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Robustness and Resilience of Supply Chains During the COVID-19 Pandemic: Findings from a Questionnaire Survey on the Supply Chain Links of Firms in ASEAN and India[*]

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Abstract: *Using a unique firm-level data set from the Association of Southeast Asian Nations (ASEAN) and India collected from November 2020 to February 2021, this paper examines how the robustness and resilience of supply chain links – i.e. maintaining links and substituting another for a disrupted partner, respectively – were determined when firms faced economic shocks due to the spread of the coronavirus disease (COVID-19). Focusing on the role of the characteristics of firms' supply chains, we find that homophily, i.e. the tendency to form a group with similar agents, was often associated with the robustness of supply chain links, most likely because of the strength of homophilous ties. In particular, when a foreign-owned firm had a supply chain link with a firm located in the same country as its home country, the link was quite robust. We also find that the geographic diversity of customers and suppliers creates resilience of supply chains. When the demand or supply from a partner of a firm was disrupted because of COVID-19, the firm likely mitigated the damage from the disruption through substitution of partners if its supply chains were well diversified across countries. In addition, larger or younger firms tended to be resilient and robust. The robustness and resilience of supply chains are found to have led to higher performance.*

Keywords: COVID-19, Robustness of supply chains, Resilience of supply chains, Homophily, Asia

JEL Classification: F14, F23, L14

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1. Introduction

When the coronavirus disease (COVID-19) pandemic hit economies across the world in 2020, global supply chains – i.e. the network of firms through which transactions of intermediate goods and services are made – were largely disrupted because the supply of and demand for goods and services shrank due to 'lockdown' policies that restricted on-site working and consumers' purchasing activities (Di Stefano, 2021). On 18 April 2020, when the level of restrictions peaked, governments in 160 out of 184 countries required workplaces to be closed or imposed work from home mandates on certain sectors or categories of workers; and 126 countries required people not to leave home, with some exceptions (Hale et al., 2020). At the end of 2020, the number of countries that required workplaces to be closed and people to stay at home declined to 117 and 77, respectively, but production activities were still heavily affected by these lockdown policies in many countries. It is notable that these lockdowns not only affected the local economy directly but also other economies indirectly through supply chain disruptions.

As supply chains have been expanded globally (Baldwin, 2016), economic shocks have often been observed to propagate through supply chains to other regions and countries because of two reasons: the customer firms of a firm affected by a shock are indirectly affected due to the shortage in the supply of inputs, whereas its suppliers are also affected due to the shortage in demand. Barrot and Sauvagnat (2016) found that economic shocks caused by natural disasters in the United States from 1978 to 2013 decreased sales of firms that were not directly hit by the disasters but connected to firms in the disaster areas through supply chains. Carvalho et al. (2021) and Kashiwagi, Todo, and Matous (2021) also confirmed the propagation of economic shocks through supply chains in the case of the Great East Japan Earthquake and Hurricane Sandy in the United States (US), respectively. Boehm, Flaaen, and Pandalai-Nayar (2019) focused on intra-firm input–output linkages between Japanese firms and their subsidiaries in the US and found international propagation of shocks due to the Great East Japan Earthquake.

The propagation of economic shocks due to the COVID-19 pandemic through supply chains has also been studied in the literature. Guan et al. (2020) simulated how the production of countries would change due to lockdown policies based on world input–output tables at the country-sector level and a macroeconomic model that incorporates inter-sectoral input–output linkages. They found that global production would decline by 40% in their worst case scenario. Inoue and Todo (2020) took a similar simulation approach but used firm-level, rather than sector-level, data for domestic supply chains in Japan and found that a lockdown in Tokyo would result in a large production decline in other regions that did not have lockdowns because of propagation through supply chains. Inoue, Murase, and Todo (2021) further showed that the substitutability of inputs across suppliers can largely mitigate propagation of the COVID-19 shock through supply chains, as found in earlier studies, such as Barrot and Sauvagnat (2016); Carvalho et al. (2021); and Kashiwagi, Todo, and Matous (2021).

Using firm-level data for 4,433 enterprises collected after the spread of COVID-19, Borino et al. (2021) found that international firms, i.e. firms engaging in international trade, were more likely to face difficulty in accessing inputs and reduce sales than domestically confined firms because of the international exposure of the former. However, international firms were also more likely to adopt resilient strategies such as promoting teleworking and online sales and starting sourcing from new suppliers than domestic firms because of the connectivity and productivity of the former. The higher resilience of international firms was also observed in the case of Hurricane Sandy by Kashiwagi, Todo, and Matous (2021).

Some other studies have examined the effect of COVID-19 on international trade. Liu, Ornelas, and Shi (2021) found that COVID-19 deaths and lockdowns reduced countries' imports from China, empirically demonstrating a negative effect of COVID-19 on trade. More importantly, Hayakawa and Mukunoki (2021) used data for the bilateral trade in intermediate goods and found that an economic shock from COVID-19 in a particular country, measured by the number of COVID-19 cases and deaths, reduced exports from that country and further reduced exports from countries that use inputs produced in that country. Their findings clearly confirmed propagation of the COVID-19 shock through global supply chains.

However, the following two important issues remained unanswered in the literature. First, facing supply and demand shocks due to COVID-19, some supply chain links were disrupted while others were maintained. What characteristics of firms and links resulted in the robustness of links has not been examined because existing studies use sector-level trade data or firm-level data without information on suppliers or customers. Second, when firms were challenged by the disruptions to links with their suppliers or customers, some could substitute transactions with other partners for the disrupted transactions and minimise the negative effect of COVID-19 while others could not. The literature has not investigated what characteristics of firms' own supply chains determine the resilience of firms, i.e. their ability to recover from supply chain disruptions, in the case of COVID-19.

Given the shortcomings of the literature, we study these two issues, using data for about 1,400 firms in the Association of Southeast Asian Nations (ASEAN) and India that were collected from November 2020 to February 2021, i.e. after the first stage of the COVID-19 pandemic, by the Economic Research Institute for ASEAN and East Asia (ERIA) and contain information on the top three suppliers and customers of each firm. The target firms include both domestically and foreign-owned enterprises. We focus on firms in ASEAN and India because international supply chains are prominent in this region (Kimura and Obashi, 2016; Ando and Kimura, 2010; Obashi and Kimura, 2017). Moreover, the COVID-19 pandemic hit the economies in the target region directly and indirectly through supply chains, e.g. due to the lockdown policies of China, a major hub of global supply chains. However, supply chains in East Asia were less vulnerable to the COVID-19 shocks than those in other regions, such as Europe and the Americas, according to Kimura (2021) and Hayakawa and Mukunoki (2021). Therefore, we expect variations in the robustness and resilience across supply chain links and firms in our target region, and thus can investigate how supply chains' robustness and resilience to network disruptions were determined.

We focus on the effect of the strength of ties on robustness and the effect of the geographic diversity of supply chain partners on resilience, obtaining notable findings. First, when a supplier and its customer were similar in firm size and when a foreign-owned firm was linked with a supplier or customer in its home country, the supply chain link between the two was less likely to be disrupted during the COVID-19 pandemic. By contrast, ownership relationships in addition to supply chain links did not lead to such a mitigation effect, perhaps due to the ease of short-run adjustments. These findings suggest that some form of homophily (tendency of agents to form a link with those with similar attributes) creates strong ties, and thus robustness of links. Second, when a firm was linked with suppliers and customers that were diversified across countries, the firm was more likely to substitute other partners for partners delinked by COVID-19. This evidence indicates that geographic diversity of suppliers and customers can promote firms' resilience to supply chain disruptions. Finally, the robustness and resilience raised the performance of firms in the short and long run after the first stage of the pandemic.

This study contributes to the literature in the following three ways. First, because of the COVID-19 pandemic and other recent natural disasters that caused supply chain disruptions, supply chain resilience is a key strategic issue for firms (Sharma, Adhikary, and Borah, 2020). This study adds to the literature evidence of how supply chains' robustness and resilience to economic shocks, particularly those that hit multiple countries, such as COVID-19, can be achieved. Second, we also contribute to the more general literature on how networks are formed and eliminated. How links amongst agents are formed and eliminated has been extensively examined in the empirical literature on network formation (Snijders, Van de Bunt, and Steglich, 2010), but substitution of links in the wake of the exogenous elimination of some links has not been studied, particularly in the context of supply chains. Finally, we show that the strength of links and the geographic diversity of partners indirectly improve the performance of agents through the robustness and resilience of their links. This conclusion is in line with the findings of existing studies on the effect of network structure on performance, such as Coleman (1988); Iino et al. (2021); Rost (2011); and Todo, Nakajima, and Matous (2015).

