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Mapping and testing product-level vulnerabilities in granular production networks

Antoine Berthou, Antton Haramboure, Lea Samek (OECD)

This paper conducts an in-depth mapping of global value chain (GVC) vulnerabilities, using granular product-level trade data to identify vulnerable products with limited suppliers and substitutability. The study reveals that, in OECD countries, approximately 8% of foreign-sourced intermediate products are vulnerable, with about 50 products identified as highly vulnerable, particularly in the pharmaceutical, mining, and manufacturing sectors. The paper also introduces a quantitative framework for simulating supply shock transmission from upstream suppliers to downstream industries over the short and medium term. This framework leverages unique data that combine Inter-Country Input-Output with detailed product-level trade data from Comtrade. Through simulation exercises, the paper highlights the role of supplier concentration and geography in shock transmissions, as well as the effectiveness of policies in mitigating these impacts. This novel cross-country assessment of GVC disruptions provides new insights on how to manage supply chains in a global economy subject to multiple risks.

Keywords: Global Value Chains, International trade, Resilience

JEL codes: F14, F68, L52

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Executive summary

Global value chains (GVCs) are made of complex networks of buyers and suppliers, operating in different countries and industries, and exchanging specific intermediate inputs that are essential to the functioning of downstream industries. These networks have received extensive policy attention in a context where major shocks have severely impaired their capacity to operate efficiently in recent years. Recent research shows that a large supply shock affecting one supplier in the production network can have large macroeconomic consequences in granular supply chains, depending on the importance of input-output linkages and the network's overall structure. For governments, being aware of existing vulnerabilities and of the quantitative diffusion of different shocks through these networks, is essential to design ex-ante adequate policies to improve economic resilience.

The first objective of this paper is to provide a granular (product-level) mapping of GVC vulnerabilities, based on a combination of product-level bilateral trade data (UN Comtrade) and input-output linkages by country and industry pairs (OECD's Inter-Country Input-Output tables, ICIO). This information allows to measure two important parameters that determine the vulnerability of product supplies in production networks: (1) the concentration of product-level purchases from specific suppliers, reflecting the specificity of the buyer-seller relationship; and (2) the concentration of global export market shares for each product, which informs about the capacity to rely on alternative suppliers in the case of an upstream supply disruption (product-level substitutability of suppliers).

Several facts emerge based on the analysis of the underlying product-level trade data. In particular, the relationship to suppliers at product level appears more concentrated than product-level global export market shares. This highlights the specificity of buyer-seller relations in production networks. Based on the granular GVC mapping, we can identify, for each country in the data, moderately and highly vulnerable products sourced from foreign partners. In each country within the OECD and G20 non-OECD economies, less than 10% of sourced intermediate products are identified as vulnerable, and about 50 products can be listed as highly vulnerable according to our selection criteria. Vulnerable products are particularly sourced from the pharmaceutical industry, mining, and other manufacturing industries.

The second objective is to develop a quantitative framework to assess the transmission of upstream product-level supply shocks to downstream industries. This quantitative framework builds on the merged ICIO-Comtrade dataset used in the granular GVC mapping exercise. It allows to track dependencies on Tier1 suppliers, and to quantify the short and medium-term reaction to shocks in stress-test scenarios. The scenarios are designed to reflect plausible shocks that could impede the functioning of production networks. A first scenario illustrates the possible consequences for downstream industry output of a large-scale natural disaster affecting the supply of all products from one country. This scenario applies shocks to two countries having faced large-scale earthquakes in the past two decades: Japan and Türkiye. A second scenario explores the consequences of a shock affecting the supply of advanced technology products.

The simulation results indicate that the impact of these shocks on downstream production can be large when the supplier share is high and substitutability is low. This reflects the criteria used to identify supply chain vulnerabilities in the granular GVC mapping exercise presented in Section 2 of this paper. Last, we conduct counterfactual exercises to evaluate the role of diversification and adaptation policies reducing ex-ante the supplier concentration or increasing the substitutability between different suppliers of the same product. Results show a complementarity between diversification policies and policies designed to enhance the adaptability of the production structure. Diversification can work if alternative suppliers can supply downstream producers with intermediate inputs that have the required characteristics and that can be embedded into the production process. This can be obtained, for instance, by adopting industry standards on certain types of key intermediate inputs for industrial production.

This study is among the first to quantify the effects of upstream product-level supply shocks to downstream industries in a cross-country framework. This work echoes similar efforts made by different institutions to improve the mapping of GVCs in different countries based on granular data. It also completes recent efforts to better map the ongoing reorganisation of GVCs in the global economy.

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1 Introduction

Global value chains (GVCs) are made of complex networks of buyers and suppliers, operating in different countries and industries, and exchanging specific intermediate inputs that are essential to the functioning of downstream industries. These complex production networks, which have evolved rapidly since the early 1990s, have received extensive policy attention in a context where major shocks have severely impaired their capacity to operate efficiently (Aiyar and Ilyina, 2023[1]). The risks threatening the smooth operation of production networks stem from rising geopolitical tensions, pandemics such as Covid-19, or the increased frequency of large-scale natural disasters due to global warming (OECD, 2021[2]; Crowe and Rawdanowicz, 2023[3]). From an economic policy point of view, it is important to better map vulnerabilities in these production networks, and to better understand the diffusion of shocks of different natures and their macroeconomic consequences at different time horizons. Against this background, governments in OECD countries are starting to evaluate the vulnerability of their production networks to build adequate resilience and industrial policies (Criscuolo et al., 2022[4]).

This paper has two complementary objectives. The first objective is to provide a granular (product-level) mapping of GVC vulnerabilities, based on a combination of product-level bilateral trade data (UN Comtrade) and input-output linkages by country and industry pairs (OECD's Inter-Country Input-Output tables, ICIO). This information allows to measure two important parameters that determine the vulnerability of product supplies in production networks: (1) the concentration of product-level purchases from specific suppliers, reflecting the specificity of the buyer-seller relationship; (2) the concentration of global export market shares for each product, which informs about the capacity to rely on alternative suppliers in the case of an upstream supply disruption (product-level substitutability of suppliers). Several facts emerge based on the analysis of the underlying product-level trade data. In particular, the relationship to suppliers at product level appears more concentrated than product-level global export market shares. This highlights the specificity of buyer-seller relations in production networks. Based on the granular GVC mapping, we can identify, for each country in the data, moderately and highly vulnerable products sourced from foreign partners. In each country within the OECD and G20 non-OECD, less than 10% of sourced intermediate products are identified as vulnerable, and about 50 products can be listed as highly vulnerable according to our selection criteria. Vulnerable products are sourced from the pharmaceutical industry, mining, or other manufacturing industries.

The second objective is to develop a quantitative framework to assess the transmission of upstream product-level supply shocks to downstream industries. This framework builds on the merged ICIO-Comtrade dataset used in the granular GVC mapping exercise. It allows to track dependencies on Tier1 suppliers, and to quantify the short and medium-term reaction to shocks in stress-test scenarios. The scenarios are designed to reflect plausible shocks that could impede the functioning of production networks. A first scenario illustrates the possible consequences for downstream industry output of a large-scale natural disaster affecting the supply of all products from one country. This scenario applies shocks to two countries that have faced large-scale earthquakes in the past two decades: Japan and Republic of Türkiye. A second scenario explores the consequences of a shock affecting the supply of advanced technology products. The simulation results indicate that the impact of these shocks on downstream production can be large when the supplier share is high and substitutability is low. This reflects the criteria used to identify supply chain vulnerabilities in the granular GVC mapping exercise presented in Section 2 of this paper. Last, we conduct counterfactual exercises to evaluate the role of diversification and adaptation policies reducing *ex-ante* the supplier concentration or increasing the substitutability between different suppliers of the same product. Results show a complementarity between diversification policies and policies designed to enhance the adaptability of the production structure. Diversification can work if alternative suppliers can supply downstream producers with intermediate inputs that have the required characteristics and that can be embedded into the production process. This can be obtained, for instance, by adopting industry standards for intermediate inputs being key for industrial production.

The great expansion of production networks since at least the beginning of the 1990's has helped to drive productivity and welfare gains in open economies. This process of GVCs expansion has, however, stabilized – and remained at a high level -- since around the Great Financial Crisis (Baldwin, 2022[5]; Aiyar et al., 2023[6]). While these supply chains are highly efficient in a frictionless world, their complexity, and the high level of dependence from a limited number of suppliers in some segments of the network, can be a source of fragility in a world characterised by greater uncertainty. A large supply shock affecting one supplier in the production network can have large macroeconomic consequences in granular supply chains, depending on the importance of input-output linkages but also the overall structure of the network (Acemoglu et al., 2012[7]; di Giovanni, Levchenko and Mejean, 2018[8]; Giovanni, Levchenko and Mejean, 2020[9]). For governments, being informed about existing vulnerabilities in production networks, and the quantitative diffusion of different shocks through these networks, is essential to design *ex-ante* adequate policies to improve economic resilience.

Evidence on the actual diffusion of shocks through production networks has been highlighted in recent studies that explored the consequences of the 2011 Tohoku earthquake in Japan towards downstream producers in Japan or in the United States (Carvalho et al., 2020[10]; Boehm, Flaaen and Pandalai-Nayar, 2019[11]). The work of Carvalho et al. (2020[10]) in particular shows that input-output relationships in Japan significantly enhanced the transmission of the shock to downstream firms, and amplified the macroeconomic output loss in Japan. Boehm et al. (2019[11]) highlight the role of foreign affiliates of Japanese business groups in the United States in the international propagation of the shock. A related work highlights the transmission of the Thai floods the same year to Swedish firms (Forslid and Sanctuary, 2023[12]). Our simulation results of a natural disaster in Japan illustrates the role played by product-level dependencies in GVCs. They predict that the motor vehicles industry in Thailand would be highly affected by a natural disaster in Japan, which is validated by the monthly data on industrial production in Thailand and Japan for the motor vehicles industry around the timing of the Tohoku earthquake in March 2011. The data indicate a quasi-full pass-through of the Japanese shock to the motor vehicles production in Thailand between one or two months after the earthquake. This evidence also highlights that the transmission of shocks across borders can be fast, and that the short-term reaction can differ strongly from the long-term one.

Mapping GVC vulnerabilities requires harmonised data combining information about industry output and cross-country input-output linkages between sectors. Such data is collected by the OECD in its ICIO dataset. Recent works based on OECD's ICIO data confirm that production networks are complex, with the output from upstream industries being embedded into the output of downstream industries and crossing several borders before reaching the final consumer. These data also allows to account for the direct linkages between Tier1 suppliers and buyers in production networks, but also for higher order, indirect ("hidden"), linkages between countries and industries (Inomata and Hanaka, 2021[13]; Schwellnus et al., 2023[14]; Baldwin, Freeman and Theodorakopoulos, 2022[15]; Baldwin, Freeman and Theodorakopoulos, 2023[16]). Baldwin et al. (2023[16]) show, for instance, that US supply chain dependencies are more accurate when accounting for the hidden exposure through indirect input-output linkages, compared with a more conventional approach based on trade data.

The assessment of upstream supply shocks on downstream output necessarily relies on quantitative tools that have become extremely popular in research and policy communities. These models are calibrated to match global input-output tables and are solved under general equilibrium (i.e., they also account for the adjustment in factors' markets). At OECD, Arriola et al. (2020[17]) rely on METRO, a Conputational General

Equilibrium model, to assess the efficiency loss due to reshoring in the context of Covid-19. Different models have been used to analyse the diffusion of the Covid-19 shock (Bonadio et al., 2021[18]; Barrot, Grassi and Sauvagnat, 2021[19]; Gerschel, Martinez and Mejean, 2020[20]), the consequences of the Russian war of aggression against Ukraine on gas supplies in Germany or France (Bachmann et al., 2022[21]; Baqaee et al., 2022[22]), the costs of decoupling from the Russian Federation (hereafter, 'Russia') (Borin et al., 2023[23]) or to analyse different scenarios of global fragmentation shocks (Attinasi, Boeckelmann and Meunier, 2023[24]; Javorcik et al., 2023[25]). The quantitative frameworks used in these studies track the diffusion of shocks through direct and indirect dependencies in production networks, and account for the factors markets' adjustments, which allows to assess the macroeconomic impacts of shocks or policies in terms of GDP gains or losses.

Some limitations in the analysis are inherent to the use of these large models. Firstly, they offer a steady-state picture of the adjustment following the initial shock, and cannot track the adjustment of output in the transition period (i.e., in the short or medium term). Secondly, they do not account for the observed high concentration in buyer-seller relations for some specific products, as these models are typically calibrated using sector-level data on trade and production. Against this backdrop, our quantitative framework is flexible enough to map product-level dependencies. Substitution elasticities are calibrated to reflect the short- and medium-term adjustment of output, which can inform on the appropriate policy response following a shock. While the initial development of this quantitative framework reflects Tier1 relationships between suppliers and buyers in production networks, further developments should account for higher-order relationships.

To the best of our knowledge, our study is among the first to quantify the effects of upstream product-level supply shocks to downstream industries in a cross-country framework. It relates to a complementary approach developed by the Bank of Italy to track dependencies in the Italian production network based on firm-level data (Borin et al., 2023[26]). Our work also echoes similar efforts made by different institutions to improve the mapping of GVCs in different countries based on more granular (product or firm-level) or alternative (e.g., survey-based) data (Bonneau and Nakaa, 2020[27]; European Commission, 2021[28]; Méjean and Jaravel, 2021[29]; Amaral et al., 2022[30]; Benoit et al., 2022[31]; Baur and Flach, 2022[32]; Vicard and Wibaux, 2023[33]; Arjona, Connell and Herghelegiu, 2023[34]).

This work also completes recent efforts to better map the ongoing reorganisation of GVCs in the global economy. There is evidence that in recent years, the People's Republic of China's (hereafter, 'China') market share in US imports declined, especially in products that were targeted by import tariffs imposed by the administrations of the two countries. Missing Chinese exports to the United States were compensated by higher exports from other Asian economies highly connected to the Chinese supply chain (Vietnam) or neighbours of the United States (Mexico) (Fajgelbaum et al., 2023[35]; Freund et al., 2023[36]; Alfaro and Chor, 2023[37]). While this evidence shows that some diversification – or nearshoring -- of supply linkages may be taking place, the hidden dependencies suggest that China remains a major supplier for an economy such as the United States.

Policy recommendations need to account for the very high degree of relationship stickiness in trade relationships (Martin, Mejean and Parenti, 2021[38]; Nunn, 2007[39]). This pattern is also observed in the aftermath of large natural disasters (Freund et al., 2022[40]). We believe that the quantifications presented in this paper can help to guide the debate about the appropriate adaptation or mitigation policies that are now widely discussed in light of the higher risks of supply chain disruptions in many OECD countries and industries (Schwellnus, Haramboure and Samek, 2023[41]).

The paper is organised as follows. Section 2 presents the granular mapping of GVC dependencies with a focus on the motor vehicles industry and summarises key findings from previous studies. Section 3 presents the quantitative framework to conduct granular GVC stress-testing. Technical details on this quantitative framework are relegated to the appendix. The last section concludes.

2 Identifying vulnerabilities in granular supply chains

This Section presents a strategy to identify vulnerable products in production networks, focusing on OECD and non-OECD G20 countries. The analysis proceeds in two stages. First, it develops an upstream mapping of dependent products based on product-level trade data (UN Comtrade), which does not account for the use of these products by downstream industries. This approach is similar to the studies discussed in Box 2.1 (e.g., the European Commission's bottom-up approach). Second, it accounts for downstream sector dependencies by combining the product-level trade data with the OECD's ICIO tables.

