinationals owning subsidiaries in Japan responded differently may have stemmed from the differences in their industrial distribution. The majority of the Japanese multinationals in Korea were agglomerated in resource- and material-related industries, such as chemicals, rubber and plastics, and other non-metal minerals, whilst the Korean mother firms owning subsidiaries in Japan were mostly concentrated in final or intermediate product-related industries, such as electronics, electrics, and motor vehicles. When the 2011 Japanese earthquake occurred in Tohoku and near Tokyo, there was damage to the manufacturing industries of motor vehicles, electrics, electronics, and machinery. So, we can reasonably guess that the impact was propagated relatively strongly to the Korean subsidiaries located in Japan.

3. Robustness Checks

We conduct two cases: (1) excluding the year 2009 (global financial crisis), and (2) a direct comparison between Japanese subsidiaries in Korea and Korean mother firms owning subsidiaries in Japan.

Firstly, 2008 and 2009 are known as the period of the global financial crisis, when the growth of the world economy was staggered. So, this may bring concern that including 2009 in our analysis could generate a pre-condition bias due to the economic situation before the 2011 Japanese earthquake. To investigate this, we exclude the year 2009 and simply compare the years 2010 and 2011. The results are summarised in Tables 9 and 10.

Table 9: Sales of Japanese Subsidiaries in Korea: 2010 versus 2011

Dependent Variable	(1) Ln(s)	(2) Ln(sr)	(3) Ln(e)	(4) Ln(er)	(5) Ln(ds)	(6) Ln(dsr)
T_{it}	-0.078	-1.592	-0.896	-1.990	-0.970	1.833
	(0.085)	(1.535)	(1.607)	(1.673)	(1.233)	(1.579)
S'_t	0.027*	-0.488	-0.289	-0.585	0.224	0.324
	(0.014)	(0.383)	(0.303)	(0.356)	(0.188)	(0.345)
T_{it} x S'_t	-0.077	-1.064	-1.125	-2.969*	-0.433	3.321**
	(0.079)	(1.447)	(1.516)	(1.602)	(1.203)	(1.546)
Industry Fixed Effects	YES	YES	YES	YES	YES	YES
Firm Fixed Effects	YES	YES	YES	YES	YES	YES
Observations	692	692	692	692	692	692
R-squared	0.023	0.036	0.007	0.060	0.022	0.080

Notes: Ln() refers to a logarithmic value. The variables in Ln() are as follows: total sales (s), total sales to related firms (sr), exports (e), exports to related firms (er), domestic sales (ds), and domestic sales to related firms (dsr). All regressions are clustered at the firm level. Values in parentheses are the heteroscedasticity and multicollinearity robust standard errors. $T_{it} = 1$ if i is a Japanese subsidiary in Korea, and $T_{it} = 0$ if i is a non-Japanese foreign subsidiary in Korea. $S'_t = 1$ if t is the year 2011, and $S'_t = 0$ if the year is 2010.
Source: Authors' regression results using data from the Survey of Business Activities (SBA), Statistics Korea.

Table 10: Purchases of Japanese Subsidiaries in Korea: 2010 versus 2011

Dependent Variable	(1) Ln(p)	(2) Ln(pr)	(3) Ln(i)	(4) Ln(ir)	(5) Ln(dp)	(6) Ln(dpr)
T_{it}	-1.443**	-2.041	-2.707*	-1.687	-0.943	-1.395
	(0.676)	(1.423)	(1.569)	(1.381)	(0.609)	(1.113)
S'_t	0.316	-0.440	0.122	-0.362	0.272	-0.434
	(0.301)	(0.389)	(0.351)	(0.341)	(0.295)	(0.349)
T_{it} x S'_t	-0.497	-2.411*	-2.466	-2.763**	0.033	-1.681
	(0.608)	(1.373)	(1.543)	(1.333)	(0.537)	(1.064)
Industry Fixed Effects	YES	YES	YES	YES	YES	YES
Firm Fixed Effects	YES	YES	YES	YES	YES	YES
Observations	692	692	692	692	692	692
R-squared	0.045	0.031	0.032	0.063	0.046	0.027

Notes: Ln() refers to a logarithmic value. The variables in Ln() are as follows: total purchases (p), total purchases from related firms (pr), imports (i), imports from related firms (ir), domestic purchases (dp), and domestic purchases from related firms (dpr). All regressions are clustered at the firm level. Values in parentheses are the heteroscedasticity and multicollinearity robust standard errors. T_{it} = 1 if i is a Japanese subsidiary in Korea, and T_{it} = 0 if i is a non-Japanese foreign subsidiary in Korea. S'_t = 1 if t is the year 2011, and S'_t = 0 if the year is 2010. Source: Authors' regression results using data from the Survey of Business Activities (SBA), Statistics Korea.

Columns (4) and (6) in Table 9 show the switching pattern of the intra-firm sales of Japanese subsidiaries in Korea, which is similar to the outcomes of Table 3. Also, column (4) in Table 10 shows a similar result to that in Table 4, which implies that excluding 2009 does not change our main results.