2. Conceptual Framework

2.1. Literature review

Existing studies find both upstream and downstream propagation through supply chains. For example, Barrot and Sauvagnat (2016) and Boehm, Flaaen, and Pandalai-Nayar (2019) examined how economic shocks to suppliers due to natural disasters propagate to their customer firms because of shortage of supplies of inputs. In addition to such downstream propagation, Carvalho et al. (2021) and Kashiwagi, Todo, and Matous (2021) found upstream propagation from customers to their suppliers because of shortage of demand for inputs.

The recent literature on the economics of networks has found that the structure of inter-firm networks can substantially affect how economic shocks propagate (Acemoglu, Ozdaglar, and Tahbaz-Salehi, 2015; Elliott, Golub, and Jackson, 2014; Joya and Rougier, 2019). The literature on supply chains has also found that the degree of propagation of economic shocks through supply chains depends on their network structure. In this paper, we focus on two types of propagation effects of economic shocks through supply chains – resilience and robustness – defining resilient supply chains as those that can recover quickly from disruptions and robust supply chains as those that are less likely to be disrupted by a shock, following Miroudot (2020) and Woods (2015).

A major factor of supply chain resilience found in the literature is the substitutability of inputs and suppliers. When a supplier of a particular input is damaged by a disaster or stops operations because of a lockdown, its customer firm can recover quickly from supply chain disruptions if the customer can easily find a substitute partner for the disrupted supply. Barrot and Sauvagnat (2016) found that input specificity results in substitution difficulties for damaged supply chain partners and thus magnifies propagation. Inoue and Todo (2019a, 2019b) used simulation on the actual supply chain data of more than 1 million firms in Japan and found that substitution of suppliers largely affected propagation of shocks through supply chains after the Great East Japan Earthquake in 2011. (Inoue, Murase, and Todo 2021) and Guan et al. (2020) reached the same conclusion, simulating the case of supply chain disruptions in the COVID-19 pandemic in 2020 on a firm- and country-sector-level model, respectively.

One way to increase input substitutability is to diversify partners. Kashiwagi, Todo, and Matous (2021) examined how the economic shocks of Hurricane Sandy, which hit the US east coast in 2012, propagated through global supply chains; and found that firms located in the US and linked with suppliers and customer firms in the disaster area lowered post-disaster sales most likely due to supply chain disruptions. However, firms located outside the US and firms located in the US and linked with firms outside the US could alleviate the negative propagation effect. These findings imply that firms with diversified partners in the world market can minimise the impact of supply chain disruptions by finding substitutes relatively easily. The conclusion of Kashiwagi, Todo, and Matous (2021) is consistent with the conclusion of Borino et al. (2021) that international firms were more resilient to the COVID-19 shock because of their connectivity to the world market.

Kashiwagi, Todo, and Matous (2021) also revealed that upstream propagation from customers to suppliers can be mitigated when suppliers are internationalised. This is possibly because firms can find substitutes for damaged customers when they are connected to various customers in the world market. In other words, diversifying customers, in addition to suppliers, can generate resilience to economic shocks.

In line with these studies, the related literature on supply chain management emphasises the importance of flexibility in supply chain resilience (Azadeh et al., 2014; Pereira, Christopher, and Da Silva, 2014; Gunasekaran, Subramanian, and Rahman, 2015; Ali, Mahfouz, and Arisha, 2017; Crum et al., 2011). Embodying diversified partners provides firms flexibility in modifying partners in the wake of supply chain disruptions.

In addition, the literature finds that supply chain links can be more robust and resilient when suppliers and customers are strongly connected. A typical type of strong tie in supply chains is supplier–customer relationships – known as *keiretsu* in Japan. In *keiretsu* relationships, suppliers and customers are often linked through other channels, such as inter-firm shareholding, knowledge and information sharing, and collaboration in research and development activities (Aoki, 1988; Dyer and Nobeoka, 2000). These multilayered and thus strong relationships promote robustness because they generate large mutual benefits from sustainable supply chains. In other words, if a supplier lowers its production capacity because of a disaster, including a pandemic, it is more likely to prioritise its supplies to strongly connected customers than other customers. Even when a strong supply chain link is disrupted because of a large shock, it is more likely to be reconnected than otherwise. In the event of the Great East Japan Earthquake, many firms outside the disaster area supported their supply chain partners to minimise the negative effect of supply chain disruptions and continued the relationships afterwards (Todo, Nakajima, and Matous, 2015; Iwao and Kato, 2019).

Another source of strong ties is homophily – the tendency of agents to connect with others who are socially and economically similar or geographically close – which has been found to be a major driving force of social network formation (Baccara and Yariv, 2013; Currarini, Jackson, and Pin, 2009; Currarini, Matheson, and Vega-Redondo, 2016; Kets and Sandroni, 2019; McPherson, Smith-Lovin, and Cook, 2001; Fafchamps and Gubert, 2007; Hoshino, Shimamoto, and Todo, 2020). For example, Hoshino, Shimamoto, and Todo (2020) found that small and medium-sized enterprises in Viet Nam tend to exchange business information with others similar in size. In homophilous links, agents tend to trust each other and thus are willing to exchange information and knowledge (Coleman 1988). In addition, it is often the case that homophilous network formation results in clusters in which agents are densely connected with each other (Jackson, 2008). Such homophilous and dense relationships promote mutual benefits of partners and hence robust supply chains.

However, strong supply chain relationships have several disadvantages. First, strong supply chain links are often associated with specific inputs developed by strongly connected suppliers and customers, as we typically observe in *keiretsu* (Dyer and Nobeoka, 2000). Therefore, when a firm reduces production due to a natural disaster or lockdown, it is difficult for its suppliers and customers to find substitutes. Second, when a firm is densely linked with its partners (i.e. its partners are also linked with each other), an economic shock can circulate amongst the densely linked firms. Inoue and Todo (2019b, 2019a) showed that when supply chains include loops in a complex manner, the propagation of negative shocks is far greater than when their structure is tree-like – simply from upstream to downstream. Accordingly, the negative effect on suppliers and customers can be quite large and long-lasting when they are linked strongly.

Empirical evidence is mixed. Boehm, Flaaen, and Pandalai-Nayar (2019) found that economic shocks due to the Great East Japan Earthquake propagated to subsidiaries of Japanese firms located in the US, although they do not compare the degree of propagation through supply chains with and without shareholding relationships. Kashiwagi, Todo, and Matous (2021) showed that US firms lowered their sales more after Hurricane Sandy when they were linked with suppliers in the disaster area through both supply chains and shareholding relationships than when they were linked through only supply chains. They also found that the propagation effect is larger when US firms are more densely linked with their suppliers and customers. These findings suggest that firms with strong supply chain ties are less robust and resilient than those without such ties. By contrast, Kashiwagi, Todo, and Matous (2021) also showed that the propagation effect from customers in the disaster area can be mitigated when customers and their suppliers are linked with shareholding relationships, suggesting robustness and resilience due to strong ties.

2.2. Hypotheses

Based on the literature above, we propose the following hypotheses to be tested in this study. It should be emphasised that some hypotheses are at the link level, i.e. they claim how the robustness of supply chain *links* is determined, while others are at the firm level, i.e. they claim how the robustness and resilience of *firms* are determined.

From the argument above, a supply chain link may be more robust, i.e. it is less likely to be disrupted, if the link is strong and thus generates long-term mutual benefits of the partners. This study defines the strength of ties in two ways and provides the following hypotheses.

Hypothesis 1: When an economic shock hits supply chains, the transaction volume between two firms connected through supply chains does not shrink if the link between the firms is homophilous. Specifically, homophily is evaluated by the firm size and country of origin.

Hypothesis 2: When an economic shock hits supply chains, the transaction volume between two firms connected through supply chains does not shrink if the firms are also connected through a shareholding relationship.

However, the argument above also suggests that strong supply chain links can be less robust if the strength of the ties is associated with dense networks that promote the circulation of shocks amongst firms. If this is the case, these two hypotheses are rejected.