Supply of intermediate products and their concentration in production networks

The analysis is based on product-level (Harmonised System, HS6) trade flows between countries reported in the UN Comtrade dataset. Given the focus on vulnerabilities in production networks, the analysis relies on flows of intermediate products identified using the OECD's product classification of goods by end use.[1] In doing so, vulnerable products exclude final goods. The supply of final goods may be highly concentrated geographically, but this would not lead to a major threat regarding production in downstream industries. The data cover the years 2017-19, i.e., prior to the Covid-19 pandemic that heavily distorted trade relationships between countries (Berthou and Stumpner, 2022[42]).

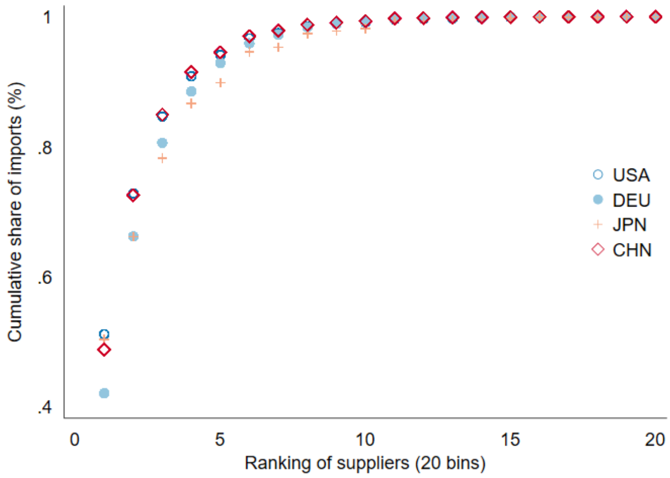
Figure 2.1 illustrates the very high degree of geographical concentration of imports in each product category, for four large open economies (the United States, Japan, Germany and China). The graph presents the cumulative share of supplying countries in imports of intermediate products, where suppliers are ranked into 20 bins of equal size. In this chart, the top 5% of suppliers account for about half of total imports of the average intermediate product.

In the approach developed in this paper, the assessment of product-level vulnerability in supply chains, for each importing country, relies on the combination of two Herfindahl-Hirschman Indexes (HHI):

- **HHI-M:** The geographical supply concentration of product-level imports, hereafter "supply concentration".
- **HHI-MSX:** The global export market shares concentration by product, hereafter "market share concentration".

Figure 2.1. Imports of intermediate products are highly concentrated in a handful of suppliers

Cumulative share of supplying countries in imports of intermediate products: Evidence from four large open economies, 2017-19



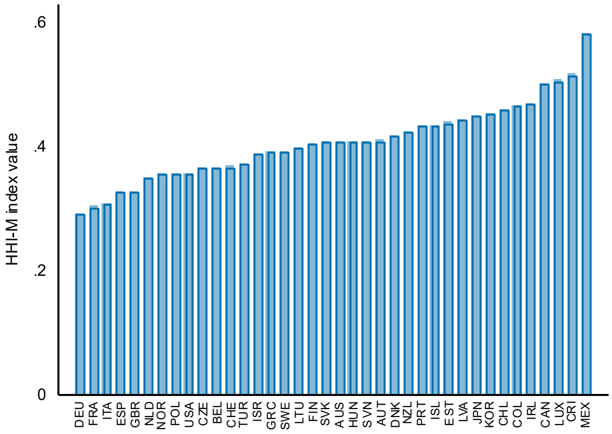
Note: This chart shows the cumulative supplier shares in intermediate products imports for three large open economies (China, Germany, United States and Japan). Each rank corresponds to 5% of the distribution (for example: suppliers of rank 1 represent the top 5%).
Source: UN Comtrade and BTDIxE, OECD calculation.

Although we should expect a positive correlation between HHI-M and HHI-MSX, the two indicators provide complementary information. For instance, input supplies may appear highly concentrated even when alternative suppliers exist, and the global export of the product is not too concentrated. This may reveal relationship-specific dependencies in supply chains that introduce a high risk for downstream producers, even when there exists a possibility to change suppliers (Martin, Mejean and Parenti, 2021[38]). In these complex supply chains, diversifying the sourcing of foreign inputs may require time and additional investment. For this reason, downstream producers may be discouraged from doing so. This may be due, for instance, to uncertainty about the quality of inputs supplied by alternative upstream firms. In highly competitive markets with strategic complementarities between major players, paying this extra cost of supply chain adaptation may be detrimental in terms of sales and profitability.

The cross-country heterogeneity in dependencies and concentration of foreign imported inputs revealed by the HHI-M index is considerably impacted by the geography, which shapes the production organisation in complex value chains. For instance, the high degree of supply concentration of imported inputs for Mexico and Canada in Figure 2.2 (which reports the simple average of the index by country) reflects these countries' close linkages with the United States. In European countries, such as Germany, France, or Italy, imported inputs are less geographically concentrated, which is also explained by the more fragmented geography in Europe. However, a very large share of European firms source their intermediate inputs from within the boundaries of the European Union, reflecting the important role played by trade costs for the organisation of production networks.

Figure 2.2. Geography has a strong impact on countries' GVC dependencies

Geographical concentration in product-level intermediate imports, by OECD country, 2017-19



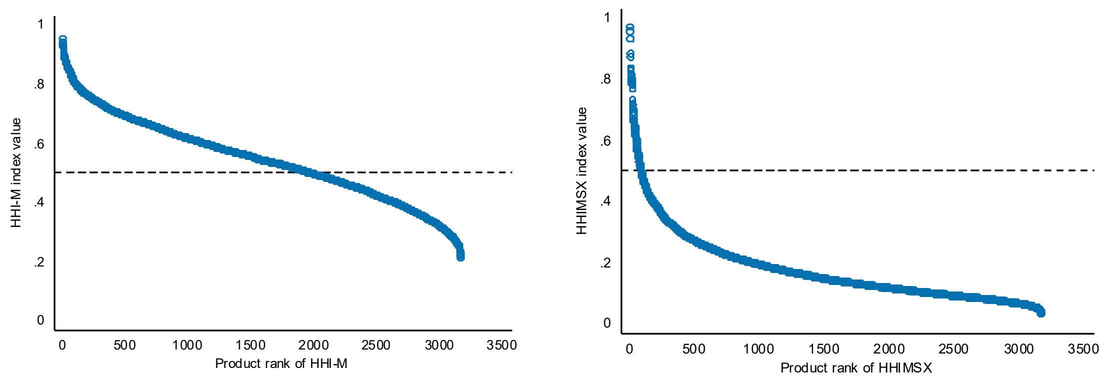
Note: This chart reports the geographical concentration of product-level intermediate input imports for OECD countries based on the HHI-M indicator.
Source: Comtrade, BTDIxE, OECD calculations.

The distributions of product concentration in the HHI-M and HHI-MSX indexes reported in Figure 2.3 show that more products appear highly concentrated on average in the HHI-M (Panel A) compared to the HHI-MSX (Panel B) index. In other words, the concentration of *actual suppliers* revealed by the geographical distribution of intermediate product imports is stronger than that of *potential suppliers* using the same data.

Figure 2.3. Downstream industries rely on few product suppliers even when exports are not too concentrated.

Geographical concentration of product-level trade (average 2017-21)

A: Intermediate imports (HHI-M) B: Global export market shares (HHI-MX)



Note: This chart reports the distribution of HHI-M and HHI-MSX indicators over the entire set of intermediate products.
Source: Comtrade, BTDIxE, OECD calculation

This leads to two competing interpretations that can have important policy implications.

- The **diversification opportunity's** view: Intermediate product imports are highly concentrated, but there are opportunities to source from alternative suppliers in case of a shock and to diversify *ex-*

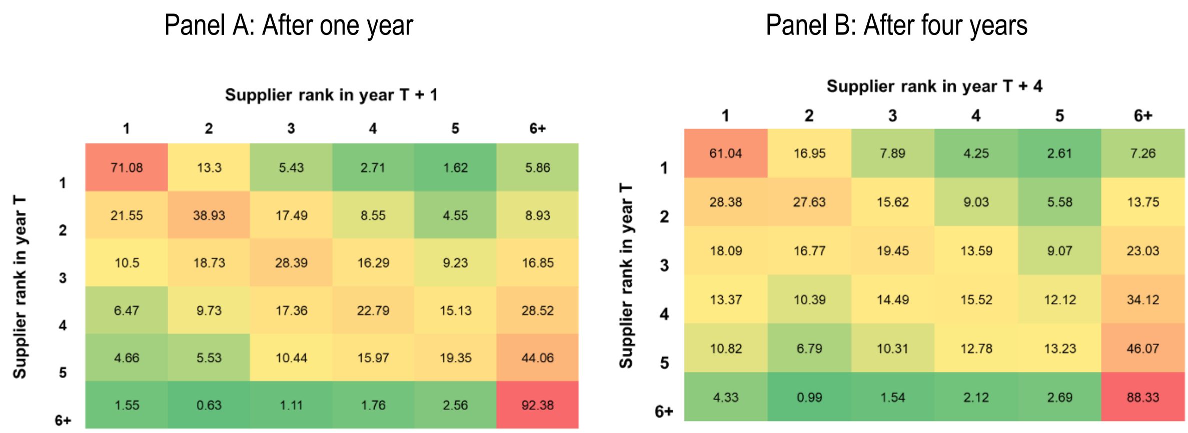
ante. This calls for governments to identify those products for which some diversification opportunities may exist.

- The **relationship-specific** view: Although possibilities to diversify intermediate product imports exist, firms in downstream production stages do not find it optimal to do so, given the high cost and the logistics challenge. Buyer-supplier relationships tend to be sticky; they are established for periods that can last several years and often require joint investment, meaning that relying on alternative suppliers in the short term may be detrimental to competitiveness in terms of production cost or product quality.

To bring new light on the persistence of buyer-seller relations in product-level trade data, Figure 2.4 reports a transition matrix of the supplier's rank for intermediate inputs. The transition matrix on the left illustrates the very high persistence of these relations between two consecutive years: On average, the probability of remaining the top supplier of an intermediate product between two consecutive years is 71% and reaches 84% when remaining among the top two suppliers (which is calculated by summing the percentages in the top cells in columns 1 and 2). However, a more substantial reallocation of market shares can be observed over a longer time, though persistence in the ranking of suppliers remains high. Over a period of five years (in our data between 2017 and 2021, see the transition matrix on the right), the probability of remaining the top supplier of intermediate inputs is 61%, and the probability to remain among the top two suppliers is 78%. Some heterogeneity may be observed between different products due to the specificity of the buyer-seller relationship, or between different countries depending on their contract enforcement capabilities (Nunn, 2007[39]). We plan to exploit this country and sector heterogeneity in future research. Overall, the pattern presented in Figure 2.4 illustrates the difficulties to find alternative suppliers in a relatively short time.

Figure 2.4. Relationships with top suppliers are persistent

Transition matrixes on supplier rank, 2017-21



Note: Transition matrixes of supplier's rank, based on product-level trade data. Frequencies sum in rows.
Source: Comtrade, BTDIxE, OECD calculation.

Identifying vulnerable intermediate products using granular trade data

The identification of vulnerable intermediate products imported by each country relies on two thresholds of the HHI-M and the HHI-MSX concentration indexes. Having two levels of vulnerabilities, rather than one single threshold, allows for a more flexible approach (Box 2.1) which, in line with other studies, can be used to illustrate dependencies and establish lists of highly vulnerable and moderately vulnerable products.[2] The classification of vulnerable products is specific to each product *and* importing country. We also add a third criteria to account for the possibility of domestic substitutability in each country: intermediate products can be classified as vulnerable according to the previous two criteria if the country-level total imports of the product exceed the country-level exports of that product. This last criterion is similar to the one used by the European Commission in its report on supply chain vulnerabilities (European Commission, 2021[28]).

- **Highly vulnerable products**: These products are characterised by a very high supply concentration in intermediate product imports (HHI-M > 0.5) and a very high concentration of global export market shares at product-level (HHI-MSX > 0.5). Total imports of that product need to exceed total exports of the same product.
- **Moderate vulnerability**: These products are characterised by a moderate supply concentration in intermediate product imports (0.5 > HHI-M > 0.3) and a moderate concentration of global export market shares at product-level (0.5 > HHI-MSX > 0.3). Total imports of that product need to exceed total exports of the same product.
- **Low vulnerability**: This category identifies product-level imports not specified in the previous two categories.

Box 2.1. A review of methodologies to identify vulnerable products

Identifying GVC dependencies at the global level requires data such as the OECD's ICIO tables. Recent geopolitical tensions, pandemics or natural disasters, however, have highlighted that dependencies can be particularly strong in specific products. This is the case, for instance, of intermediate products such as semiconductors and critical raw materials, or strategic products of consumption such as paracetamol. Such dependencies may, however, be visible only based on data reporting supplier-buyer relationships at the granular level.

Against this background, several studies on GVC vulnerabilities have relied on product-level trade data from different sources (UN Comtrade, BACI, or firm-level data) to identify vulnerable products sourced from foreign suppliers (see Bonneau and Nakaa (2020[27]), Méjean and Jaravel (2021[29]), European Commission (2021[28]), Baur and Flach (2022[32]), Vicard and Wibaux (2023[33]), Arjona et al. (2023[34])). These studies have relied on different indicators with the goal to identify (i) the concentration of suppliers, (ii) the importance of foreign suppliers in domestic demand, or (iii) the substitutability of different suppliers (e.g., between domestic and foreign, or among foreign suppliers of different origins).

As an illustration of this type of approach, the European Commission (2021[28]) defines products as vulnerable if three conditions are met: (i) the HHI measuring import concentration exceeds 0.4; (ii) extra-EU imports represent more than 50% of total EU *imports*; (iii) the ratio of extra-EU *imports* over total EU *exports* is above one, reflecting low substitutability. Different metrics are used in these studies, but all cover these dimensions with different thresholds. For instance, the European Commission (2021[28]) uses a threshold for the HHI index measuring product-level import concentration of 0.4, and together with the other two criteria listed above, identify about 390 vulnerable products sourced from extra-EU partners. Out of these 390 products, 137 are involved in the most sensitive ecosystems identified by the European Commission. The exact number of vulnerable products identified is influenced by the choice of the vulnerability threshold and the degree of disaggregation in the data. For instance, a low degree of concentration obtained based on poduct-level trade data with 6 digit codes (such as in BACI or UN Comtrade) may hide highly differentiated products when considering more detailed product categories. Accounting for re-exports in international trade data can also modify substantially the patterns in terms of import concentration, as shown by Arjona et al. (2023[34]).

As a first remark, it is important to stress that these classifications of product vulnerabilities (and the one presented in this paper) do not account for the nature of shocks (i.e., their frequency, size, or duration). The mapping of vulnerabilities identifies which dependencies are risky based on the high concentration of foreign supply, but does not specify the nature of possible foreign shocks that could diffuse through production networks, or evaluate the economic consequences should these risks materialise. To address this gap, Section 3 of this paper presents a methodology to simulate the transmission of granular supply shocks along the production network to foreign downstream industries.