Secondly, the empirical strategy employed thus far involves comparing the results from two different settings using distinct treated groups and control groups. The first treated group comprises Japanese subsidiaries in Korea, with the control group consisting of non-Japanese foreign subsidiaries in Korea. The second treated group comprises Korean mother firms that own subsidiaries in Japan, whilst the control group comprises Korean mother firms that own subsidiaries in foreign countries other than Japan.

As a robustness check of our results, we directly compare the two treated groups. To emphasise the negative impact of the Japanese earthquake on Korean firms with subsidiaries

in Japan, we define the treated group as Korean mother firms owning subsidiaries in Japan, and the control group as Japanese subsidiaries in Korea. The summarised results are presented in Tables 11 and 12.

Table 11: Direct Comparison: Sales of Korean Firms with Subsidiaries in Japan versus Sales of Japanese Subsidiaries in Korea

Dependent Variable	(1) Ln(s)	(2) Ln(sr)	(3) Ln(e)	(4) Ln(er)	(5) Ln(ds)	(6) Ln(dsr)
T_{it}	0.153***	4.047***	6.839***	3.477***	-0.508***	0.750***
	(0.030)	(0.196)	(0.161)	(0.254)	(0.126)	(0.225)
S_t	0.103***	-0.059	-0.470	-1.141***	0.626***	1.270***
	(0.035)	(0.345)	(0.348)	(0.357)	(0.207)	(0.423)
T_{it} x S_t	-0.119**	-0.649	0.214	0.710	-0.865***	-1.817***
	(0.056)	(0.452)	(0.423)	(0.520)	(0.280)	(0.539)
Industry Fixed Effects	YES	YES	YES	YES	YES	YES
Firm Fixed Effects	YES	YES	YES	YES	YES	YES
Observations	1,025	1,025	1,025	1,025	1,025	1,025
R-squared	0.032	0.015	0.018	0.024	0.038	0.032

Notes: Ln() refers to a logarithmic value. The variables in Ln() are as follows: total sales (s), total sales to related firms (sr), exports (e), exports to related firms (er), domestic sales (ds), and domestic sales to related firms (dsr). All regressions are clustered at the firm level. Values in parentheses are the heteroscedasticity and multicollinearity robust standard errors. T_{it} = 1 if i is a Japanese subsidiary in Korea, and T_{it} =0 if i is a Korean firm with subsidiaries in Japan. S_t = 1 if t is the year 2011 or 2012, and S_t = 0 if the year is 2009 or 2010.
Source: Authors' regression results using data from the Survey of Business Activities (SBA), Statistics Korea.

Table 12: Direct Comparison: Purchases of Korean Firms with Subsidiaries in Japan versus Purchases of Japanese Subsidiaries in Korea

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent Variable	Ln(p)	Ln(pr)	Ln(i)	Ln(ir)	Ln(dp)	Ln(dpr)
T_{it}	5.708***	2.460***	5.098***	2.461***	4.850***	1.566***
	(0.141)	(0.228)	(0.228)	(0.212)	(0.143)	(0.222)
S_t	0.419**	-0.944**	-0.495	-1.451***	0.401**	-0.876***
	(0.182)	(0.382)	(0.347)	(0.406)	(0.194)	(0.331)
T_{it} x S_t	-0.644**	0.033	-0.443	0.500	-0.636**	0.051
	(0.279)	(0.511)	(0.485)	(0.515)	(0.289)	(0.469)
Industry Fixed Effects	YES	YES	YES	YES	YES	YES
Firm Fixed Effects	YES	YES	YES	YES	YES	YES
Observations	1,025	1,025	1,025	1,025	1,025	1,025
R-squared	0.020	0.041	0.047	0.067	0.018	0.038

Notes: Ln() refers to a logarithmic value. The variables in Ln() are as follows: total purchases (p), total purchases from related firms (pr), imports (i), imports from related firms (ir), domestic purchases (dp), and domestic purchases from related firms (dpr). All regressions are clustered at the firm level. Values in parentheses are the heteroscedasticity and multicollinearity robust standard errors. $T_{it} = 1$ if i is a Japanese subsidiary in Korea, and $T_{it} = 0$ if i is a Korean firm with subsidiaries in Japan. $S_t = 1$ if t is the year 2011 or 2012, and $S_t = 0$ if the year is 2009 or 2010.
Source: Authors' regression results using data from the Survey of Business Activities (SBA), Statistics Korea.

The results demonstrate a qualitatively similar outcome, indicating that the negative impacts of the 2011 Japanese earthquake on Korean mother firms with subsidiaries in Japan persist. Specifically, columns (1) and (5) in Table 11 indicate a reduction in total sales (-0.119), likely attributable to a decrease in domestic sales (-0.865), when compared to Japanese subsidiaries in Korea. Similar impacts are observed on the purchasing side, as shown in columns (1) and (5) in Table 12. They reveal reductions (-0.644) in total purchases by Korean mother firms with subsidiaries in Japan, along with reductions (-0.636) in domestic purchases compared to Japanese subsidiaries in Korea. This robustness check reaffirms that the 2011 Japanese earthquake had a negative impact on Korean firms through their intra-firm connections with Japan but with no discernible influence on Japanese subsidiaries in Korea.