In addition, the robustness of the supply chain links of a particular firm is directly affected by its own production. If the production of a firm reduces, the transaction volume with its customer and supplier should decline because of the shortage of supply and demand, respectively. When the production sites of a firm are geographically diversified across firms, whether or not its production declines depend on the following two forces. On the one hand, when a firm with production sites across countries faces multi-country economic shocks, the probability that any of its production sites is affected by the shocks increases. Thus, its production would decline. On the other hand, if a reduction in the production of an establishment can be mitigated by an increase in another that is not directly affected by a shock, the total production of the firm may not decline. By contrast, if the production sites of a firm are concentrated in a country, the probability that its production sites are affected by the shock is low, but once affected, substitution across production sites is impossible. This consideration leads to the following conditional hypothesis.

Hypothesis 3: When an economic shock hits supply chains, the transaction volume between two firms connected through supply chains is more or less likely to shrink if any of the firms diversifies its production sites geographically, depending on the magnitude of concentration or substitution effect of geographic diversity.

At the firm level, the supply chains of a firm are more resilient, i.e. the firm can replace partners disrupted by a shock with others more easily, when its partners are geographically diversified. Therefore, we test the following hypothesis using firm-level data.

Hypothesis 4: When an economic shock hits supply chains, the reduced transaction volume of a firm with its partners is more likely to be substituted by an increase in transactions with another partner, if the firm's supply chain partners are more diversified geographically.

3. Empirical Methodology

To test the hypotheses in the previous section, we take the case of lockdowns at the country level in the world to prevent the spread of COVID-19 in 2020, which reduced production in various regions. Following the hypotheses, we run two types of estimations: one at the supply chain link level (i.e. bilateral firm level) and the other at the firm level.

3.1. Link-level analysis

Our link-level analysis employs the following linear probability model:

$$SHRINK_{ij} = \beta_0 + \beta_1 W_i + \beta_2 X_{ij} + \beta_3 Z_j + \varepsilon_{ij}, \quad (1)$$

where $SHRINK_{ij}$ is the dummy variable that takes a value of 1 if the transaction between firms i and j was suspended or its volume decreased in and after 2020 compared with 2019 due to COVID-19. Because of the data limitation explained in the next section, firm j is one of the top three suppliers or customers of firm i. W_i, X_{ij}, and Z_j are vectors of variables for the reporting firm i, the supply chain link between i and j, and the partner firm j, respectively. To test hypotheses 1 and 2, vector X_{ij} includes several variables that measure the strength of the link between i and j: the dummy variable that indicates whether or not firm i owns partner j, the dummy variable that indicates whether or not firm i is owned by j, the dummy variable that indicates whether or not partner j is located in the home country of firm i if foreign owned, and the dummy variables that indicate whether or not firms i and j are similar in terms of the number of workers. To test hypothesis 3, vector W_i includes a reverse measure of the diversity of the production sites of firm i, i.e. the Herfindahl-Hirschman Index (HHI) of its production across countries. W_i also includes control variables, including country-industry dummies. Finally, Z_j is a vector of attributes of partner j, including country-industry dummies. These two types of country-industry dummies control for the effect of lockdowns in industries and countries of the respondent firm and its partner, and other country-industry specific effects. Other control variables are fully explained in section 4.2.

We estimate equation (1) by ordinary least squares (OLS) estimation, assuming that independent variables are either exogenous or predetermined before the pandemic. Cluster robust standard errors at the level of firm i's country and industry, and firm j's country, are used.

3.2. Firm-level analysis

We also estimate the following linear probability model at the firm level:

$$RESc_i = \delta_0 + \delta_1 V_i + e_i, \qquad (2)$$

where $RESc_i$ is the dummy variable for firm i's resilience to upstream supply chain shocks from its customers. Precisely, it is 1 if firm i decreased the volume of transactions with any of its top three customers after the spread of COVID-19 while it increased the transaction volume with another. In other words, this dummy is 1 when the firm could substitute another for disrupted customer and thus can be considered to be resilient. To test hypothesis 4, vector V_i includes a measure of the diversity of customers, i.e. the number of countries where firm i's top three customers are located. V_i also includes control variables explained in section 4.2 and country-industry dummies for firm i and country-industry dummies for each of its top three partners. As in the link-level analysis, these country-industry dummies control for the direct effect of lockdowns. In this estimation, we also rely on OLS and use robust standard errors at the country-industry level.

An alternative dependent variable to test hypothesis 4 is the dummy variable that takes a value of 1 if firm *i* increased the volume of transactions with any of its top three customers or suppliers after the spread of COVID-19, or $EXPANDc_i$.

$$EXPANDc_i = \delta_0 + \delta_1 V_i + e_{i.}, \qquad (3)$$

In this estimation, we focus on the subsample of firms whose transaction volume with any of its top three customers or suppliers decreased because of COVID-19. By so doing, we test if, given a decrease in transactions with a partner, the respondent firm could increase transactions with another partner to substitute for the decreased transaction.

In addition to the resilience to upstream supply chain shocks, we examine the resilience to downstream shocks from suppliers, using the same framework where customers are replaced with suppliers. More precisely, the dependent variable in equation (2) is $RESs_i$, the dummy variable that is the value of 1 if firm *i* decreased the volume of transactions with any of its top three suppliers after the spread of COVID-19 while it increased the transaction volume with another. In equation (4), the dependent variable is replaced with $EXPANDs_i$, the dummy variable that takes a value of 1 if firm *i* increased the volume of transactions with any of its top three customers or suppliers after the spread of COVID-19. In both equations, the key independent variable is a measure of the geographic diversity of suppliers, or the number of countries where the firm's top three suppliers are located.

4. Data

4.1. Firm-level survey

ERIA commissioned Deloitte Consulting Pte Ltd (Deloitte) to conduct a survey on the impact of COVID-19 on business activities and supply chains (hereafter, the survey) in the ASEAN Member States (Brunei Darussalam, Cambodia, Indonesia, the Lao People's Democratic Republic (Lao PDR), Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Viet Nam) and India. The primary purpose of the survey is to comprehend the degree of the COVID-19 impacts on supply chains in the East Asia and ASEAN region. The targeted firms include both locally owned firms and multinational enterprises.

The survey questionnaire comprised three parts. The first part covered the COVID-19 impact on business performance and outlook. Precisely, the questionnaire asked about respondent firms' sales, exports, and operating profits in 2020; and their outlook for operating profits and employment in the next 1–2 years. The first part also asked whether the COVID-19 pandemic caused changes in operating profits. The second part covered the COVID-19 impact on supply chains. In particular, the respondent of each firm answered questions about the attributes of the firm's top three customers and suppliers (including their locations, industries, and firm size) and whether and why the firm changed (shrank/did not change/expanded) and will change the transaction amount with each of the top three customers and suppliers. The third part covers the respondents' evaluation of government support in response to COVID-19. The responses in this part are not used in this study. All the survey questions are available in Oikawa et al. (2021). The respondents answered the questionnaire online and spent about 30 minutes completing the survey.

One of the survey's challenges was how to collect respondents to a lengthy questionnaire when firms faced difficult economic circumstances because of the COVID-19 pandemic and received several COVID-19-related questionnaire surveys.[3] To respond to this challenge, we designed multiple survey channels to collect respondents. The first channel was Deloitte's customer network. The primary target firms through this channel were multinational or relatively large-scale companies. Deloitte sent the online questionnaires to 3,269 companies operating in ASEAN and India, and it collected responses from 412, or 12.6%. The second survey distribution channel was industry associations. We approached several local and foreign industry associations, including the Japanese and British chambers of commerce in our target countries. These industry associations distributed the online questionnaire to their member firms. The estimated number of firms through the second channel that received the questionnaire was 11,199, and the number of respondents was 93 (0.8%). The third distribution channel was business-to-business market research companies to reach small and medium-sized enterprises, since the above two channels had access to relatively large-scale companies. For this purpose, we commissioned SIS International Research and Market Xcel Data Matrix, which are experienced in the East Asia and ASEAN regions. These two research companies distributed the questionnaire to 62,620 companies, and they gathered 1,578 respondents (2.5%).

The survey was split into two phases to collect and analyse the responses efficiently. The first phase – covering Malaysia, Singapore, and Thailand – was carried out from 17 November 2020 to 8 January 2021. The second phase targeted the other eight countries and took place from 1 December 2020 to 16 February 2021.