A second remark on the methodology developed in these studies is that they mostly focus on European countries and are tailored to this context. In the bottom-up approach developed by the European Commission (2021[28]), highly concentrated trade dependencies are not considered as vulnerable when most imports are sourced from within the EU. This perspective may, to some extent, overlook risks associated with supply disruptions arising within the EU itself. In the car industry, for instance, disruptions in the upstream production in Czechia or Slovakia could greatly impact car assembly in Germany. France also has strong ties with Spain in particular, where many car parts are produced and then re-exported to other final producers in the rest of Europe. Therefore, our paper adopts a uniform approach to defining vulnerable products, treating intra-European trade not differently from extra-EU trade. While this has the benefit of a standardised analysis across nations, it does so at the expense of not accounting for the specificity of free trade areas and, in particular, of the EU Single Market.

A last remark is that the static identification of vulnerabilities may change over time. This point is illustrated by Vicard and Wibaux (2023[33]), who show that, over time, products can change status in terms of vulnerability.

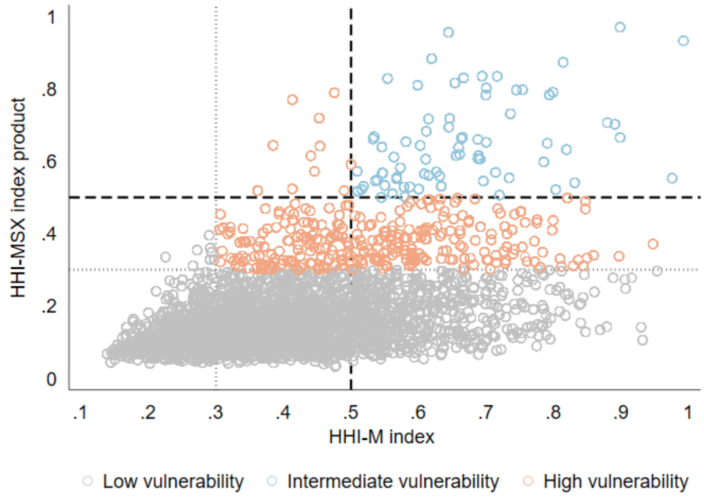
The identification of vulnerable products in this paper relies on three criteria for each product: the suppliers' concentration in each importing country, the global export market shares concentration, and the balancing between product-level imports and exports. These three criteria account for the specificity of the buyer-seller relationships (buyers tend to have very few suppliers), and for the capacity to rely on alternative suppliers in the case of a shock (substitutability is low in a very concentrated product market).

Figure 2.5 shows a scatter plot of the two concentration indexes, considering all intermediate products and countries in the UN Comtrade data. Only a small share of product-level intermediate imports appears as highly vulnerable. This assessment remains illustrative as it depends on the choice of the vulnerability thresholds for import flows classified as moderately or highly vulnerable.

In Section 3, the quantitative framework simply relies on supplier shares and substitution elasticities for the quantification of upstream product-level supply shocks on downstream sector-level production. It does not rely on ad-hoc choices regarding the thresholds for classifying product-level imports in terms of vulnerability.

Figure 2.5. A classification of intermediate input supplies by degree of GVCs vulnerability

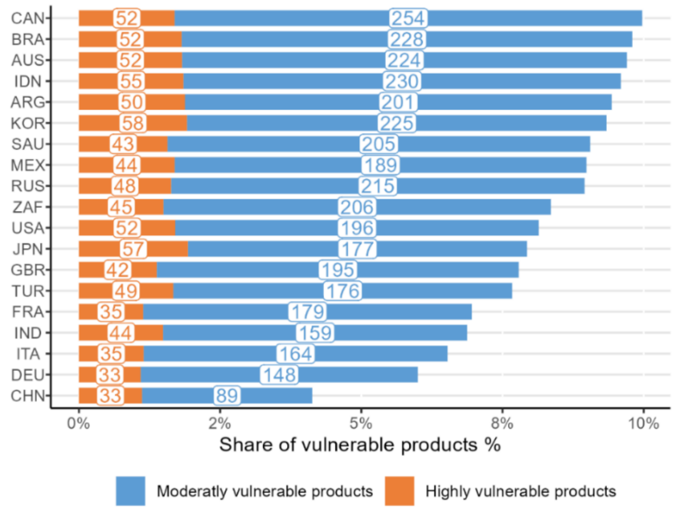
Identifying supply chain vulnerability based on HHI-M and HHI-MSX indexes, OECD countries



Note: This chart shows a classification of country-product GVC vulnerability, based on the HHI-M and HHI-MSX indexes.
Source: Comtrade, BTDIxE, OECD calculation.

Figure 2.6. About 8% of products are vulnerable across G20 economies

Share of vulnerable product among all intermediary products, 2019



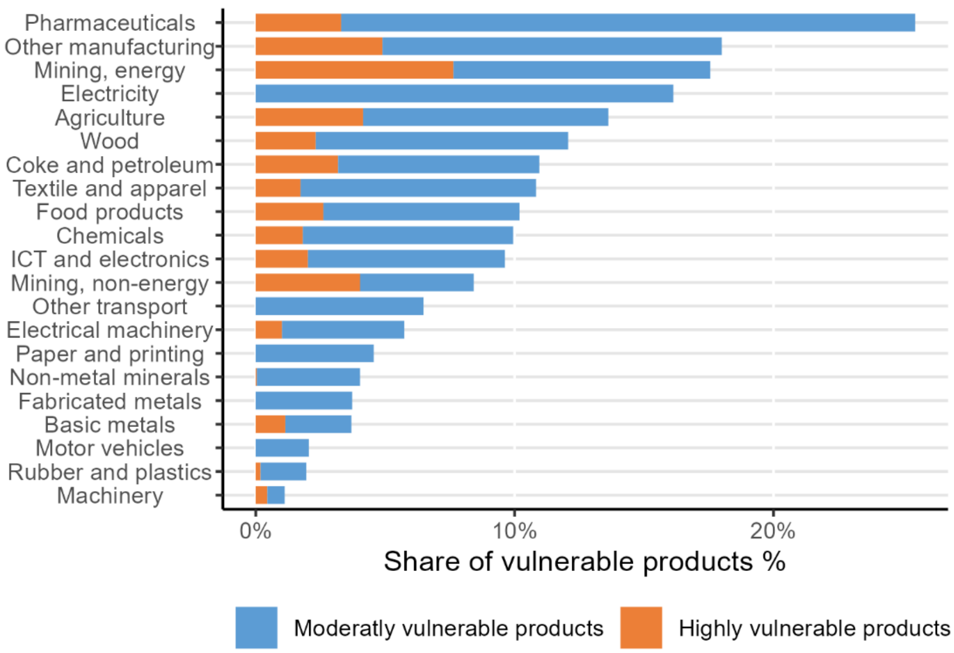
Note: Products are categorised based on their vulnerability using two key indicators: Global export market share concentration (HHI-MSX) and suppliers' concentration (HHI-M). A product is deemed to be "highly vulnerable" if both the HHI-MSX and HHI-M exceed 0.5. Conversely, a product is considered "moderately vulnerable" if both indicators are above 0.3 but below 0.5. Vulnerable products have their imports exceeding the imports of the same product in each country.
Source: Comtrade, OECD calculation

The number of (highly and moderately) vulnerable products per country is reported in Figure 2.6 for G20 economies. In most countries, around 250 imported products can be classified as moderately vulnerable according to our classification, while around 50 of them are classified as highly vulnerable. This suggests that policies aimed at improving the resilience of industries against various types of shocks (e.g. natural disasters or geopolitical events) should focus on a limited set of highly dependent products.

Based on this analysis, strong dependencies appear in chemical products (alkaloids, antibiotics, and halogenated derivatives), mineral products (lignite, cobalt, and copper) or agricultural products (vegetable oils). Focusing on moderately vulnerable products, the list can further be extended, for instance, by mineral products like iron, steel, nickel, or uranium, but also other chemical products such as fertilisers. The sourcing of products, such as semiconductors, appears highly concentrated as well for some countries based on the HHI-M index. When classifying imported products based on their upstream industry, we find that vulnerable products often belong to sectors like pharmaceuticals, mining, energy, chemicals, or ICT and electronics (Figure 2.7).

Figure 2.7. Raw materials are more often among vulnerable products than complex goods

Share of vulnerable product by supplying industry, 2019

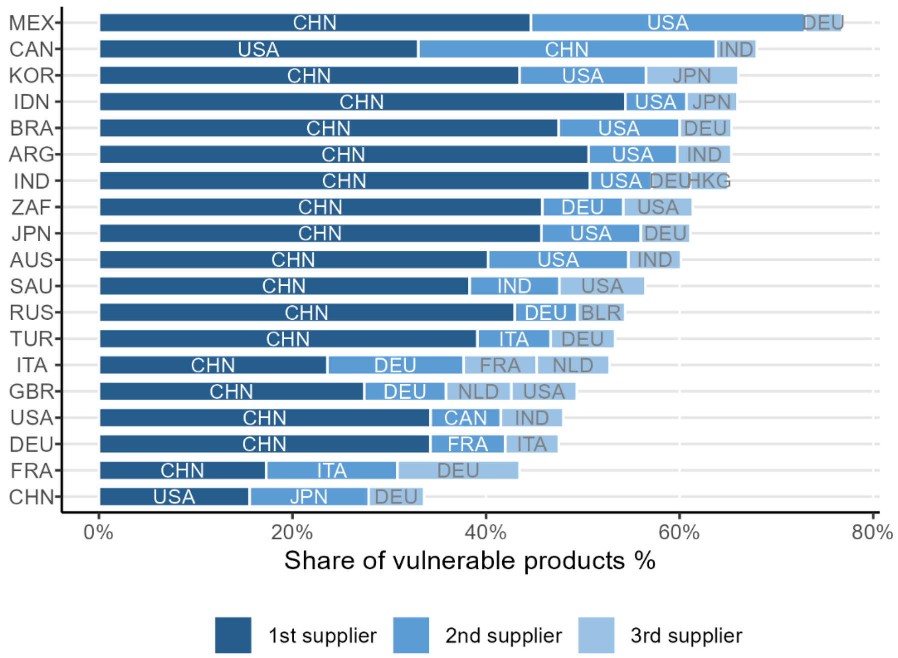


Note: Products are categorised based on their vulnerability using two key indicators: Global export market shares concentration (HHI-MSX) and suppliers' concentration (HHI-M). A product is deemed to be "highly vulnerable" if both the HHI-MSX and HHI-M exceed 0.5. Conversely, a product is considered "moderately vulnerable" if both indicators are above 0.3 but below 0.5. Vulnerable products have their imports exceeding the imports of the same product in each country. Each product is linked to a producing industry. The proportion of vulnerable products is initially calculated for each supplying industry and downstream country within the G20. These proportions are then aggregated by taking a simple average across all downstream countries.
Source: Comtrade, OECD calculation

Importantly, and as discussed before, this classification does not account for the nature of the risks, which can be related to the geographical origin of the imported intermediate product. To complete this picture, Figure 2.8 reports the geographical origin of vulnerable intermediate products by country of destination. Each bar represents the share of the total number of vulnerable intermediate products sourced from the top three suppliers of these products. For instance, Mexico sources nearly 80% of its vulnerable intermediate products from three countries: China, the United States and Germany. In many countries, China appears as the top supplier of vulnerable intermediate products. Other countries among the top three suppliers of vulnerable products are often located within the region of the destination country (e.g., the United States for Mexico; Japan for Indonesia, Korea or China; France, Germany or Italy for European countries etc.). This picture confirms the unique role of China in production networks as a supplier of key intermediate inputs for the production in downstream industries.

Figure 2.8. China is the main supplier of vulnerable products for the G20

Share of vulnerable products by supplier rank, 2019



Note: Products are categorised based on their vulnerability using two key indicators: Global export market shares concentration (HHI-MSX) and suppliers' concentration (HHI-M). A product is deemed to be "highly vulnerable" if both the HHI-MSX and HHI-M exceed 0.5. Conversely, a product is considered "moderately vulnerable" if both indicators are above 0.3 but below 0.5. Vulnerable products have their imports exceeding the imports of the same product in each country.
Source: Comtrade, OECD calculation

Supply vulnerability for downstream industries: A focus on motor vehicles

So far, most studies have provided a mapping of upstream supply vulnerabilities (see Box 2.1) without relating these vulnerabilities to the activity in downstream sectors. Our objective is to close this gap by combining product-level trade data with the ICIO tables developed by the OECD. The latter maps the economic interrelatedness of 76 countries and 45 industries, establishing economic links between sectors from different countries. However, it lacks the granularity necessary to measure concentration and risks in GVCs accurately. The analysis presented in this study relies on merged ICIO-Comtrade datasets (the methodology used to merge the two datasets is described in Annex A). The critical step is to use the information on intermediate input flows from the ICIO tables ("Z matrix") to allocate imported intermediate goods across using sectors in a given using country. The resulting data has four dimensions. It contains, for each using country j and industry s, the amount of imported product p (that belongs to upstream sector

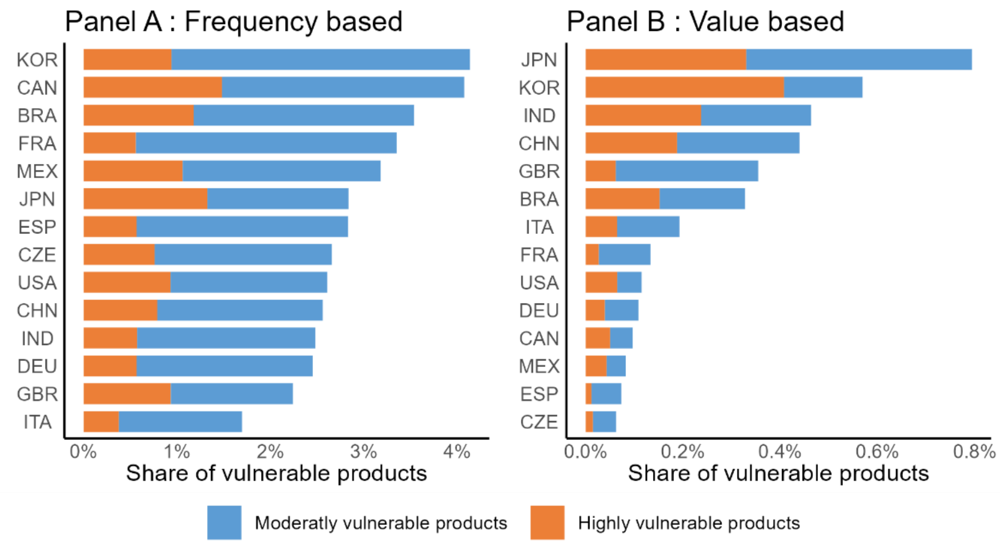
r) from country i: V_{ijps}^{r}. This merged dataset only accounts for the flows of intermediate goods trade, and disregards at this stage the flows of services trade.

To illustrate our granular GVC mapping exercise, this Section focuses on the analysis of the motor vehicles industry (D29). The sample is restricted to the top 15 OECD motor vehicle producers.[3] Box 2.2 compares the average supply concentration resulting from our granular approach at the product level with the equivalent measure based on ICIO flows of intermediate goods. It shows that the sectoral-level ICIO approach consistently underestimates the actual concentration level.

Figure 2.9 presents an indicator of the downstream dependency of the motor vehicles industry on vulnerable products supplied by the top three supplying industries in ICIO: motor vehicles, basic metals, and machinery. The indicator of product dependencies is reported as a percentage of the total number of imported products from these three upstream industries (Panel A) or as a share of the total value of imports from these upstream industries (Panel B). A notable feature in both graphs is that, while vulnerable products represent a substantial part of the total number of products supplied from the top three upstream industries (around 4% of imported products), these products represent a small share of the total imports of intermediate products (between 0.1% and 0.8% depending on the countries). In value terms, Japan, Korea, or India are more exposed to imports from vulnerable products given their concentration in HHI-M and HHI-MSX indicators. Vulnerability appears less strong in the European and North American supply chain.