4. Conclusion

In a new world economy where the global supply chain plays an important role in synchronising economic conditions amongst countries, understanding the mechanism of how a shock in a country can be transmitted to another country has become more important than ever. In this regard, we considered the shock of the 2011 Japanese earthquake and examined how it affected firms located in its neighbouring country, Korea. Focusing on firm-and-subsidiary link data, we found two facts. First, the sales and purchases of the Japanese subsidiaries in Korea were not negatively affected much compared to the non-Japanese foreign subsidiaries in Korea. However, they switched intra-firm sales from exports to domestic markets, whilst they reduced their intra-firm imports. Second, the sales and purchases of the Korean mother firms with subsidiaries in Japan were negatively affected compared to other Korean firms. Unlike the Japanese subsidiaries in Korea, we could not find switching patterns of sales or purchases within the intra-firm networks of the Korean mother firms. However, we found that their sales or purchases were reduced either internally or externally.

This result may imply that the Japanese multinationals in Korea have relatively more flexible and resilient intra-firm supply chains than the Korean multinationals who have subsidiaries in Japan. Also, the differences in the distributions of the industries of the two groups of multinationals might have partly caused the difference in the consequences of the 2011 Japanese earthquake.

One noteworthy point is the presence of a negative impact found in our analysis of the annual firm-level data. This raises a new question in the literature: whether the impact is long-term or short-term. Most of the existing literature on the Japanese earthquake has shown short-term negative impacts, with Japanese firms' performance returning to normal status after around six months. However, our study reveals that the negative impact on Korean firms seems to have persisted longer than that. At this moment, due to the lack of monthly data on firms' sales and purchases, we will defer this issue for future research agendas.

Given that our research is to explore the flexibility and resilience of a global production network when confronted with an unforeseen external shock, our empirical findings have the potential to assist policymakers in reforming supply chains, both domestically and internationally. For instance, policymakers may consider implementing a special industrial complex system in some selected local regions within their countries with the aim of attracting global firms from around the world to make industrial clusters there. Our research can provide

the basic insight that foreign investment should not rely on a small set of countries so that an unexpected shock can be diversified in the future.

References

Barrot, J.N. and J. Sauvagnat (2016), 'Input Specificity and the Propagation of Idiosyncratic Shocks in Production Networks', *The Quarterly Journal of Economics*, 131(3), pp.1543–92.

Boehm, C.E., A. Flaaen, and N. Pandalai-Nayar (2019), 'Input Linkages and the Transmission of Shocks: Firm-Level Evidence from the 2011 Tohoku Earthquake', *Review of Economics and Statistics*, 101(1), pp.60–75.

Carvalho, V.M. (2014), 'From Micro to Macro via Production Networks', *Journal of Economic Perspectives*, 28(4), pp.23–48.

Chun, H., J. Hur, Y.G. Kim, and H.U. Kwon (2017), 'Cross-border Vertical Integration and Intra-firm Trade: New Evidence from Korean and Japanese Firm-level Data', *Asian Economic Papers*, 16(2), pp.126–39.

Cravino, J. and A.A. Levchenko (2017), 'Multinational Firms and International Business Cycle Transmission', *The Quarterly Journal of Economics*, 132(2), pp.921–62.

MacKenzie, C.A., J.R. Santos, and K. Barker (2012), 'Measuring Changes in International Production from a Disruption: Case Study of the Japanese Earthquake and Tsunami', *International Journal of Production Economics*, 138(2), pp.293–302.

Ramondo, N., V. Rappoport, and K.J. Ruhl (2016), 'Intra Firm Trade and Vertical Fragmentation in U. S. Multinational Corporations', *The Journal of International Economics*, 98(1), pp.51–59.

Appendix: Korean Standard Industry Classification (KSIC) for the Manufacturing Sector

10. Manufacture of food products
11. Manufacture of beverages
12. Manufacture of tobacco products
13. Manufacture of textiles, except apparel
14. Manufacture of wearing apparel, clothing accessories and fur articles
15. Manufacture of leather, luggage and footwear
16. Manufacture of wood and of products of wood and cork; except furniture
17. Manufacture of pulp, paper and paper products
18. Printing and reproduction of recorded media
19. Manufacture of coke, briquettes and refined petroleum products
20. Manufacture of chemicals and chemical products; except pharmaceuticals and medicinal chemicals
21. Manufacture of pharmaceuticals, medicinal chemicals and botanical products
22. Manufacture of rubber and plastics products
23. Manufacture of other non-metallic mineral products
24. Manufacture of basic metals
25. Manufacture of fabricated metal products, except machinery and furniture
26. Manufacture of electronic components, computer; visual, sounding and communication equipment
27. Manufacture of medical, precision and optical instruments, watches and clocks
28. Manufacture of electrical equipment
29. Manufacture of other machinery and equipment
30. Manufacture of motor vehicles, trailers and semitrailers
31. Manufacture of other transport equipment
32. Manufacture of furniture
33. Other manufacturing

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