[3] The Asian Development Bank (ADB) conducted a survey of Philippine businesses in April and May 2020 (ADB, 2020). Japan External Trade Organization (JETRO) carried out a survey of Japanese affiliated enterprises in Southeast Asia in August and September 2020 (JETRO, 2021). The American Chamber of Commerce in Indonesia (AmCham Indonesia) and ERIA conducted a rapid survey for AmCham Indonesia's member firms in April 2020 and undertook a more detailed survey of foreign firms in ASEAN in collaboration with 24 chambers and business organisations in September 2020 (AmCham Indonesia and ERIA, 2020).

4.2. Variable construction

Using the information about the top three customers and suppliers of each respondent firm, we construct two link-level data sets: one for the supply chain flows from our sample firms to their top three customers, and the other for the flows from their top three suppliers to the sample firms. Using the data set for links with customers, we define $SHRINK_C$ as the dummy variable that takes the value of 1 if the volume of transactions between the respondent firm and its customer shrank due to COVID-19. In addition, to measure the degree of homophily between the respondent firm and its customer, we construct the following variables. First, HOM_SIZE_C is the dummy variable that takes a value of 1 if the number of workers of the two firms is in the same firm size category. More precisely, this variable is 1 if the number of workers of both firms is 19 or less, if it is 20–99, or if it is 100 or more. Second, HOM_FDI_C is the dummy variable that takes the value of 1 if the respondent firm is foreign owned and if its home country and the country where its customer is located are the same. In addition, OWN_C and $OWNED_C$ are the dummy variables that take a value of 1 if the customer owns and is owned by the respondent firm, respectively. Using the data set for links with suppliers, we define $SHRINK_S$, HOM_SIZE_S, HOM_FDI_S, OWN_S, and $OWNED_S$ in the same way (the subscripts C and S stand for customers and suppliers, respectively).

In the link-level analysis, our key dependent variables are RES_k and $EXPAND_k$, where $k = C$, S, or measures of the resilience of firms' links with customers and suppliers. RES_C is the dummy variable that takes a value of 1 if, while the transaction volume with any of the top three customers shrank because of COVID-19, the transaction volume with another increased. $EXPAND_C$ is the dummy variable that takes a value of 1 if the transaction volume with any of the top three customers increased. Note that when we use $EXPAND_C$, we limit our sample to firms whose transaction volume of any top customer declined. In addition, we define measures of the robustness of supply chains of the respondent firm, ROB_k, where $k = C$, S, which are used in alternative specifications. ROB_C is the dummy variable that takes a value of 1 if the transaction volume with any of the top three customers did not shrink because of COVID-19. RES_S, $EXPAND_S$, and ROB_S are defined similarly, using relationships with top three suppliers.

For the firm-level analysis, we construct two types of measures of geographic diversity of customers/suppliers of each respondent firm. First, $DIVERS_C$ and $DIVERS_S$ are the number of countries where the top customers and suppliers are located, respectively. Because we focus on the top three customers and suppliers of each respondent firm, the value of these variables is either one, two, or three. Second, besides the information on the top three customers of each respondent firm, our data include information on the share of sales, input purchases, and production by country (and by region outside Asia). Using this information, we define HHI_C and HHI_S as HHIs of the shares of sales (customers) and input purchases (suppliers), respectively, at the country level. Because HHIs measure the degree of concentration, these variables are considered to indicate the reverse of geographic diversity of customers and suppliers. In addition, we also construct HHI_P, the HHI of the share of production at the country level.

In both the link- and firm-level analyses, we include the attributes of each respondent firm, as explained in section 3. These are the number of workers; firm age; type of firm (holding company, branch office, subsidiary, or independent company); business functions (multiple choices amongst sales, procurement, and production); the dummy for listed firms; the dummy for foreign-owned firms; dummies for the home country if foreign owned; the dummy for firms managed by owners; and country-industry dummies. In the link-level analyses, we also incorporate the attributes of each customer/supplier, such as categories for the number of workers (19 or less, 20–99, or 100 or more); dummies for the home country if foreign owned; and country-industry dummies for the customer/supplier. Because the total number of home countries of foreign-owned firms in our sample is quite large, we simplify them into six categories: Japan, China, ASEAN, the US, Europe, and others. These attribute variables are directly taken from the responses to the survey.

4.3. Descriptive statistics

Although the total number of respondent firms is 1,578, a number of firms did not respond to questions about their supply chain partners. After dropping these firms, our firm-level sample for the analysis of the resilience of links with customers and suppliers consists of 1,416 and 1,316 firms, respectively. Using the supply chain information of these firms, we obtain 4,269 and 3,931 links with customers and suppliers, respectively.

Tables 1 and 2 show the distribution of countries and industries, respectively, in the customer-link sample. More than one-third of firms are located in India, whereas about 10% are located in each of Singapore, Thailand, Indonesia, and the Philippines. In the survey, we do not necessarily focus on the manufacturing sector because service industries are also involved in global supply chains. For example, the reduction in demand in the retail and wholesale sector due to lockdowns should affect production in upstream manufacturing sectors. Lockdowns usually restrict the restaurant and tourism industry and hence affect their upstream industries, such as the food and transportation industry. As a result of our broad focus, the share of manufacturing firms is 29%, followed by the communications and software industry (21%), and the business services industry (18%). Some 441 firms, or 31%, amongst the 1,416 in the customer-link sample are foreign owned, whereas 30%, 20%, and 7.5% of the foreign-owned firms are primarily owned by Japanese, US, and Singaporean firms, respectively (Table 3). Customers and suppliers of the respondent firms are located mostly in the ASEAN Member States and India, while some are outside the region. Some 8% of their customers are in the US, 5% are in Europe, 3% are in Japan, and another 3% are in China (panel A of Table 4). The distribution of countries of suppliers is similar (panel B).

Table 1: Country Distribution of Respondent Firms

Country	Frequency	Percentage
Singapore	150	10.59
Thailand	132	9.32
Malaysia	96	6.78
Indonesia	149	10.52
Philippines	129	9.11
Viet Nam	114	8.05
Cambodia	50	3.53
Lao PDR	8	0.56
Myanmar	27	1.91
Brunei	13	0.92
India	548	38.70
Total	**1,416**	**100.00**

Note: The percentages may not total 100% due to rounding.

Source: Authors.

Table 2: Industry Distribution of Respondent Firms

Industry	Frequency	Percentage
Manufacturing	410	28.95
Wholesale, retail	118	8.33
Communications, software	296	20.90
Transportation	81	5.72
Business services	257	18.15
Others	254	17.94
Total	**1,416**	**100.00**

Note: The percentages may not total 100% due to rounding.

Source: Authors.

Table 3: Distribution of Home Countries of Foreign-Owned Respondent Firms

Country	Frequency	Percentage
Japan	132	29.93
United States	86	19.50
Singapore	33	7.48
United Kingdom	27	6.12
France	19	4.31
Germany	19	4.31
Australia	11	2.49
Switzerland	10	2.27
India	9	2.04
Netherlands	9	2.04
Malaysia	8	1.81
Hong Kong	7	1.59
Taiwan	6	1.36
Thailand	6	1.36
Viet Nam	6	1.36
Others	53	12.04
Total	**441**	**100.00**

Note: The percentages may not total 100% due to rounding.

Source: Authors.

Table 4: Country Distribution of Customers and Suppliers

(A) Customers			(B) Suppliers		
Country	**Frequency**	**Percentage**	**Country**	**Frequency**	**Percentage**
India	1,142	26.75	India	1,140	29.00
Indonesia	400	9.37	Indonesia	307	7.81
United States	350	8.20	United States	280	7.12
Singapore	293	6.86	China	269	6.84
Thailand	293	6.86	Singapore	265	6.74
Philippines	282	6.61	Malaysia	248	6.31
Malaysia	275	6.44	Thailand	244	6.21
Europe	202	4.73	Europe	197	5.01
Viet Nam	186	4.36	Philippines	190	4.83
Japan	145	3.40	Japan	177	4.50
China	139	3.26	Viet Nam	176	4.48
Cambodia	103	2.41	Cambodia	71	1.81
Myanmar	80	1.87	Myanmar	45	1.14
Republic of Korea	36	0.84	Hong Kong	42	1.07
Brunei Darussalam	35	0.82	Republic of Korea	39	0.99
Hong Kong	30	0.70	Taiwan	28	0.71
Lao PDR	20	0.47	Brunei Darussalam	26	0.66
Taiwan	19	0.45	Lao PDR	21	0.53
Others	239	5.60	Others	166	4.23
Total	**4,269**	**100.00**	**Total**	**3,931**	**100.00**

Note: The percentages may not total 100% due to rounding.