Figure 2.9. About 4% of the inputs of the car industries are vulnerable

Share of vulnerable products by supplying industry, 2019



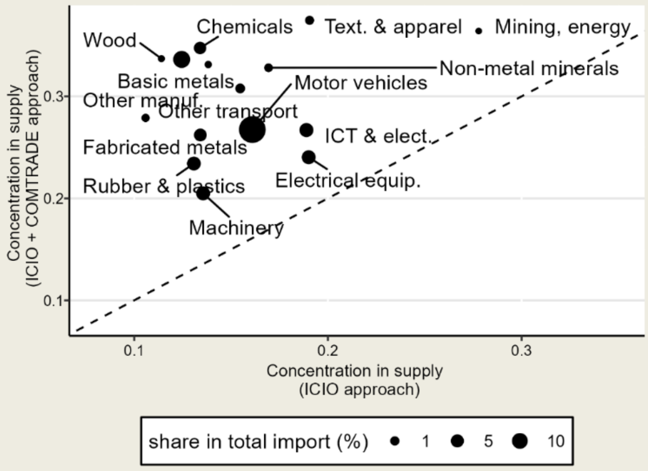
Note: The graph illustrates the percentage of intermediate inputs that are categorised as either vulnerable or highly vulnerable, used by the motor vehicle industry and originating from its top three supplier industries: motor vehicles, basic metals, and machinery. Panel A calculates the number of these vulnerable products as a share of all products sourced from the top 3 industries. Panel B measures the traded value of these vulnerable products in comparison to the total value of goods sourced from these top 3 industries. The sample is restricted to the top 15 producers of motor vehicles. Products are categorised based on their vulnerability using two key indicators: global export market shares concentration (HHI-MSX) and suppliers' concentration (HHI-M). A product is deemed to be "highly vulnerable" if both the HHI-MSX and HHI-M exceed 0.5. Conversely, a product is considered "moderately vulnerable" if both indicators are above 0.3 but below 0.5. Vulnerable products have their imports exceeding the imports of the same product in each country.
Source: Comtrade and ICIO, OECD calculation

Box 2.2. Measuring GVC concentration at product or sector level

One of the key contributions of this paper is to bring the granularity analysis into the ICIO framework. However, a critical question arises: What are the benefits of this approach for measuring concentration and risks in the GVC? Figure 2.10 presents a simple exercise allowing for a direct comparison of the supply concentration calculated from the sectoral intermediate input imports in the ICIO data and the proposed granular approach at the product level. To ensure comparability, the granular approach is aggregated at the supplying sector level (sector average of the underlying product-level HHI-M index). Supply concentration appears consistently more pronounced when it is calculated based on product-level data compared to the ICIO-based approach. We find similar evidence for different sectors outside of motor vehicles. This implies that studies relying on sector-level information, such as the one contained in the ICIO tables, may substantially underestimate the actual degree of concentration and, by extension, the level of risks.

Figure 2.10. Concentration of supply is consistently higher using the proposed granular approach

Average supply concentration by supplying sector for motor vehicle producers, two approaches, 2019



Note: This plot presents the average supply concentration by supplying sector of the motor vehicle industry based on two approaches. On the x-axis, supply concentration is based on intermediary input flows (Z) from the ICIO table and computed as an average across the top 15 producers of vehicles in the OECD. On the y-axis, product-level supply concentration is first averaged by supplying sector using the share of imports of the product in total imports from the supplying sector (w_{jrp}) as a weight. The result is then averaged across the top 15 producers of vehicles j. Supplying sectors accounting for less than 0.2% of the total value of intermediary goods imported are dropped.
Source: Comtrade and ICIO, OECD calculation

While the small share of vulnerable products in total imports of intermediate products could indicate a low vulnerability of the motor vehicles supply chain to shocks, the actual degree of vulnerability depends crucially on the capacity to substitute in the short to medium term (the horizon of a year) and rely on alternative suppliers. The question of the “value of the elasticities” of substitution, between suppliers, between products, is at the core of the economic debate on resilience. One important illustration of this question is the fierce academic, policy and political debate that occurred in Germany following the start of the Russian war of aggression against Ukraine, and the risks of disruption in the gas supplies coming from Russia. This debate precisely focused on the empirical question of the value of the substitution elasticities, i.e., the capacity of Germany to attenuate the shock by relying on alternative sources of gas supplies and other sources of energy. The work published by Bachmann et al. (2022[21]) offers a thorough discussion of this issue and provides a scenario quantification of the consequences of a sharp drop in gas supplies to Germany in terms of output loss. Baqaee et al. (2022[22]) offer a similar quantification for France. In these studies, elasticities of substitution tend to be very small in the short run, reflecting the difficulty to find easily alternative suppliers. With very small elasticities, a negative supply shock in one supplier can have a large impact on downstream output, even in the case where the share of impacted products is small. In a Leontief world, with full complementarity between suppliers and products (no substitutability), a 50% decline in upstream supplies of a product would lead to an equivalent drop in the downstream industry's output, even when the product represents a minor share of the total industry foreign supplies.

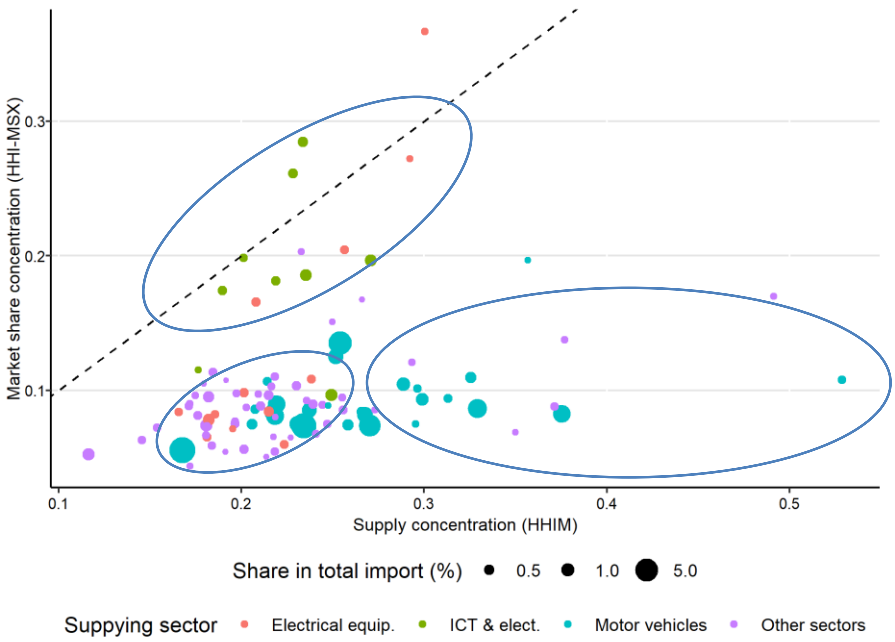
Figure 2.11 presents the HHI-M and HHI-MSX concentration indexes, calculated based on the 100 most imported products by the motor vehicle industry.[4] In the graph, the dotted line represents the 45 degrees line where the HHI-M index would equal the HHI-MSX index of concentration. The plot reveals several distinct clusters of products.

- The first cluster, located at the bottom left of the graph, comprises a majority of products that have a low global export market share and foreign supply concentration. This suggests that the motor vehicles industry sources these products from diversified partners, and many suppliers in the world economy could act as a replacement in case of disruption in the value chain.
- A second cluster, located at the top left, includes mostly products from the "ICT and electronics" and "electrical equipment" sectors, such as the different types of semiconductors. For these products, the geographical concentration of foreign suppliers is not too high despite a high degree of global export market shares concentration in ICT products. The high concentration of global export market shares implies that opportunities of diversification in these products may be quite limited.
- The last cluster contains products for which global exports are not too concentrated, but the motor vehicles industry relies on a few suppliers. Such a high degree of geographical concentration may reveal different patterns of the industry: the structure of business groups that shapes the production network and enhances buyer-seller relations between affiliates and the headquarter (Head and Mayer, 2019[43]), or the role of just-in-time relations between suppliers and clients, which involves to rely on only few foreign suppliers with a high degree of vertical integration (Pisch, 2020[44]).

The second and third clusters reveal vulnerabilities of different nature that expose downstream production to different shocks. For instance, geopolitical shocks can be highly persistent over time, which can be very problematic when global supply is too concentrated. Concentrated buyer-seller relationships (e.g., in the context of just-in-time), on the other hand, can be fragilised by repeated shocks that would distort the efficient relation between the seller and the buyer. This can occur for instance with repeated natural disasters that would regularly impede the upstream production, and lead to a substantial loss in competitiveness for downstream producers.

Figure 2.11. Supply concentration is very high for some critical products of the motor vehicle industry

Market share and supply concentration by product, average across top 15 motor vehicle producers, 2017-19



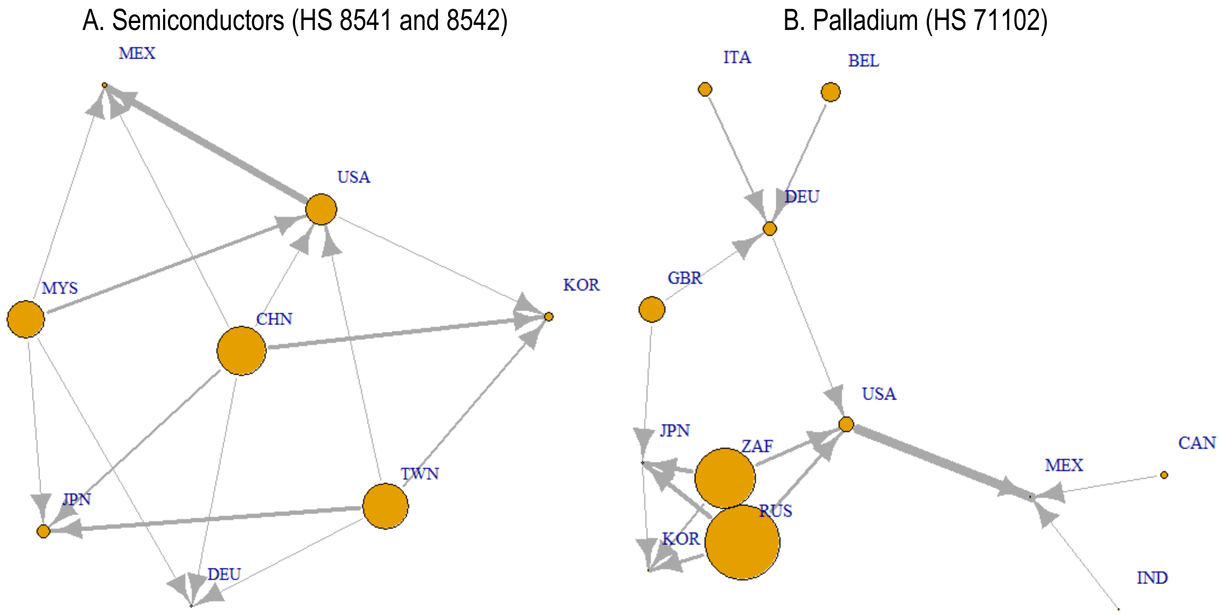
Note: The chart presents the average supply and market share concentration by product imported by the 15 OECD countries with the highest gross output in the motor vehicle sector. More precisely, the supply concentration is first computed for each using country of the top 15 OECD countries before being averaged across country. The market share concentration is measured at the world level. The size of the dot represents the product share in total imports of the motor vehicle industry. Only the top 100 products are plotted; they account for 72% of total imports.
Source: Comtrade & ICIO, OECD calculation

Taking a detailed view with the microscope reveals nicely the organisation of the production networks, and the high degree of concentration in buyer-seller relations. Figure 2.12 shows two production networks for the top five motor vehicles producing countries (namely the United States, Germany, Japan, Korea, and Mexico). Each network shows the trade flows of one of the key inputs used to produce motor vehicles: semiconductors in Panel A, and palladium in Panel B. In this graph, the size of the edges reflects the supplier concentration in intermediate imports for each country. The size of the nodes reflects the global export market share of each upstream producer.

Results show some potential vulnerabilities in the supply networks of the top motor vehicle producers. Downstream producers of motor vehicles rely on a handful of large suppliers of semiconductors (Panel A: China, Chinese Taipei, Malaysia, the United States or Japan), which reflects the high concentration of global semiconductor supply documented in previous OECD work (Haramboure et al., 2023[45]). The graph reported in Panel B also highlights the very high degree of concentration of global supply in upstream products such as palladium (with a high dominance of Russia, South Africa, and to a lower extent the United Kingdom).

In the quantitative framework developed in the next Section, the quantification of the impact of upstream product-level supply shocks on downstream industry-level output will account for the high concentration of supply relationships in some products and industries, but also for the substitutability in different stages of production, between suppliers and between products.

Figure 2.12. Supply networks of intermediate input vary greatly across products



Note: The size of the edges reflects the geographical distribution of input sourcing across different producing countries, while the size of the nodes reflects the global market share of those upstream producers. Sizes of nodes and edges are rescaled for presentation purposes and should not be compared across the two panels. The networks are restricted to the top five motor vehicle-producing countries (based on their output production), namely United States, Germany, Japan, Korea and Mexico, and their top three suppliers (based on intermediate input shares).
Source: Comtrade, OECD calculation.

3 Quantifying the effects of granular supply shocks: Model-based approach

The third Section of this study presents a methodology to quantify the effects of upstream supply shocks on downstream production and exports. The analysis relies on two approaches. In Section 0, we present a quantitative framework inspired by the work of Bachmann et al. (2022[21]). This framework is generalised to a greater variety of shocks. In Section 0, we propose a stress-test approach based on this modelling framework to quantify the potential effects of supply disruptions in strategic sectors. In Section 0, we detail the results of the stress test under several scenarios of interest.

Model-based approach: A simplified framework

The quantification of upstream granular supply shocks on downstream production requires mainly two ingredients. Firstly, a detailed mapping of the granular dependencies, such as the one presented in Section 2. Secondly, it requires making assumptions regarding the substitutability or complementarity of different inputs at different stages of the production process. For example, inputs like semiconductors have become essential for making modern vehicles. These inputs are complementary to other inputs, so a decline in their availability would significantly reduce vehicles production. In different sectors and for different inputs, alternative suppliers offer opportunities for substitution, especially in the medium to long term.

These substitutions or complementarities can intervene at different stages within the production function of the firm: Between different suppliers of the same upstream product (e.g., different suppliers of semiconductors), between different intermediate products, or between intermediate inputs and the value-added generated by downstream producers. In practical terms, the exposure to product-level supply disruptions and the substitutability between suppliers and between different products need to be measured or calibrated.