Source: Authors.

Table 5 shows the summary statistics of variables in the link-level data. In 31% of links with major customers or suppliers, the amount of transactions declined because of the spread of COVID-19. Some 66% and 61% of links with customers and suppliers, respectively, are homophilous (i.e. the two firms are similar) in terms of the number of workers. In 6.9% and 7.6% of links with customers and suppliers, respectively, the home country of the respondent firm is the same as the location of the partner if the respondent firm is foreign owned. Finally, in 9%–13% of the links, the pair of firms is also linked through capital ownership.

Table 5: Summary Statistics (Link-Level Data)

Variable	Definition	N	Mean	S.D.	Min.	Max.
SHRINKc	= 1 if transaction with the customer shrank	4,269	0.305	0.460	0	1
HOM_SIZEc	= 1 if firm size of the firm and its customer is similar	4,269	0.662	0.473	0	1
HOM_FDIc	= 1 if the home country of the FDI firm is the same as the location of the customer	4,269	0.0693	0.254	0	1
OWNc	= 1 if the customer owns the firm	4,269	0.112	0.316	0	1
OWNEDc	= 1 if the customer is owned by the firm	4,269	0.126	0.332	0	1
SHRINKs	= 1 if transaction with the supplier shrank	3,931	0.311	0.463	0	1
HOM_SIZEs	= 1 if firm size of the firm and its supplier is similar	3,931	0.605	0.489	0	1
HOM_FDIs	= 1 if the home country of the FDI firm is the same as the location of the supplier	3,931	0.0763	0.266	0	1
OWNs	= 1 if the supplier owns the firm	3,931	0.0911	0.288	0	1
OWNEDs	= 1 if the supplier is owned by the firm	3,931	0.0908	0.287	0	1

FDI = foreign direct investment, S.D. = standard deviation.

Source: Authors.

Summary statistics of the variables used in the estimations using firm-level data are shown in Table 6. Some 9% and 7% of firms embodied resilient links with customers and suppliers, respectively (see *RESc* and *RESs*), i.e. transactions with a major partner increased while those with another decreased. The minimum of the three HHIs is 0 because they are defined to be 0 when the respondent firm did not provide any information about the shares of country-level sales, input procurement, and production. To control for the effect of the HHIs of value 0, we include dummies for these observations in all estimations. The average number of countries where the top three customers/suppliers are located (*DIVERSc* and *DIVERSs*) is 1.6, indicating that firms diversify their supply chain partners across countries to some extent. The average of the number of workers and firm age is 5,868 and 24.9, respectively. The minimum of the number of workers is 0, possibly because these firms are family owned without any employees. Accordingly, before we take a log of the number of workers, we add 1 to the number of workers. Similarly, because firm age can be 0 for newly born firms, we add 1 to the firm age and take a log. It should also be noted that the maximum of the number of workers is 550,000, and its top 1-percentile is 138,000. Although its mean is 5,867, its median is 151.5. These figures indicate that our sample includes some extremely large firms. To check whether this skewed distribution leads to biased results, we run all the estimations described below, using both the full sample and the subsample, which excludes the top 1% of firms in terms of the number of workers and those with 0 workers, and obtain essentially the same results. Therefore, in the following, we report only the results from the full sample, while those from the subsample are presented in Appendix Tables A1–A4.

Table 6: Summary Statistics (Firm-Level Data)

Variable	Definition	N	Mean	S.D.	Min.	Max.
RESc	= 1 if transaction with a major customer shrank while transaction with another increased	1,416	0.0911	0.288	0	1
EXPANDs	= 1 if transaction with a major customer increased	1,416	0.476	0.500	0	1
ROBs	= 1 if transaction with any major customer did not shrink	1,416	0.567	0.496	0	1
DIVERSc	# of countries of major customers	1,416	1.603	0.819	1	3
HHIc	HHI of country-level shares of sales	1,416	0.466	0.404	0	1
RESs	= 1 if transaction with a major supplier shrank while transaction with another increased	1,316	0.0714	0.258	0	1
EXPANDs	= 1 if transaction with a major supplier increased	1,316	0.403	0.491	0	1
ROBs	= 1 if transaction with any major supplier did not shrink	1,316	0.563	0.496	0	1
DIVERSs	# of countries of major suppliers	1,316	1.648	0.833	1	3
HHIs	HHI of country-level shares of input purchases	1,316	0.473	0.414	0	1
HHIp	HHI of country-level shares of production	1,416	0.431	0.449	0	1.620
L	Number of workers	1,416	5,868	33,566	0	550,000
ln*L*	Number of workers + 1 in logs	1,416	5.209	2.574	0	13.22
AGE	Firm age	1,416	24.92	32.44	0	466
ln*AGE*	Firm age + 1 in logs	1,416	2.755	1.040	0	6.146
FDI	Dummy for foreign-owned firms	1,416	0.321	0.467	0	1
Listed	Dummy for listed firms	1,416	0.256	0.437	0	1
Owner	Dummy for owner-managed firms	1,416	0.646	0.478	0	1

HHI = Herfindahl-Hirschman index, S.D. = standard deviation.

Source: Authors.

5. Results

5.1. Link-level analysis

Table 7: Link-Level Analysis

	(1)	(2)		(3)	(4)
Independent variable	***SHRINKc***	***SHRINKc***		***SHRINKs***	***SHRINKs***
HOM_SIZEc	-0.0360*	-0.0371*	*HOM_SIZEs*	0.0121	0.0121
	(0.0192)	(0.0191)		(0.0223)	(0.0223)
HOM_FDIc	-0.0816**	-0.0725**	*HOM_FDIs*	-0.139***	-0.137***
	(0.0346)	(0.0346)		(0.0430)	(0.0433)
OWNc	0.161***	0.213***	*OWNs*	0.121***	0.120*
	(0.0393)	(0.0535)		(0.0433)	(0.0672)
OWNEDc	-0.0274	-0.0447	*OWNEDs*	0.0303	0.0424
	(0.0337)	(0.0382)		(0.0468)	(0.0701)
OWNc × FDI		-0.138**	*OWNs × FDI*		-0.00280
		(0.0665)			(0.0868)
OWNEDc × FDI		0.0375	*OWNEDs × FDI*		-0.0327
		(0.0619)			(0.0827)
HHIp	-0.0655*	-0.0649*	*HHIp*	-0.0697	-0.0687
	(0.0376)	(0.0375)		(0.0445)	(0.0448)
ln*L*	-0.0111***	-0.0108***	ln*L*	-0.00179	-0.00177
	(0.00409)	(0.00410)		(0.00568)	(0.00571)
ln*AGE*	0.0287***	0.0286***	ln*AGE*	0.0328**	0.0328**
	(0.0104)	(0.0104)		(0.0159)	(0.0160)
Lc_medium	-0.000794	0.000148	*Ls_medium*	-0.0896***	-0.0892***
	(0.0397)	(0.0400)		(0.0310)	(0.0313)
Lc_large	-0.0471	-0.0452	*Ls_large*	-0.126***	-0.126***
	(0.0316)	(0.0314)		(0.0307)	(0.0309)
Country × industry FE	Yes	Yes	Country × industry FE	Yes	Yes
Customer's country ×industry FE	Yes	Yes	Supplier's country ×industry FE	Yes	Yes

Home country FE (if foreign owned)	Yes	Yes	Home country FE (if foreign owned)	Yes	Yes
Controls	Yes	Yes	Controls	Yes	Yes
Observations	4,269	4,269	Observations	3,931	3,931
R-squared	0.112	0.113	R-squared	0.117	0.117

FE = fixed effect.

Notes: Robust standard errors at the country-industry-partner's country level are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Source: Authors.

We start with the analysis at the level of supply chain links, as described in section 3.1. The estimation of equation (1) using the data for links with customers generates the following results, as shown in column (1) of Table 7.

First, *HOM_SIZEc*, the dummy variable for homophily (similarity) in the firm size of each pair of linked firms, is negatively correlated with *SHRINKc*, the dummy variable for shrunk transaction volumes between the pair, at the 10% significance level. *HOM_FDIc*, the dummy variable for the equivalence of the home country of a foreign-owned respondent firm and the country of its customer, is also negatively correlated with *SHRINKc* at the 5% level. These results support hypothesis 1 in section 2, and indicate that homophily in size and geography leads to the robustness of supply chain links with customers. The size of the coefficients suggests that the probability of shrinking the transaction volume between a homophilous link is 3.6 or 8.2 percentage points lower than that between a heterophilous link, depending on the type of homophily. Because the average probability of shrinking transactions is 31% (Table 6), the effect of homophily on the robustness of supply chain links is large. We further investigate whether the effect of *HOM_FDIc* differs across home countries by using interaction terms between *HOM_FDIc* and home country dummies. The results, not shown here for brevity, indicate that the coefficient of any of the interaction terms is not significantly different from 0, implying no variation across home countries.

Second, *OWNc* is positively and significantly correlated with *SHRINKc*, indicating that the transaction between a firm and its customer was more likely to shrink due to COVID-19 when the customer owns the firm. In addition, *OWNEDc* is not significantly correlated with the dependent variable. These findings do not support our hypothesis 2 that supply chain ties additionally associated with ownership relationships are strong and thus robust to economic shocks. In particular, the former finding implies that a supplier tends to decrease its sales to its customer that owns the supplier more than to other arm's-length customers without any ownership relationship. However, it should be noted that this finding does not fully contradict our conceptual consideration and existing empirical findings described in section 2.1. The coexistence of supply chain and ownership relationships may have resulted in input specificity that causes vulnerability in the wake of economic shocks (Barrot and Sauvagnat, 2016) and dense networks that facilitate the circulation of shocks amongst partners (Inoue and Todo, 2019b, 2019a). Boehm, Flaaen, and Pandalai-Nayar (2019) and Kashiwagi, Todo, and Matous (2021) also showed propagation of economic shocks through supply chains associated with ownership relationships. Another possible interpretation of this finding is that the owner firm benefits more in the long run from prioritising arm's-length transactions than from prioritising intra-firm transactions because the arm's-length transaction cannot recover easily once destroyed by a shock. In other words, firms can modify the volume of intra-firm transactions more flexibly than that of arm's-length transactions because of the smaller short-run adjustment costs of the former. The importance of flexibility in supply chain resilience is emphasised in the literature

(Azadeh et al., 2014; Pereira, Christopher, and Da Silva, 2014; Gunasekaran, Subramanian, and Rahman, 2015; Ali, Mahfouz, and Arisha, 2017; Crum et al., 2011).

We further check heterogeneity in the effect of ownership by incorporating the interaction terms between the dummies for ownership relationships and the dummy for foreign ownership of the respondent firm. The results presented in column (2) of Table 7 indicate that the coefficient of the interaction term between the dummy for the customer owning its supplier (*OWNc*) and the foreign ownership dummy (*FDI*) is negative and significant at the 5% level. Moreover, the hypothesis that the sum of the coefficients of *OWNc* and *OWNc*FDI* is 0 cannot be rejected. These results suggest that foreign-owned firms can mitigate the negative effect of strong ties on robustness found in column (1) of Table 7.

Third, *HHIp* is negatively correlated with *SHRINKc* at the 10% level (column (1) of Table 7). As our hypothesis 3 in section 2.2 explained, this result implies that when a firm's production sites were diversified across countries, the firm was more likely to be damaged by multi-country economic shocks due to COVID-19 but could not substitute other undamaged sites for the damaged sites.

Columns (3) and (4) in Table 7 show corresponding results using the data for links between the respondent firms and their suppliers. The results are mostly similar to those using the data for links with customers, but there are several notable differences. First, homophily in firm size between the respondent firm and its supplier (*HOM_SIZEs*) is not significantly correlated with the change in transaction volume, although the effect of homophily in location on robustness is still observed in links with suppliers. Second, the interaction term between the dummies for ownership relationship and for foreign ownership is not significantly correlated with the change in transaction volumes, suggesting no difference between domestically and foreign-owned firms in the effect of the supplier's ownership of its customer.

Finally, we touch on some interesting results on the control variables. ln*L* shows negative and significant correlation with *SHRINKc* while ln*AGE* shows positive and significant correlation in columns (1) and (2) of Table 7. ln*AGE* is also positively correlated with *SHRINKs* in columns (3) and (4) of Table 7, whereas the coefficients of *Ls_medium* and *Ls_large* are negative and significant. In other words, the transaction between a supplier and its customer was less likely to shrink because of COVID-19, or more likely to be robust, when the two firms are younger and when the supplier is larger.

In addition, we check differences in the effect on transaction volumes across the home countries of foreign-owned firms. Then, we find that Japanese-affiliated suppliers in ASEAN and India were less likely to reduce the transaction volume with their customers by 15–16 percentage points than other suppliers, including domestically owned and other foreign-owned suppliers. By contrast, the transactions of foreign-owned firms from any other country were affected as much as those of domestically owned firms. The results imply the relative robustness of links with Japanese-owned firms in Asia.

5.2. Firm-level analysis

Table 8: Firm-Level Analysis Focusing on Relationships with Customers

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Independent variable	**Dependent variable**					
	RESc		***EXPANDc***		***ROBc***	
DIVERSc	0.0235***		0.0644***		-0.000924	
	(0.00822)		(0.0231)		(0.0128)	
HHIc		-0.0704**		-0.165**		-0.0570
		(0.0344)		(0.0798)		(0.0594)
HHIp	0.0707*	0.0804**	0.154**	0.172**	0.0324	0.0778
	(0.0355)	(0.0353)	(0.0750)	(0.0728)	(0.0599)	(0.0748)
ln*L*	0.00160	0.00133	0.0115	0.00952	0.0152***	0.0161***
	(0.00457)	(0.00458)	(0.0105)	(0.0104)	(0.00568)	(0.00566)
ln*AGE*	0.0169*	0.0163*	0.0181	0.0209	-0.0426**	-0.0424**
	(0.00933)	(0.00942)	(0.0199)	(0.0200)	(0.0173)	(0.0176)
Country × industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Home country FE (if foreign owned)	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,416	1,416	666	666	1,416	1,416
R-squared	0.080	0.083	0.178	0.177	0.093	0.097

FE = fixed effect.

Notes: Robust standard errors at the country-industry level are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Source: Authors.

Now we turn to firm-level analysis to examine how the resilience of firms' supply chains is determined. We first investigate how the resilience of links with customers is determined by the geographic diversity of customers and other firm attributes and show the results in Table 8. In columns (1) and (2), the dependent variable is *RESc*, the dummy variable for the coexistence of a decrease in the transaction volume with a customer and an increase in the transaction volume with another that indicates the resilience of links with customers. In column (1), the key independent variable is *DIVERSc*, the number of countries where the top three customers are located, whereas in column (2), it is *HHIc*, the HHI of the share of sales by country. *DIVERSc* is positively correlated with *RESc*, while *HHIc* is negatively correlated. Because *HHIc* is an inverse measure of diversity, both results indicate that geographic diversity of customers leads to resilience of links with customers when firms are faced with supply chain disruptions due to the COVID-19 pandemic. Because the standard deviations of *DIVERSc* and *HHIc* are 0.82 and 0.40 (Table 5), an increase in the diversity measures by one standard deviation results in an increase in the resilience dummy, *RESc*, by 0.02–0.03. Because the average of the resilience dummy is 0.091 (Table 5), the effect of diversity is not small.

In columns (3) and (4) of Table 8, the dependent variable is *EXPANDc*, the dummy variable for an increase in the transaction volume with any of the top three customers, and the sample is restricted to firms whose transaction volume with any customer declined due to COVID-19. The direction and significance of the coefficients of the two diversity measures are the same as those in columns (1) and (2).

By contrast, throughout columns (1)–(4) of Table 8, *HHIp*, the HHI of the share of production by country, is positively and significantly correlated with the resilience measures. This finding implies that the geographic diversity of production sites deteriorates the resilience of links with customers, possibly because under multi-country economic shocks due to the global spread of COVID-19, several production sites may be affected and thus substitution across production sites can be difficult.