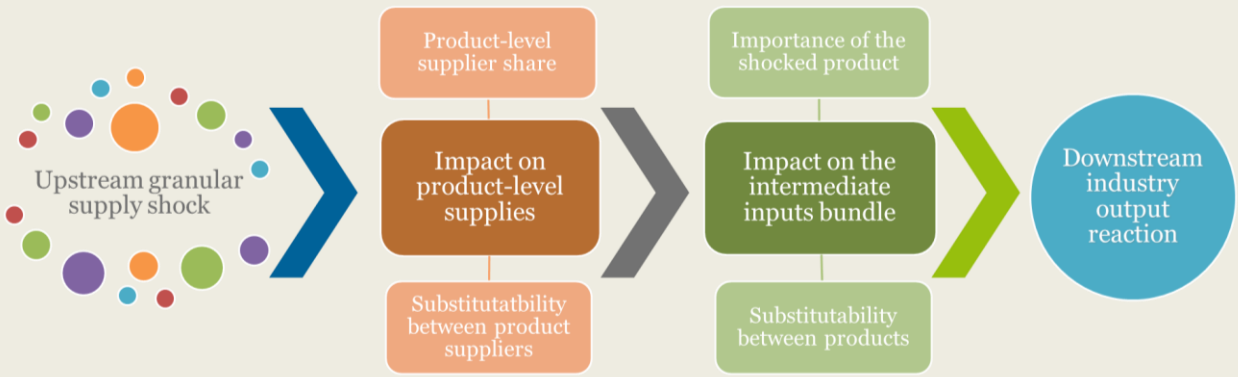
The treatment of upstream supply shocks in quantitative general equilibrium models requires complex tools. This is, for instance, the case in recent works focusing on the international consequences of the Covid-19 pandemic in China and its impact through sector-level supply networks (Gerschel, Martinez and Mejean, 2020[20]), the energy shock in Germany (Bachmann et al., 2022[21]) or the geopolitical tensions following Russia's war of aggression against Ukraine in terms of friend-shoring scenarios (Javorcik et al., 2023[25]).

Against this background, our objective is to provide a tractable and transparent quantitative framework in the spirit of the simplified model proposed by Bachmann et al. (2022[21]). The model is flexible enough to track the impact of product-level supply shocks on downstream industries. We add to their framework different levels of substitutability (between suppliers, between products). The conceptual quantitative approach is presented in Box 3.1, with mathematical and calibration details provided in Annex B.

Box 3.1. Quantifying the effects of upstream supply shocks on output: A simplified framework adapted from Bachmann et al. (2022)

The quantitative framework presented in this paper allows to track the response of an industry's output following a shock to product-level supplies from one specific country. We provide in Annex B the mathematical details of the quantitative framework and the parameters calibration. A conceptual representation of the quantitative framework is provided in Figure 3.1.

Figure 3.1. Granular GVC stress-testing: A conceptual framework



Note: Simplified graphical representation of the quantitative framework for GVC stress-testing.
Source: OECD

The framework combines data from the OECD's ICIO tables detailed at the country-pair, industry-pair and year level, together with information on product-level (HS6) imports between countries. This information allows measuring granular GVC dependencies as detailed in the granular GVC mapping presented in Section 2 of this paper. The underlying (partial equilibrium) model relies on essentially three stages of production, in which we track the impact of foreign product-level supply shocks on downstream production.

- Impact of the shock on product-level supplies. In the first stage of the production process, producers operating in the downstream industry can import a product from different origins. At this stage, two important parameters govern the response of the downstream product-level supplies following an upstream shock: (i) the share of the shocked supplier in terms of product-level supplies; and (ii) the capacity to substitute between different suppliers. The response of product-level supplies consecutive to the shock is attenuated when producers in the downstream industry can easily substitute and rely on alternative suppliers. In our quantification, we assume that the substitutability between suppliers at the product level is low in the short term given the specificity of buyer-seller relationships. In the medium term, the product-level substitutability between suppliers is higher than in the short term, as downstream industries can alleviate their supply constraint by searching for alternative suppliers over time. The capacity to find alternative supplies, however, is specific to each product. In our empirical application, we calibrate the elasticity of substitution for each product using estimated parameters from the literature (details on the calibration are provided at the bottom of this box).
- Impact on the intermediate input bundle. In the second stage of the production process, the model quantifies how the decline in the availability of the shocked product impacts the total use of

intermediate inputs by the downstream industry. This depends on (i) the relative importance of the shocked imported product in the intermediate input bundle. This share accounts for the degree of foreign offshoring of production and is typically higher in countries and industries depending more on foreign imported inputs. The quantification also depends on (ii) the capacity to substitute between different products. A low substitutability between products magnifies the impact of the upstream shock on the use of intermediate inputs. Alternatively, the shock can be dampened if the shocked product can be easily replaced by other products. As in the first stage of the model, we consider here a low substitutability in the short term, and a higher substitutability in the medium term, reflecting that industry adaptability requires innovation or practices that need time to be implemented.

- The reaction of final output. In the third stage, we account for the fact that the decline in the availability of intermediate inputs can be partly compensated by the domestic value-added in the downstream industry (substitutability between intermediate inputs and the use of capital and labour by downstream producers). As in the previous stages, the final reaction of industry output depends on the drop in the availability of intermediate inputs (the shock), the importance of inputs for final production (the exposure related to the overall degree of externalisation of production), and the substitutability between intermediate inputs and domestic value-added. In our quantification, we assume that this parameter is the same in the short and in the medium run.

Importantly, this quantification does not account for general equilibrium effects related to factor prices (labour or intermediate input prices), so we do not provide any long-term quantification of the shock, which would require to embed factor markets in our model. Another limitation is that the quantification only focuses on direct linkages between Tier1 suppliers and buyers of a product in the production network. Accounting for direct and indirect linkages would typically require using a different approach, based on product-level ICIO data, which do not exist. Against this backdrop, the GVC accounting literature has provided mappings of ultimate dependencies between countries, but only based on sector-level global input-output tables without product detail (Baldwin, Freeman and Theodorakopoulos, 2022[15]).

The stress-test simulation exercise presented in this paper requires to calibrate the different parameters of the quantitative model. The supplier shares in the first stage, the shares of the shocked products in the second stage and the share of total intermediate inputs in production are taken from the merged ICIO-Comtrade data. Short-term elasticities are taken from the work of Baqaee and Farhi (2019[46]), Barrot et al. (2021[19]), and Bachmann et al. (2022[21]). In the medium run, we account for the greater substitutability of suppliers and take elasticities that are estimated at the product level in Fontagné et al. (2022[47]) (see, for instance, Table 5 of their published paper where the elasticities are aggregated and presented for each section of the HS product classification).

Contrary to more complex general equilibrium models with sector detail, this framework allows to use our mapping of dependencies at the product level and to conduct a more detailed stress-test analysis for different using sectors, following upstream product-level supply shocks, under different assumptions on complementarity and substitution. We provide an illustration of the quantification of a shock in the first stage of the quantitative framework, and discuss the transmission mechanisms, in Box 3.2.

Our simulation scenarios rely on different types of shocks that could impact the global economy in the future:

- **Natural disasters** (earthquakes in Japan or the Republic of Türkiye) where exports of all products are reduced temporarily by 30%.
- **A productivity shock affecting the supply of advanced technology products** by China to all its partners, implying a temporary reduction of 50% of exports for such products.

It is noteworthy that the origins of the supply shock which could be attributed to a negative productivity shock in supplying firms, or to large-scale supply disruptions related to, e.g., natural disasters or mobility restrictions of workers as a result of Covid-19, are not specified. Therefore, these differ from a geopolitical shock that would impact some – but not all – downstream partners.

Box 3.2. Quantifying the impact of a supply shock on product supplies

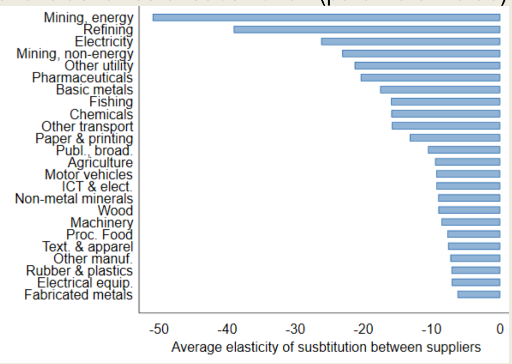
This box illustrates the effects of a supply shock on product supplies in the first stage of the granular GVC quantitative model presented in this paper. It discusses the role played by the elasticity of substitution between suppliers, and its calibration. The quantification of shocks on industry output (accounting for all production stages in the model) is detailed in specific scenarios later in the paper.

Accounting for the product-level substitutability

As discussed in Box 3.1, the product-level substitutability between suppliers is an important parameter for the first stage of the quantitative model presented in this paper. Different elasticities are used in the short and medium run. In the short run, the substitutability between suppliers of each product is low, reflecting the difficulty to make up for the missing product due to search and matching frictions as well as contractual rigidities. In the model, this short-run elasticity is calibrated to 0.1, implying that finding an alternative supplier may be difficult when the shock occurs. While this elasticity is low, it is not zero and there is still some possibility for downstream producers to mitigate the shock. In the model, this will attenuate the impact of the shock on downstream product supplies, as shown in the simulation below. Bachmann et al. (2022[21]) discuss this in detail in their paper and show that assuming a low but non-zero substitutability (i.e. departing from the pure Leontief case with full complementarity between products and suppliers) can strongly attenuate the quantitative impact of an upstream supply shock on downstream production. In the medium run, we allow for a larger elasticity of substitution between the suppliers of each product and rely on the substitution elasticities provided in Fontagné et al. (2022[47]). The average product-level elasticity of substitution by sector is detailed in Figure 3.2. It shows a strong heterogeneity between sectors, with mining, energy and refining products being highly substitutable whereas electrical equipment or fabricated metals show a low elasticity in the medium to long run. We use these product-level elasticities for the calibration of the model in the medium term. Annex B shows that these elasticities are correlated with those provided in related work by Caliendo and Parro (2014[48]).

Figure 3.2. Product-level elasticities of substitution

Sector averages of the product-level elasticities of substitution (parameter value)



Note: Sector averages of the product-level elasticities of substitution.
Source: Fontagné et al. (2022[47]), OECD calculations.

Quantifying the effects of a 50% supply shock on product supplies (1st stage of the model)

As discussed in Box 3.1, the quantitative impact of an upstream granular supply shock (e.g., in the context of a severe disruption in the supplying partner) on downstream product supplies (e.g., car parts or electronic components) is affected by two parameters: the supplier share in product supplies, and the substitutability parameter, which can take a low value in the short term and a high value in the medium term. Figure 3.3 reports the results of a 50% shock on one upstream producer. The shock is applied on simulated data to illustrate a key mechanism in the quantitative framework.

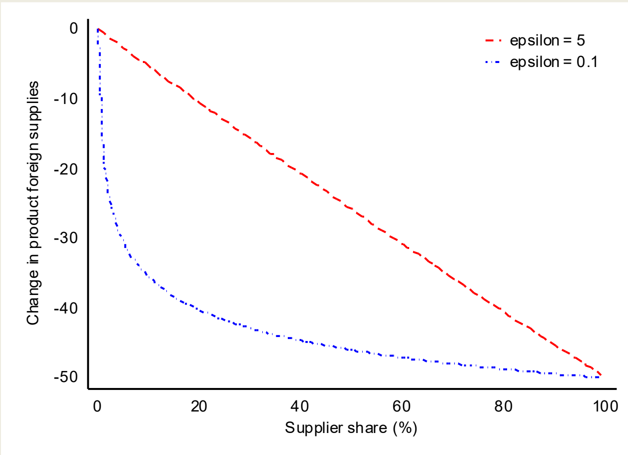
In the short term, with low substitution elasticity, most downstream industries suffer a large shock even when the supplier share is not too high. Intuitively, it is simply very difficult to switch from one supplier to the other. In the stress-test scenarios, this feature will tend to reduce the heterogeneity between countries in terms of output response, even when their supplier share can be very different. The blue line in Figure 3.3 shows little quantitative difference between an exposure of 20% and 90%: in both cases the quantitative response of product supplies ranges between -40% and -50%, which is an almost complete pass-through of the shock. However, different parameters will drive the response of countries' output following the shock, including the share of the foreign imported input in the intermediate inputs' bundle (product composition and foreign offshoring) in stage 2, or the degree of externalisation of production in stage 3 (the relative importance of intermediate inputs in total industry output).

In the medium term, with high substitution elasticity, the output response of the downstream industry is more heterogeneous and depends more strongly on the supplier share parameter. With an elasticity of 5, the response of product supplies is now about -10% for a supplier share of 20%. In other words, the capacity to find an alternative supplier allows to attenuate the shock on product supplies.

An implication of this result for resilience policies is that beyond the concentration of product supplies, which reflects the organisational structure of companies regarding their sourcing decisions, a more stable output can be obtained by promoting alternative sources of supplies for specific products. This can be realised, for instance, through a higher degree of product standardisation, shared among upstream suppliers in an industry.

Figure 3.3. Quantifying the effects of a 50% supply shock on product supplies

Results from the 1st stage of the quantitative model (% change in product supplies)



Note: Results from the 1st stage of the quantitative model based on simulated data with a range of supplier shares from 0 to 100%. Epsilon is the product-level elasticity of substitution between suppliers, with the low value corresponding to the short-term elasticity and the high value in the ballpark of medium-term elasticities.
Source: OECD calculations.

Diffusion of a natural disaster in Japan through production networks

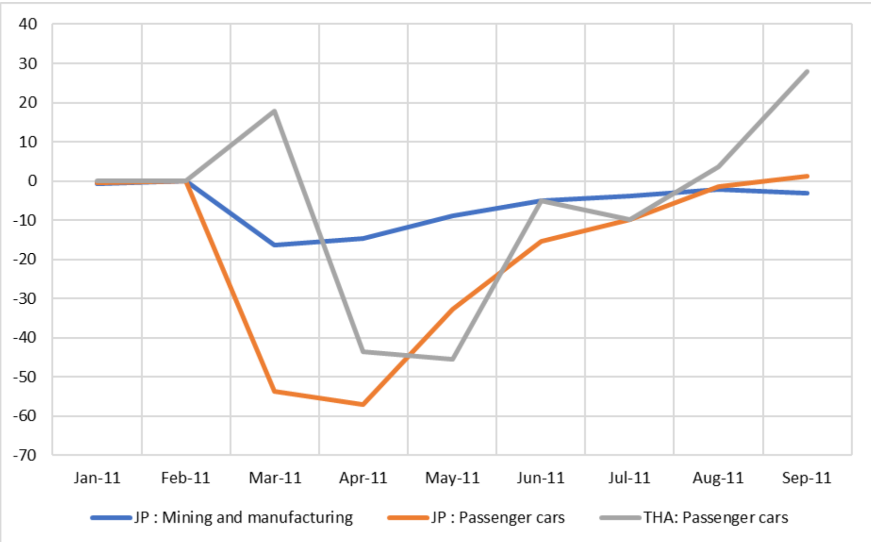
Baseline simulation results

The first stress-test scenario presented in this paper is a natural disaster in Japan temporarily reducing the supply of products to all partners. In this simulation, the choice of Japan is motivated by the Tohoku earthquake that the country experienced in March 2011. Its consequences for Japan and foreign economies via production networks have been studied in particular by Boehm et al. (2019[11]) and Carvalho et al. (2020[10]). They show that input-output linkages propagated and amplified the initial shock via direct and indirect linkages between firms. Carvalho et al. (2020[10]) show that the disaster resulted in a 0.47 percentage point decline in Japan's real GDP growth in the year after the disaster. Boehm et al. (2019[11]) emphasise the role played by affiliates of Japanese multinationals abroad in the diffusion of the shock.