Table 9: Firm-Level Analysis Focusing on Relationships with Suppliers

	(1)	(2)	(3)	(4)	(5)	(6)
Independent variable	**Dependent variable**					
	RESs		***EXPANDs***		***ROBs***	
DIVERSs	0.0423***		0.0832***		-0.0114	
	(0.0109)		(0.0258)		(0.0179)	
HHIs		-0.0352		-0.0446		0.0318
		(0.0391)		(0.0992)		(0.0619)
HHIp	-0.00607	-0.0264	0.00663	-0.0607	0.0320	0.0268
	(0.0364)	(0.0437)	(0.0814)	(0.0979)	(0.0554)	(0.0659)
ln*L*	0.00371	0.00378	0.0165***	0.0179***	0.00979	0.00967
	(0.00284)	(0.00283)	(0.00607)	(0.00593)	(0.00659)	(0.00657)
ln*AGE*	0.0136	0.0139	0.0166	0.0213	-0.0484**	-0.0475**
	(0.00857)	(0.00861)	(0.0209)	(0.0216)	(0.0186)	(0.0182)
Country × industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Home country FE (if foreign owned)	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,316	1,316	607	607	1,316	1,316
R-squared	0.092	0.079	0.195	0.172	0.098	0.099

FE = fixed effect.

Notes: Robust standard errors at the country-industry level are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Source: Authors.

In Table 9, we focus on links with suppliers and conduct the corresponding analysis. In columns (1) and (3), we find a positive effect of the measure of diversity of suppliers, *DIVERSs*, on the resilience of links with suppliers. Although the effect of the reverse diversity measure, *HHIs*, is not significant in columns (2) and (4), our findings suggest that firms that diversify suppliers across countries, when facing disruption of supplies from a supplier, can flexibly procure supplies from another supplier.

In columns (5) and (6) of Tables 8 and 9, we experiment with placebo tests where measures of the robustness of supply chain links are used as the dependent variable. Theoretically, the robustness measures, which are 1 if the transaction volume with any of the top three customers or suppliers did not shrink because of COVID-19, are not supposed to be correlated with the measures of geographic diversity of suppliers or customers. That is, the diversity of partners may help firms replace damaged partners with another partner, i.e. resilience of firms, but may not affect the probability of reductions in transactions with partners, i.e. robustness of firms. As predicted, none of the (reverse) diversity measures is correlated with the robustness measures. These placebo tests highlight the importance of the geographic diversity of customers and suppliers in the resilience of supply chain links, i.e. the substitutability of partners after economic shocks, but not in their robustness.

In columns (5) and (6) of Tables 8 and 9, it is notable that *HHIp*, the measure of the geographic concentration of production sites, is not significantly correlated with any robustness measure. This finding contrasts with the negative correlation of *HHIp* with *SHRINKc* in columns (1) and (2) of Table 7, which presents a positive effect of geographic concentration on robustness at the link level. Considering further that the correlation in Table 7 is significant at only the 10% level, the positive effect of the geographic concentration on the robustness of a firm's supply chains is not robust or at best weak.

We further investigate whether firm performance is correlated with the resilience and robustness of supply chain links. For this purpose, we run OLS regressions of either sales in 2020, profits in 2020, exports in 2020, predicted profits in 2021, or predicted employment in 2021 on the measures of the robustness and the resilience of links with customers and suppliers and other controls. These dependent variables are categorical variables that take a value of 1, 2, 3, 4, and 5 if the change rate in the firm performance from the previous year is −50% or less, −1 to −49%, 0%, 1%−49%, and 50% or more, respectively. The results are shown in Table 10. Throughout the estimations, the robustness of links with customers is positively and significantly correlated with firm performance, indicating the importance of keeping links with customers. The robustness of links with suppliers is positively and significantly correlated with the predicted firm performance in the future, implying a longer-term effect of the robustness of links with suppliers. Similarly, the resilience of links with customers is correlated with the predicted firm performance but not with the current performance. In addition, the resilience of links with suppliers is not significantly correlated with any of the performance measures.

Table 10: Firm-Level Analysis of Effects of Robustness and Resilience of Supply Chains

	(1)	(2)	(3)	(4)	(5)
Independent variable	**Dependent variable**				
	Sales in 2020	**Profits in 2020**	**Exports in 2020**	**Predicted profits in 2021**	**Predicted employment in 2021**
ROBc	0.436***	0.266***	0.224***	0.299***	0.127***
	(0.0900)	(0.0892)	(0.0753)	(0.0708)	(0.0447)
RESc	0.117	0.154	0.147	0.342***	0.0901*
	(0.109)	(0.120)	(0.0927)	(0.0868)	(0.0453)
ROBs	0.0629	0.102	-0.0249	0.129**	0.129**
	(0.0972)	(0.125)	(0.0881)	(0.0537)	(0.0622)
RESs	-0.226	-0.0105	-0.182	0.0686	0.0620
	(0.168)	(0.187)	(0.120)	(0.0929)	(0.0646)
ln*L*	0.0404**	0.0430*	0.0198	0.0155	0.0119
	(0.0162)	(0.0240)	(0.0168)	(0.00953)	(0.00769)
ln*AGE*	-0.161***	-0.188***	-0.100***	-0.0657***	-0.0739***
	(0.0392)	(0.0383)	(0.0313)	(0.0226)	(0.0147)
Country × industry FE	Yes	Yes	Yes	Yes	Yes
Home country FE (if foreign owned)	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes
Observations	1,222	1,093	1,237	1,267	1,274
R-squared	0.165	0.131	0.112	0.159	0.154

FE = fixed effect.

Notes: Robust standard errors at the country-industry level are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Source: Authors.

Finally, we point to the effect of the size and age of firms on their resilience, robustness, and performance. The results in Tables 8–10 indicate that larger and younger firms are more likely to be resilient, robust, and high-performing during the COVID-19 pandemic. Although the conclusion does not always hold and depends on specifications, it is consistent with the results from the link-level analysis presented in Table 7.

6. Discussion and Conclusions

This paper examines how the robustness and resilience of supply chain links, i.e. maintaining links and substituting another for a disrupted partner, respectively, were determined when firms faced the economic shocks due to the pandemic of COVID-19, focusing on the role of the characteristics of firms' supply chains. The empirical results and implications obtained from the results can be summarised as follows.

First, homophily is often associated with robustness of supply chain links, most likely because of the strength of homophilous ties as suggested in the literature (Louch, 2000; Ruef, Aldrich, and Carter, 2003). In particular, when a foreign-owned firm has a supply chain link with a firm located in the same country as its home country, the link is quite robust. Further, the robustness of supply chains is found to be a key factor of higher firm performance in the middle of economic shocks – both in the short and long run.

Second, when firms are linked through both supply chains and ownership relationships, the transaction volume between them tends to decline more than when they are linked through only supply chains. This negative effect of ownership relationships on the robustness of links is prominent for domestically owned firms but not for foreign-owned firms. There are several possible reasons for the negative effect of strong supply chain links. First, strong links are often associated with specific inputs and thus vulnerability in the wake of shocks. Second, strong links are often associated with clusters where firms are densely connected with each other, resulting in circulation of shocks in the cluster. Finally, firms may try to maintain arm's-length transactions more than intra-firm transactions because the former may not be recovered easily once lost due to economic shocks. Combining with the first finding, this implies that strong supply chain links are not necessarily robust.

Third, the geographic diversity of customers and suppliers creates resilience of supply chains. When the demand or supply from a partner of a firm is disrupted because of economic shocks, the firm can mitigate the damage from the disruption by replacing the affected partner with another if its supply chains are well diversified across countries. The resilience of supply chains, particularly those with customers, further results in higher performance in the long run.

Finally, the geographic diversity of production sites is found to be negatively correlated with the robustness and resilience of supply chain links in some specifications, although the correlation is not statistically significant in others. The lack of robustness of the negative effect of the geographic diversity of production sites arises possibly due to the following two contrasting forces. On the one hand, when the production sites of a firm are geographically diversified and economic shocks spread across countries, the probability that some of its production sites are affected by a shock increases. On the other hand, because the probability that some others are not affected is also higher in the case of geographic diversity than otherwise, the firm may mitigate the economic shock by substituting active sites for affected sites. Because of the two opposing forces, the overall effect of the geographic diversity of production on the robustness and resilience of supply chains is unclear.