The graph reported in Figure 3.4 shows that on impact, industrial production in Japan declined by 16.5%, with the recovery already starting in April 2011, one month after the disaster occurred. Six months later, industrial output was still 3% below its February 2011 level. The output response following the earthquake was also highly heterogeneous across industrial sectors, and affected more strongly passenger cars production, with a production decline of almost 60% on impact for the automobile industry in March-April 2011, with full recovery in September of the same year.

Figure 3.4. Manufacturing and car production in Japan around the March 2011 earthquake

Event study: Industry output gap relative to February 2011 (in %)



Note: Indices of industrial production by sector, data seasonally adjusted.
Source: METI, Japanese Ministry of Economy, Trade, and Industry, OECD calculations.

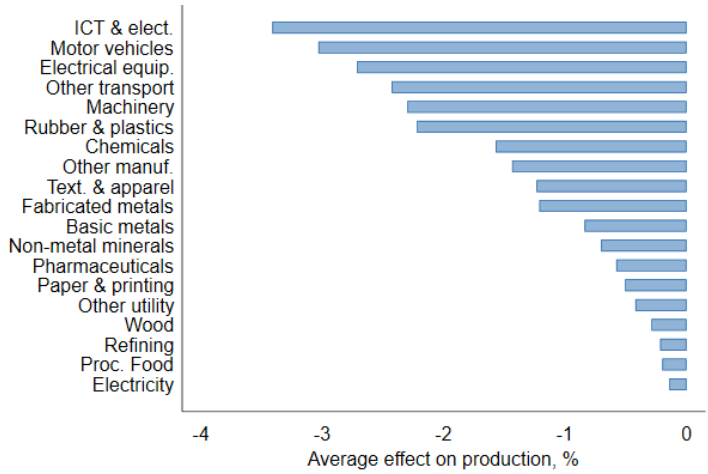
The simulation scenario that we adopt in this first stress-test exercise consists of a temporary 30% drop in the supply by Japan of all products to all partners. The quantitative framework also allows to track the output impact of the simulated disaster by downstream country and industry. It is possible to report, for instance, the reaction of output in the car industry in different countries potentially affected by the Japanese shock.

The foreign impact of the Japanese earthquake by industry is reported in Figure 3.5. Each bar corresponds to the unweighted average short-term reaction of output among the top 15 producing (OECD and non-

OECD) countries in each industry. ICT and electronics, motor vehicles and electrical equipment are the most impacted downstream sectors abroad, following a 30% negative supply shock that would affect all upstream Japanese industries uniformly. This result in terms of sector diffusion of the shock is explained by the specialisation of Japan in the production of intermediate inputs that are heavily used in these industries. For these three foreign industries, the unweighted average reaction of output in the top 15 foreign-producing countries reaches -3% or more in the short run.

Figure 3.5. Short-term impact of a Japanese earthquake

Short-term simulated effect on production (% change), industry averages

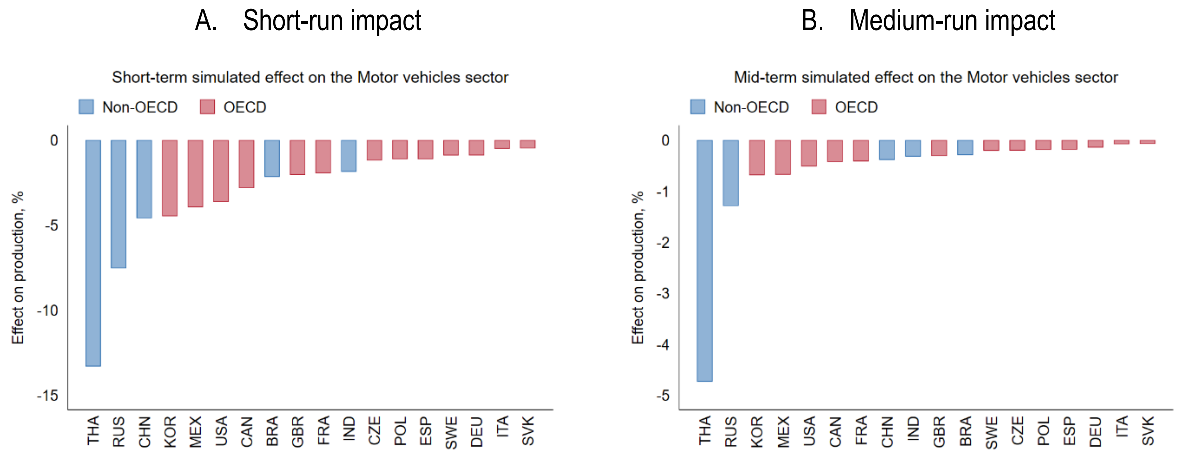


Note: The graph reports the simulated effect of a temporary 30% decline in the supply of all products from Japan, following a natural disaster. Each bar corresponds to the unweighted average simulated effect of the top 15 downstream producers (countries) in each industry.
Source: OECD calculations.

The average reaction of output per industry hides a strong heterogeneity across different countries within each industry. The country-level output reaction for the vehicle industry is reported in Figure 3.6. Results are reported for the top 15 producers in this sector according to the ICIO data. This is an interesting sector in the simulation, as it was strongly affected by the Japanese earthquake in 2011, with a decline of production in March-April (on impact) of about 55% (Figure 3.4). It is also a sector which is heavily fragmented in terms of the organisation of production: according to Schwellnus et al. (2023[14]), this industry has a high degree of Foreign Input Reliance.[5] In the descriptive statistics reported in Figure 3.5, motor vehicles is one of the top three sectors that would suffer from the foreign diffusion of a natural disaster in Japan.

Figure 3.6. Impact of a Japanese earthquake: Focus on motor vehicles

Simulated effect on production (% change)



Note: The two graphs report the simulated effect of a temporary 30% decline in the supply of all products from Japan, following a natural disaster in the short term (Panel A) and the medium term (Panel B). They report the adjustment in foreign downstream production in the motor vehicles industry, in the short run (low supplier substitutability) and in the medium term (high supplier substitutability).
Source: OECD calculations.

In the motor vehicles sector, the model simulation results reported in Figure 3.6 indicate that a natural disaster in Japan would affect both OECD and non-OECD countries in the short and medium term. The simulation shows that, in the short run, the reduction in output is the largest in Thailand, Russia and China. The most affected OECD countries are Korea, and countries of the motor vehicles industry supply chain in North America, namely Mexico, the United States, and Canada. We present a decomposition of the adjustment mechanisms in Box 3.3. A similar application focusing on the Republic of Türkiye is presented in Box 3.4.

The quantitative impact is, however, very heterogeneous across countries in the motor vehicles industry. In the short run, Thailand is the most impacted country, with an output loss of about 13% (Panel A), which is reduced to about -4.5% in the medium run when the simulation allows for more substitutability between suppliers (Panel B). In the North American supply chain, the short-term impact of the shock in Japan results in a decline of up to -5% in industry output. In the medium term, with greater substitutability between upstream suppliers, it is about half of a percentage point. European suppliers are quantitatively less affected by the shock on production in Japan, which reflects that European Union producers rely more on intermediate inputs being produced in Europe. We will show in a different simulation that a natural disaster would have a stronger impact on European producers if it were to occur in the Republic of Türkiye for example.

Importantly, the specific case of Thailand provides us with a useful data-driven validation of the quantitative model simulation of a natural disaster in Japan and its consequences for other countries in the production network. Thailand is the most impacted country in the motor vehicles industry in the model simulation, with approximately half of the shock on the motor vehicles in Japan being transmitted to the motor vehicles industry in Thailand. In the quantitative model, this is explained by the strong input-output linkages between Japan and Thailand that are recorded in this industry, and that are accounted for in the calibration of the model that relies on the merged ICIO-Comtrade data detailed in the granular GVC mapping in the first part of the paper.

Box 3.3. Decomposing the simulated impact of a natural disaster in Japan

In order to understand the driving forces behind the downstream output impact of a natural disaster in Japan in the granular GVC simulation, Figure 3.7 shows scatter plots illustrating the correlation of the average output reaction following the shock with the product supplier share of Japan (Panel A), and the share of the imported product in the total use of intermediate products (Panel B). The correlation between the downstream output impact of the Japanese natural disaster and the product supplier share of Japan (Panel A) is negative. About 80% of the overall downstream output impact is explained in the simulation by the upstream product-level supplier share of Japan. Considering all downstream industries, Asian countries appear most impacted, in particular, Chinese Taipei, the Philippines, Thailand and Malaysia. This reflects the strong input-output linkages within the Asian production network, driven by the relative geographical proximity of these countries. China and countries of the NAFTA region are also impacted; less so European economies, reflecting the illustrative example of the motor vehicles industry (

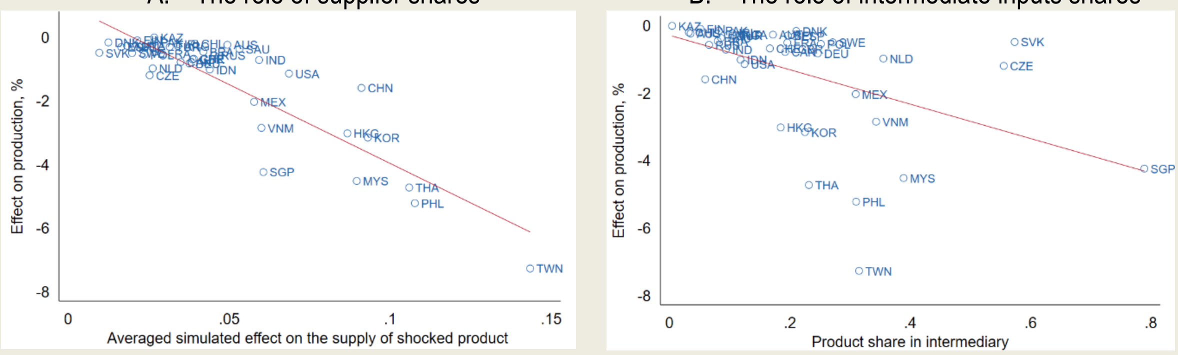
Figure 3.6). Panel B of Figure 3.7 indicates that about 20% of the reaction of downstream industry output is explained by the share of affected imported products in the total use of intermediate inputs (second stage of the granular GVC framework). This shows that, beyond the difficulties associated with finding an alternative supplier for a specific product, the missing products need to be replaced by alternatives with limited substitutability. This mechanism has a quantitatively important impact in our simulation, in particular for countries where the type of product imported from Japan represents a large share of the total use of intermediate products in each industry (e.g., Singapore, but also Slovakia and Czechia). The share of products affected by the upstream shock is also driven by the size of countries: small countries are typically more open and dependent on foreign imported inputs than large ones. This mechanism is accounted for in the second stage of our quantitative framework. For example, based on Panel B in Figure 3.7, countries like Slovakia and Czechia could suffer from a supply shock in Japan, not necessarily because they import a lot from Japan directly, but because they import products in which Japan is specialised (and e.g. products used in the assembly of vehicles) and because they are small, open economies that are dependent on foreign imported inputs.

Figure 3.7. Granular GVC shock: Decomposing the impact on output

Correlation between the short-term output impact of the simulation and the product-level supplier share (Panel A), or the share of the imported product in intermediate inputs used in downstream production (Panel B)

A. The role of supplier shares

B. The role of intermediate inputs shares



Note: Decomposition of the granular GVC simulation. The scatter plots illustrate the correlation between the short-term output impact of the simulation and (A) the product-level supplier share (1st stage), or (B) the share of the imported product in intermediate inputs used in

downstream production (2nd stage). The output reaction corresponds to the unweighted average country-level output impact when we consider all downstream industries (beyond motor vehicles).
Source: OECD calculations.

Consistently with the model predictions, the actual data reported in Figure 3.4 for Japan and Thailand indicate that the production of motor vehicles in Thailand was strongly impacted by the March 2011 earthquake in Japan. The strong drop in Japanese production is recorded in March-April 2011, with approximately a one-month lag for the production in Thailand. The very short time lag for the reaction of the production in Thailand illustrates the just-in-time production structure in the production network, which enhances the transmission of upstream supply shocks to downstream producers. This case study also shows that the pass-through of the shock can be almost complete: while the motor vehicles production in Japan declined almost immediately by about 55% for two consecutive months, the fall of production in Thailand reaches about 45% with a one-month lag, implying a close to complete transmission of the shock.

It is important to note here that the model is frictionless, so the reaction of downstream production following a granular upstream supply shock is not modified by market frictions affecting production. In a different model, financial frictions could, for instance, amplify the reaction of output following a shock on upstream supplies. The model also only accounts for the reaction of output in the first degree of input-output relationships in the production network and cannot identify possible bullwhip effects after the shock is transmitted in different stages of the production network.

Policies: diversification and adaptability

Diversification policies

Diversification policies can, to some extent, help attenuate the impact of upstream supply product-level shocks on downstream industry production. The capacity to diversify the risks depends on the existence of alternative suppliers and the overall concentration of supplier shares, which can be specific to each product. We propose a counterfactual simulation exercise presented in Figure 3.8, where the main simulation, based on a natural disaster in Japan, is reported together with three diversification policies:

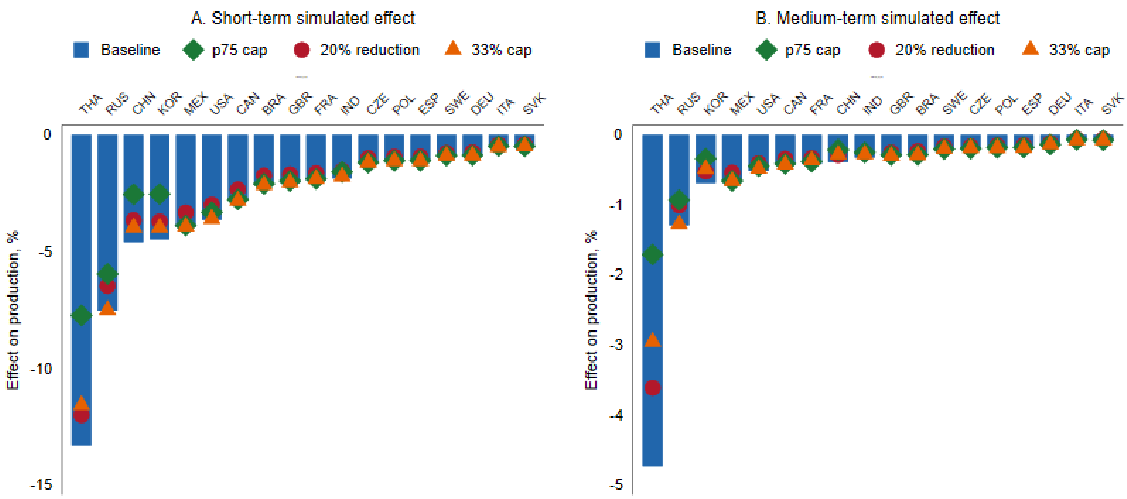
- Diversification policy #1: The maximum supplier share is set to the 75th percentile observed in the supplier shares distribution for each product. This policy has the advantage of accounting for the specificity of each product (it relies on the underlying product-specific distribution of supplier shares), and it is asymmetric (only those countries with the highest concentration of supplier shares diversify).
- Diversification policy #2: Every downstream producer reduces its exposure to its top supplier by 20%. The treatment here is symmetric across downstream countries and industries.
- Diversification policy #3: This policy is asymmetric and sets a maximum for the supplier share of 33% (not more than one-third of the total supplies of a product obtained from one single supplier). Compared with the first policy, the maximum of the supplier share is an absolute number and is not set depending on the underlying product-specific distribution.

The simulation results reported in Figure 3.8 indicate that diversification policies work and can contribute to significantly attenuate the impact of an upstream supply shock. The quantitative impact of the policy implemented depends on the underlying distribution of the supplier shares. In the case of the supplier shock in Japan, setting the maximum product-level supplier exposure to the 75th percentile of the distribution leads to a significant attenuation of the decline in output in the downstream industry, both in the short and medium run. In this case, the drop in output in Thailand's motor vehicles production is reduced by about half in the short run, and by about two-thirds in the medium term.

The other diversification policies (reducing exposure by 20% or setting a maximum of 33%) have a quantitatively weaker impact on output loss because the 75th percentile of the suppliers' distribution is relatively low compared to, for instance, an exposure of 33% of total product supplies. The capacity of diversification policies to reduce the risk in terms of supply disruptions for downstream industries is, however, subject to a high degree of uncertainty. These counterfactual simulations should therefore be interpreted with caution. Still, they suggest that diversification policies can have a quantitative impact on output performance by reducing the volatility related to the failure of suppliers in the production network.

Figure 3.8. Natural disaster in Japan: Effect of diversification policies

Baseline and counterfactual simulated effect on production (% change), motor vehicles industry



Note: The two graphs report the simulated effect of a temporary 30% decline in the supply of all products from Japan, following a natural disaster in the short term (Panel A) and the medium term (Panel B). The bars represent the baseline simulation effect and the dots show the simulated impact under several diversification policies.
Source: OECD calculations.

Fostering adaptability of the production structures

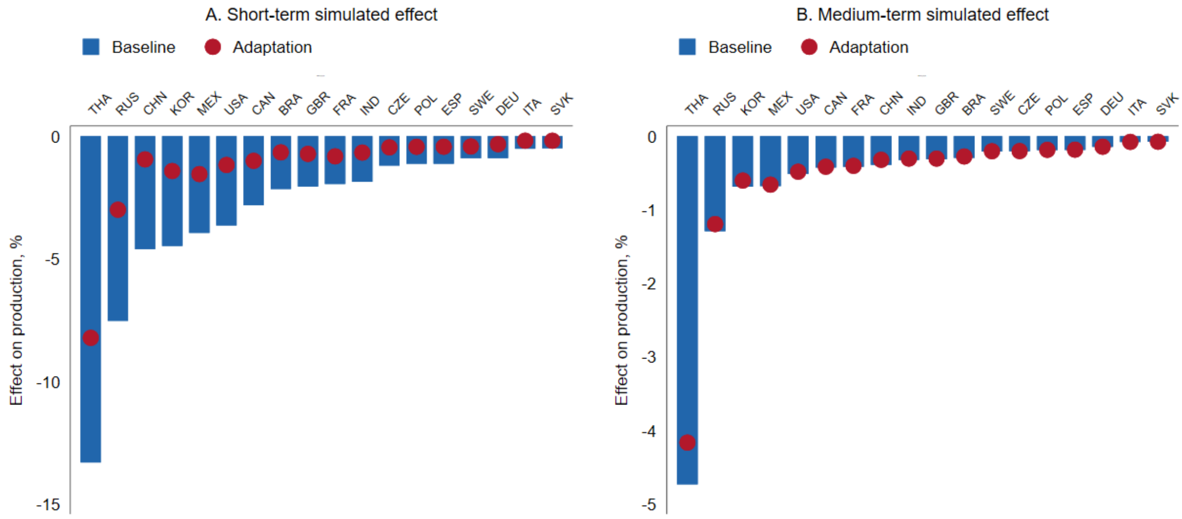
In a different policy experiment, we explore the role of the adaptability of the production network by increasing the value of the substitution elasticities between suppliers in the first stage of the quantitative framework, and the value of the substitution elasticity between products in the second stage. Concretely, we double the value of these parameters in order to reflect a significantly stronger adaptability of the production.

Simulation results reported in Figure 3.9 show that increasing the adaptability of downstream producers in the short term, for instance by establishing standards for key intermediate inputs, can substantially reduce the size of the shock transmitted to downstream producers and the reaction of output.

Intermediate inputs substitutability may be however restricted by the organisation of the production networks within multinational companies. In the case of the automobile industry, different firms within the business group tend to produce specialised inputs for downstream firms of the same group. In the absence of sufficient diversification of production sites, the failure of an upstream supplier can have large-scale consequences for the entire production network (Castro-Vincenzi, 2022[49]). Against this background, a greater resilience to shocks within the production network can be obtained by the combination of diversification policies (in particular within the business group) and adaptability policies by relying, when possible, on intermediate inputs that are not specific to the needs of one single downstream firm but rather relies on standards established for the entire industry.

Figure 3.9. Natural disaster in Japan: Effect of adaptation policies

Baseline and counterfactual simulated effect on production (% change), motor vehicles industry



Note: The two graphs report the simulated effect of a temporary 30% decline in the supply of all products from Japan, following a natural disaster in the short term (Panel A) and the medium term (Panel B). The bars represent the baseline simulation effect and the dots show the simulated impact under adaptation policies.
Source: OECD calculations.

Box 3.4. Consequences of a natural disaster in the Republic of Türkiye

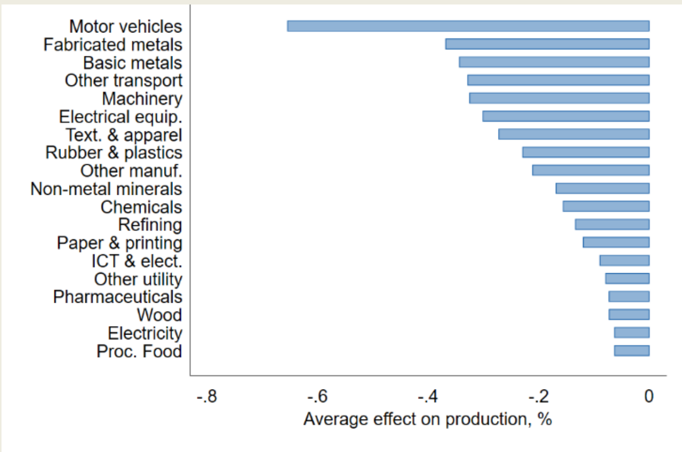
As discussed earlier in the context of the earthquake in Japan, the reaction of foreign countries' output depends on the structure of the production network, which is shaped by two important factors: firstly, the sector and product specialisation of the country that suffers from the natural disaster, and secondly, the patterns of intermediate inputs trade that is strongly influenced by geography or proximity between upstream suppliers and downstream producers.

To illustrate this point, we propose to conduct a similar exercise applied to the Republic of Türkiye, which also suffered from a large-scale earthquake that reduced industrial production by about 6% on impact in February 2023 compared to the previous month, according to statistics on industrial production. The shock was particularly strong in mining, textiles, refining, non-metallic products, and basic metals, of which many are intermediate products that are used in foreign industries, especially in Europe.

The results from the simulation are reported in Figure 3.10. As for Japan, we illustrate the consequences of a large-scale natural disaster by reducing the foreign supply of all products by 30%. The objective here is not to assess the consequences of the February 2023 earthquake, but rather to illustrate the patterns of shocks transmission in the quantitative model presented in the paper, and the potential consequences of a new shock in the Republic of Türkiye. The Figure shows that a large-scale natural disaster affecting all products in the Republic of Türkiye would have a significant negative impact on the output in the production of motor vehicles in foreign trade partners. The unweighted average indicates an output drop of about 0.6%, although the country-by-country output reaction is very heterogeneous and can be much larger for some countries. Other foreign industries impacted due to the sector specialisation of the Republic of Türkiye are fabricated and basic metals, other transport equipment, machinery, or electrical equipment.

Figure 3.10. Impact of an earthquake in the Republic of Türkiye

Simulated effect on production (% change), short-term average impact, industry averages



Note: The graph reports the simulated effect of a temporary 30% decline in the supply of all products from the Republic of Türkiye, following a natural disaster. Each bar corresponds to the unweighted average simulated effect of the top 15 downstream producers (countries) in each industry.
Source: OECD calculations.

A supply shock on advanced technology products in China

Baseline simulation results

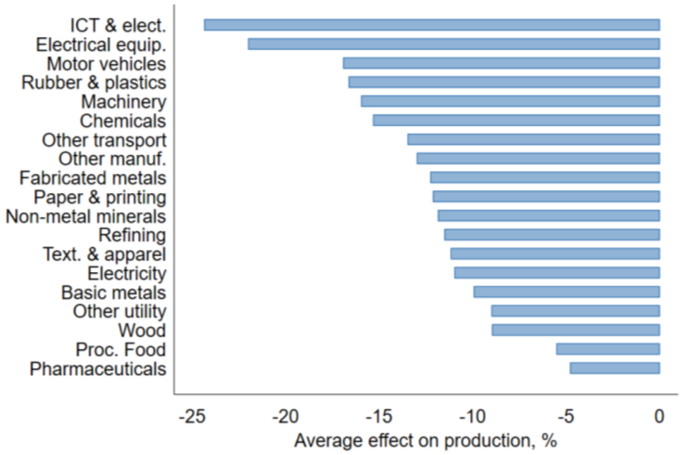
China has a very central role in the global production network. According to Baldwin et al. (2022[15]), over 40% of the nations in the OECD ICIO data have China as their top supplier.[6] China is also the most critical choke point in GVCs across a broad range of industries, both as a dominant supplier and as a dominant buyer (Schwellnus et al., 2023[14]). The central role of China in production networks is not limited to consumption goods. It is important, for instance, in the supply of intermediate inputs that are critical to strategic industries. The analysis presented in Section 2 of the paper confirms the central role of China as a key supplier of vulnerable products.

In this section, we conduct a stress-test exercise on the supply of advanced technology products (ATP) exported by China. This exercise relies on the list of ATPs provided by the United States Census Bureau.[7] The simulation scenario consists of a large and temporary drop of 50% in the supply of these products by China to all its partners uniformly. As previously mentioned, we do not specify the origins of the supply shock which could be attributed to a negative productivity shock in supplying firms, or to large-scale supply disruptions. Therefore, this differs from a geopolitical shock that would impact some – but not all – downstream partners.

Results from the simulation reported by industry in Figure 3.11 indicate that ICT, electrical equipment, and motor vehicles would be the most impacted industries. Compared with previous simulations, the short-run output reaction is large (up to 25% of output loss *on average* in the ICT sector). This is due to the large size of the shock (50% drop in supplies *but* for a limited set of products) and China's relatively significant role in supplying these products to downstream foreign industries.

Figure 3.11. Short-term impact of a 50% supply shock in ATPs in China

Short-term simulated effect on production (% change), industry averages

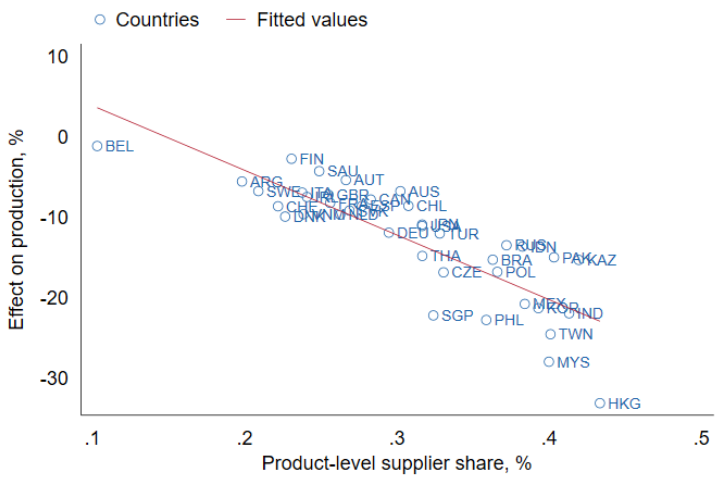


Note: The graph reports the simulated effect of a temporary 50% decline in the supply of ATP in China. Each bar corresponds to the unweighted average simulated effect of the top 15 downstream producers (countries) in each industry.
Source: OECD calculations.

The simulation results provided in Figure 3.12 show that the supplier share of China in downstream countries and industries explains about 70% of the output reaction (taking country averages over industries). On average, other South-East Asian economies (Hong Kong, Malaysia, Chinese Taipei, Korea, Philippines, Singapore), India, or Mexico are strongly impacted by the simulated shock on ATPs.

Figure 3.12. A 50% supply shock in ATPs in China: The role of China's supplier share

Correlation between the short-term output impact of the simulation and the product-level supplier share



Note: Decomposition of the granular GVC simulation. The graph illustrates the correlation between the short-term output impact of the simulation and the product-level supplier share (1st stage). The output reaction corresponds to the unweighted average country-level output impact when we consider all downstream industries (beyond motor vehicles).
Source: OECD calculations.

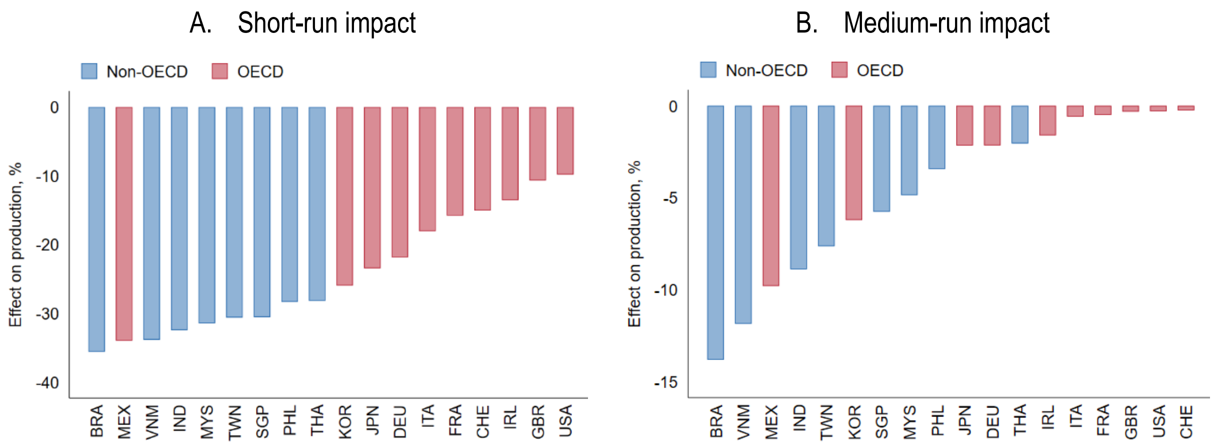
The reaction of output in the ICT sector is highly heterogeneous across countries and depends on the different parameters of the model that are calibrated based on merged ICIO-Comtrade data: the supplier share of China in ATPs by country and downstream industry, the share of shocked product in the intermediate input bundle of the sector, and the value-added to output ratio (the degree of externalisation of production). These parameters can differ across countries within each industry and can affect the quantification of the ATP shock in China.

The simulation results reported in Figure 3.13 show that the reaction of output in ATPs is highly heterogeneous across countries as expected. The reaction reflects the direct impact of the shock and does not account for the indirect linkages in complex supply chains. In the short run, the shock has the largest impact in Brazil, Mexico, Vietnam, India and Malaysia, where the ICT output drop reaches -30% or above. This represents a very high pass-through of the shock to downstream production, which is explained by the very large scale of the shock itself (the model has non-linearities that amplify the downstream impact of large shocks) and the very low elasticities in the short-run simulation.