These two forces related to the geographic diversification of production sites can also be applied to the diversification of supply chain partners. Our results on the effect of supply chain diversity (columns [1]–[4] of Tables 8 and 9), which are more robust and significant than those on the effect of production diversity, suggest that the positive effect of supply chain diversity through increasing the substitutability of customers and suppliers surpasses its negative effect through increasing the risk of supply chain disruptions.

Two caveats to this paper should be pointed out. First, although we made every effort to collect data from as many firms as possible in the target region, the response rate is quite low (section 4.1), and the number of firms in our sample for the estimations is not very large. Moreover, how we chose target firms was not random but relied heavily on the existing network of Deloitte, a global consulting company. Accordingly, foreign-owned firms and fast-growing firms are over-weighted in our sample. However, this sampling strategy may be justified because our focus is on global supply chains. In addition, it should be emphasised that our data are quite unique in that they contain information about changes in transactions in each supply chain link, not only changes in firm-level performance or country-industry-level trade. Second, although our key independent variables, such as the measures of homophily between firm pairs and the geographic diversity of customers and suppliers, are predetermined, they would still be correlated with the error term through related but unobservable effects. For example, our homophily measures are based on firm size and geographic location, but supply chain partners could be homophilous in other aspects unobserved in our data. As a result, the effect of our homophilous measures may pick up the effect of homophily in unobserved aspects and thus be overvalued. The effect of the geographic diversity of customers and suppliers may also capture the effect of unobserved variables that are correlated with geographic diversity, such as managers' outgoing characteristics. Although we include as many control variables as possible, including a full set of dummy variables, endogeneity may arise due to unobservable effects. We leave this issue for future research.

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Appendix

Table A1: Link-Level Analysis

	(1)	(2)		(3)	(4)
Independent variable	***SHRINKc***	***SHRINKc***		***SHRINKs***	***SHRINKs***
HOM_SIZEc	-0.0360*	-0.0371*	*HOM_SIZEs*	0.0121	0.0121
	(0.0192)	(0.0191)		(0.0223)	(0.0223)
HOM_FDIc	-0.0816**	-0.0725**	*HOM_FDIs*	-0.139***	-0.137***
	(0.0346)	(0.0346)		(0.0430)	(0.0433)
OWNc	0.161***	0.213***	*OWNs*	0.121***	0.120*
	(0.0393)	(0.0535)		(0.0433)	(0.0672)
OWNEDc	-0.0274	-0.0447	*OWNEDs*	0.0303	0.0424
	(0.0337)	(0.0382)		(0.0468)	(0.0701)
OWNc × FDI		-0.138**	*OWNs × FDI*		-0.00280
		(0.0665)			(0.0868)
OWNEDc × FDI		0.0375	*OWNEDs × FDI*		-0.0327
		(0.0619)			(0.0827)
HHIp	-0.0655*	-0.0649*	*HHIp*	-0.0697	-0.0687
	(0.0376)	(0.0375)		(0.0445)	(0.0448)

ln*L*	-0.0111***	-0.0108***	ln*L*	-0.00179	-0.00177
	(0.00409)	(0.00410)		(0.00568)	(0.00571)
ln*AGE*	0.0287***	0.0286***	ln*AGE*	0.0328**	0.0328**
	(0.0104)	(0.0104)		(0.0159)	(0.0160)
Lc_medium	-0.000794	0.000148	*Ls_medium*	-0.0896***	-0.0892***
	(0.0397)	(0.0400)		(0.0310)	(0.0313)
Lc_large	-0.0471	-0.0452	*Ls_large*	-0.126***	-0.126***
	(0.0316)	(0.0314)		(0.0307)	(0.0309)
Country × industry FE	Yes	Yes	Country × industry FE	Yes	Yes
Customer's country ×industry FE	Yes	Yes	Supplier's country ×industry FE	Yes	Yes
Home country FE (if foreign owned)	Yes	Yes	Home country FE (if foreign owned)	Yes	Yes
Controls	Yes	Yes	Controls	Yes	Yes
Observations	4,269	4,269	Observations	3,931	3,931
R-squared	0.112	0.113	R-squared	0.117	0.117

FE = fixed effect.
Notes: Robust standard errors at the country-industry-partner's country level are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.
Source: Authors.

Table A2: Firm-Level Analysis Focusing on Relationships with Customers

	(1)	(2)	(3)	(4)	(5)	(6)
Independent variable			**Dependent variable**			
	RESc		***EXPANDc***		***ROBc***	
DIVERSc	0.0235***		0.0644***		-0.000924	
	(0.00822)		(0.0231)		(0.0128)	
HHIc		-0.0704**		-0.165**		-0.0570
		(0.0344)		(0.0798)		(0.0594)
HHIp	0.0707*	0.0804**	0.154**	0.172**	0.0324	0.0778
	(0.0355)	(0.0353)	(0.0750)	(0.0728)	(0.0599)	(0.0748)
ln*L*	0.00160	0.00133	0.0115	0.00952	0.0152***	0.0161***
	(0.00457)	(0.00458)	(0.0105)	(0.0104)	(0.00568)	(0.00566)
ln*AGE*	0.0169*	0.0163*	0.0181	0.0209	-0.0426**	-0.0424**
	(0.00933)	(0.00942)	(0.0199)	(0.0200)	(0.0173)	(0.0176)
Country × industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Home country FE (if foreign owned)	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,416	1,416	666	666	1,416	1,416
R-squared	0.080	0.083	0.178	0.177	0.093	0.097

FE = fixed effect.
Notes: Robust standard errors at the country-industry level are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.
Source: Authors.

Table A3: Firm-Level Analysis Focusing on Relationships with Suppliers

	(1)	(2)	(3)	(4)	(5)	(6)
Independent variable			**Dependent variable**			
	RESs		***EXPANDs***		***ROBs***	
DIVERSs	0.0423***		0.0832***		-0.0114	
	(0.0109)		(0.0258)		(0.0179)	
HHIs		-0.0352		-0.0446		0.0318
		(0.0391)		(0.0992)		(0.0619)
HHIp	-0.00607	-0.0264	0.00663	-0.0607	0.0320	0.0268
	(0.0364)	(0.0437)	(0.0814)	(0.0979)	(0.0554)	(0.0659)
ln*L*	0.00371	0.00378	0.0165***	0.0179***	0.00979	0.00967
	(0.00284)	(0.00283)	(0.00607)	(0.00593)	(0.00659)	(0.00657)
ln*AGE*	0.0136	0.0139	0.0166	0.0213	-0.0484**	-0.0475**
	(0.00857)	(0.00861)	(0.0209)	(0.0216)	(0.0186)	(0.0182)
Country × industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Home country FE (if foreign owned)	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,316	1,316	607	607	1,316	1,316
R-squared	0.092	0.079	0.195	0.172	0.098	0.099

FE = fixed effect.

Notes: Robust standard errors at the country-industry level are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Source: Authors.

Table A4: Firm-Level Analysis of Effects of Robustness and Resilience of Supply Chains

	(1)	(2)	(3)	(4)	(5)
Independent variable			**Dependent variable**		
	Sales in 2020	**Profits in 2020**	**Exports in 2020**	**Predicted profits in 2021**	**Predicted employment in 2021**
ROBc	0.436***	0.266**	0.224***	0.299***	0.127***
	(0.0977)	(0.105)	(0.0857)	(0.0626)	(0.0416)
RESc	0.117	0.154	0.147	0.342***	0.0901*
	(0.130)	(0.140)	(0.113)	(0.0817)	(0.0541)
ROBs	0.0629	0.102	-0.0249	0.129**	0.129***
	(0.0975)	(0.104)	(0.0849)	(0.0621)	(0.0413)
RESs	-0.226	-0.0105	-0.182	0.0686	0.0620
	(0.140)	(0.151)	(0.125)	(0.0892)	(0.0593)
ln*L*	0.0404**	0.0430**	0.0198	0.0155	0.0119
	(0.0173)	(0.0185)	(0.0151)	(0.0111)	(0.00734)
ln*AGE*	-0.161***	-0.188***	-0.100***	-0.0657***	-0.0739***
	(0.0387)	(0.0411)	(0.0332)	(0.0243)	(0.0161)
Country × industry FE	Yes	Yes	Yes	Yes	Yes
Home country FE (if foreign owned)	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes
Observations	1,222	1,093	1,237	1,267	1,274
R-squared	0.165	0.131	0.112	0.159	0.154

FE = fixed effect.

Notes: Robust standard errors at the country-industry level are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Source: Authors.

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