In the medium run, with large elasticities of substitution between suppliers, the adjustment of the downstream production in ICT is reduced in absolute terms. It remains however very large with a drop of ICT output of -10% or more in Brazil, Vietnam, or Mexico. This reflects the central role of China as a key supplier in the ICT industry. Even when substitution elasticities are larger in the medium term, reflecting the progressive adjustment of downstream producers looking for alternative supply possibilities, the transmission of the shock remains large in countries with initially large supplier shares of China in ATPs.

Figure 3.13. Impact of a 50% supply shock in ATPs in China: Focus on the ICT sector

Simulated effect on production (% change)



Note: The two graphs report the simulated effect of a temporary 50% decline in the supply of ATP in China in the short term (Panel A) and the medium term (Panel B). They report the adjustment in foreign downstream production in the ICT industry in the short run (low supplier substitutability) and in the medium term (high supplier substitutability).
Source: OECD calculations.

Diversifying away from China in ATPs

This section presents a counterfactual simulation on the benefits from diversification outside of China for ATPs, in the short- and medium-term simulations of the granular GVC model. The *ex-ante* diversification scenarios are similar to the ones presented in the simulated impact of a natural disaster in Japan: (1) The supplier share of China in ATPs is set to a maximum corresponding to the 75th percentile in the supplier shares distribution; (2) all supplier shares are reduced uniformly by 20%; (3) a maximum of 33% is set for the supplier share of China.

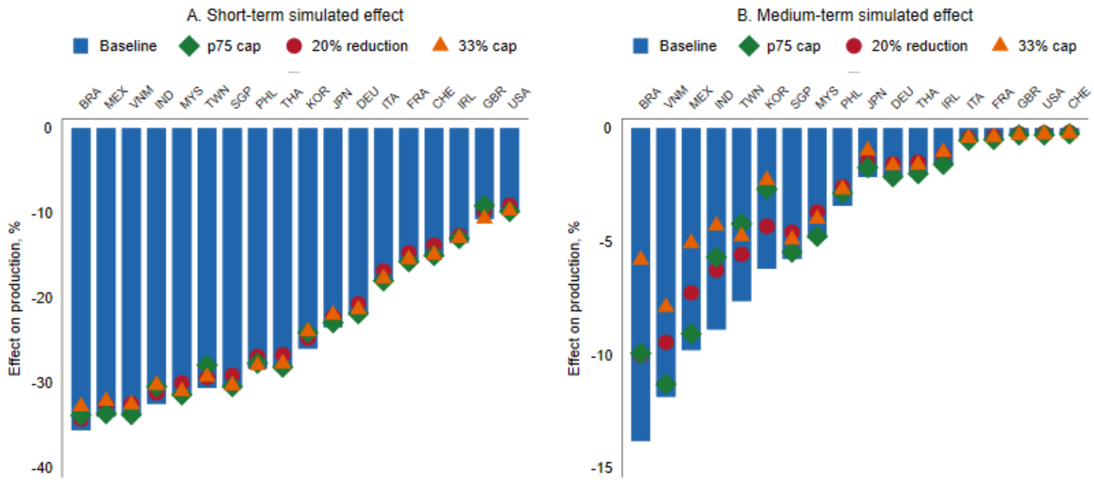
The simulation results for the counterfactual scenarios with diversification are presented in Figure 3.14. Two interesting patterns emerge. Firstly, geographical diversification of ATP supplies has little impact in the short run, as shown in Panel A. This is explained by the initially very large market share of China before diversification combined with low elasticities. Even when the market share of China is reduced to a maximum of 33%, the weak substitutability between suppliers in the short run implies a large pass-through of the Chinese supply shock to foreign downstream industries.

This implies that diversification away from China in ATPs would require massive investment into finding new suppliers and developing new capacities in these alternative production sites. This process may be already ongoing. Recent research shows that a current reshaping of GVCs involves more imports by the United States from large developing economies with comparative advantages in products also exported by China (Freund et al., 2023[36]; Alfaro and Chor, 2023[37]). However, these alternative suppliers are also highly integrated in the Chinese supply chain, and presumably depend on intermediate inputs supplied by China. Therefore, the reshaping of the production networks in ATPs may not eliminate the risks related to a supply disruption in China but simply displace this risk by adding one more layer in an already complex production network.

The medium-term quantifications presented in Panel B of Figure 3.14 show that diversification policies can contribute to attenuate the transmission of an upstream supply shock to downstream production when substitutability between suppliers and products is enhanced. For instance, the downstream reaction of production in the ICT sector of Brazil is halved when the supplier share of China is limited to 33% in ATPs, but only in the medium-term quantification where the substitution elasticities used in the model calibration are not too low. In other words, there is complementarity between diversification policies and policies designed to enhance the adaptability of the production structure. Diversification can work if alternative suppliers can supply downstream producers with intermediate inputs that have the required characteristics and can be easily embedded into the production process. This can be obtained, for instance, by adopting industry standards regarding certain types of key intermediate inputs for industrial production.

Figure 3.14. A 50% supply shock in ATPs in China: Effect of diversification policies

Baseline and counterfactual simulated effect on production (% change), ICT and electronics industry



Note: The two graphs report the simulated effect of a temporary 50% decline in the supply of ATP in China in the short term (Panel A) and the medium term (Panel B). The bars represent the baseline simulation effect and the dots show the simulated impact under the different policies.
Source: OECD calculations.

4 Conclusion

The rising risks and increased uncertainty affecting the global economy and GVCs have increased the calls for policy intervention to foster the resilience of supply chains in OECD countries.

This paper presents a new tool to evaluate the granular vulnerability of supply chains consecutive to shocks of different nature, such as natural disasters or productivity shocks affecting the supply of some products to all partners. The granular GVC mapping, which is presented in Section 2 of the paper, highlights the vulnerability of the supply of some intermediate products, characterised by a high concentration of supplier shares, and a weak capacity to substitute, as measured by the global export market share concentration in the same product. In many OECD and other G20 economies, about 5% to 8% of intermediate products can be classified as vulnerable, with different degrees of vulnerability in our classification (moderately to highly vulnerable products). Vulnerability is high in intermediate products belonging to industries such as pharmaceuticals, other manufacturing inputs, or mining. China appears in most cases as the main supplier of these vulnerable products.

The quantitative tool presented in Section 3 of the paper allows to conduct stress-test exercises on the vulnerability of supply chains following shocks. We present different simulations, based on scenarios related to the occurrence of natural disasters in supplying countries (Japan, Republic of Türkiye) or based on productivity shocks affecting the supply of intermediate products from China (ATP, critical raw materials). Simulations show that these shocks can have a large detrimental impact on downstream production when supply is highly concentrated in the shocked supplier and when opportunities to rely on alternative suppliers for the same product are low. Counterfactual simulations show that diversification and adaptation policies are complementary for improving the resilience of the supply chain to foreign shocks: limiting the exposure to specific suppliers works when substitutability between products is high. In this respect, ex-ante adaptation policies can target the harmonisation and certification of some key intermediate inputs to help the process of diversification when it is possible.

This work also shows that the identification of vulnerabilities in supply chains requires extremely detailed data. Future work should concentrate on using alternative product and/or firm-level data to better identify vulnerabilities and the transmission of shocks through production networks.

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Annex A. Combining ICIO tables and Comtrade data

We detail here the matched ICIO-COMTRADE dataset that is used in the analysis and extensively discussed in Section 2. This section describes the two datasets, the merging procedure and the underlying hypotheses.

The COMTRADE data used in this project contains V_{ijp}, the value of gross export from country i to destination j and HS6 product p. It is enriched with information on the sector of production (r) of each product as well as the end use for the product from the BEC classification. The data is then restricted to the set of products used as intermediate inputs. Each element of this product-level trade matrix is a gross export flow V_{ijp}^{r}. This data allows analysing the trade relations at a granular (product) level but lacks one crucial piece of information for industrial policy analysis: the using sector in which a product is employed within the using country.

The ICIO table is an OECD data framework that captures the economic interdependencies between 76 countries and 42 industries. It combines input-output tables with trade data to calculate sector-level and bilateral trade of intermediate and final goods in value-added and gross output terms, making it a powerful tool for understanding GVCs. The empirical work presented in this paper notably relies on Z_{ijrs}, the gross flow of input from country i and input sector r that is used for intermediate production in using sector s and country j, elements of matrix Z in ICIO**.**

Merging the two datasets require making a proportionality assumption based on sectoral information from the ICIO Z matrix to allocate trade flows (V_{ijp}^{r}) across using sectors. The allocation is based on c_{ijrs} defined as the share of intermediate input imported from country i and sector r to be used in country j and sector s (Z_{ijrs}) in the total imported intermediate inputs from ir to j: $c_{ijrs} = \frac{Z_{ijrs}}{Z_{ijr}}$, with $Z_{ijr} = \sum_s Z_{ijrs}$. The trade flows V_{ijp}^{r} is then allocated as follows: $V_{ijps}^{r} = c_{ijrs} \times V_{ijp}^{r}$.

The underlying simplifying assumption is that the allocation of product across using sector s for a given triple (i,r,j) corresponds to the allocation of intermediate goods at the more aggregated sectoral level: $\frac{V_{ijrps}}{V_{ijrp}} = \frac{Z_{ijrs}}{Z_{ijr}}$.

Annex B. Details on the quantitative framework

The quantitative framework presented in this paper is adapted from the simplified framework detailed in Bachmann et al. (2022[21]). Bachmann et al. (2022[21]) quantify the effects of a shock on the availability of gas or brown energy in Germany in the context of the Russian war of aggression against Ukraine, and its effects on output. Our quantitative framework borrows the properties of this simplified framework and extends it to quantify the effects of product-specific shocks in supplying countries, and the effects of these shocks on downstream output in buying countries and industries. This framework relies on the matched ICIO-Comtrade dataset presented in this paper, which is used to compute the supplier share in the first stage, the share of the shocked product in the second stage and the share of total intermediates in production are taken from the merged ICIO-Comtrade data. Elasticities of substitution between different suppliers of each product, between products, and between the intermediate inputs bundle and the value added in the downstream industry are taken from the literature.

In the quantitative framework, we adapt a nested constant elasticity of substitution (CES) structure to account for the substitutability (1) between different suppliers of a given product, (2) between different products used in the production process, and (3) between intermediate inputs and value-added. We detail below these different stages in the quantification exercise, and the calibration of the different elasticities is presented in Table A B.1.

The response of output in the buying country and downstream industry is a partial equilibrium quantification that relies on observed product-level ICIO weights, and assumes elasticities at each stage in the short and medium-long term. In the presentation of the results we will therefore have two quantifications for each shock scenario, one for each time horizon.

1. **Substitutability between different suppliers of each product.** We firstly account for the capacity of producers to substitute between different suppliers of one product. In the expression below, $\tilde{X}_{jps}$ corresponds to the total use of product p in the production of sector s in country j, $\tilde{Z}_{ijps}$ is the set of shocked suppliers of that product, ω_{ijps} is the share of each upstream supplier in the total imports of product p by the downstream industry, ε is the elasticity of substitution between the different upstream suppliers of that product.

$$\tilde{X}_{jps} = \left(\omega_{ijps}{}^{\frac{1}{\varepsilon}} \tilde{Z}_{\mathrm{ijps}}^{\frac{\varepsilon-1}{\varepsilon}} + (1-\omega_{ijps})^{\frac{1}{\varepsilon}} Z_{\mathrm{ijps}}^{\frac{\varepsilon-1}{\varepsilon}} \right)^{\frac{\varepsilon}{\varepsilon-1}} \quad \text{Equation 1}$$

2. **Substitutability between different products used as intermediate inputs by the downstream industry.** In this second stage, we account for the capacity of downstream producers to substitute different intermediate products used in final production. $\widetilde{M}_{js}$ is the total use of intermediate inputs, $\tilde{X}_{jps}$ is the set of shocked products from the first stage, α_{jps} is their product share in total intermediate input cost (accounting for domestic and imported inputs), σ is the elasticity of substitution between different intermediate products in the downstream industry.

$$\widetilde{M}_{js} = \left(\alpha_{jps}{}^{\frac{1}{\sigma}} \tilde{X}_{\mathrm{jps}}^{\frac{\sigma-1}{\sigma}} + (1-\alpha_{jps})^{\frac{1}{\sigma}} X_{\mathrm{jps}}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \quad \text{Equation 2}$$

3. **Substitutability between intermediate products and the value-added in the downstream industry.** In a third stage, we account for the possibility that the shock on intermediate inputs can be partly absorbed by adjusting the domestic value-added. $\tilde{Y}_{js}$ is the final output in industry s, ρ_{js} is the share of intermediate inputs in total production, $\widetilde{M}$ is the use of intermediate inputs for final production, VA is the value-added, μ is the parameter that governs the substitutability between the value-added produced in the downstream industry and the intermediate input bundle.

$$\tilde{Y}_{js} = \left(\rho_{js}^{\frac{1}{\mu}} \widetilde{M}_{\text{js}}^{\frac{\mu-1}{\mu}} + (1-\rho_{js})^{\frac{1}{\mu}} VA_{\text{js}}^{\frac{\mu-1}{\mu}} \right)^{\frac{\mu}{\mu-1}} \quad \text{Equation 3}$$

We follow Bachmann et al. (2022[21]) and use a hat algebra to assess the transmission of the upstream supplier shocks to the different stages of downstream production. With the hat algebra (Dekle, Eaton and Kortum, 2007[50]), each variable is expressed in deviation from a benchmark level $\hat{G} = \frac{G_1}{G_0}$. With the nested-CES framework detailed above, this implies a very straightforward transmission of the upstream supplier shock to downstream output in each country and industry.

$$\hat{X}_{jps} = f(\hat{Z}_{ijps})$$
$$\widehat{M}_{js} = g(\hat{X}_{jps})$$
$$\hat{Y}_{js} = h(\widehat{M}_{js})$$

Table A B.1. Elasticities used for the quantification exercise

Substitutability parameter	ε between suppliers of a same product	σ between products	μ between intermediate inputs and value-added
Short term	0.1	0.04	0.5
Medium / long term	[3.6; 18.5]	0.1	0.5

Note: The elasticities (σ, μ) in the short and medium-long term are taken from Baqaee and Farhi (2019[21]), Barrot et al. (2021[20]), and Bachmann et al. (2022[4]). The elasticity of substitution between suppliers of each product is calibrated to a low value in the short run to account for the relationship specificity of supplier-buyer relationships (ε=0.1). In the medium-long run we account for the greater substitutability of suppliers and take elasticities that are estimated at the product level in Fontagné et al. (2022[8]) (See for instance, Table 5 of their published paper where the elasticities are aggregated and presented for each section of the Harmonised System product classification).
Source: Baqaee and Farhi (2019[21]), Barrot et al. (2021[20]), and Bachmann et al. (2022[4])

Endnotes

[1] This classification is used by the OECD to produce the Bilateral Trade by Industry and End-use (BTDIxE) database.

[2] Such a classification remains, however, subject to methodological choices due to the level of thresholds. Using two different sets of thresholds reduces the risk of misclassification. In the stress-test approach presented in the next Section of this paper, the quantifications of shocks rely on actual trade shares and do not require the establishment of a specific threshold. This is a more convenient and flexible approach, which also allows to emphasize the role played by the nature of shocks.

[3] The top 15 countries are selected based on their gross output and are in ascending order: United States, Germany, Japan, Korea, Mexico, United Kingdom, Canada, Spain, France, Italy, Czechia, Sweden, Poland, Slovak Republic, Hungary. For the rest of the section, the using sector s dimension is dropped from the formula as implicitly s = motor vehicle industry (D29).

[4] They represent 72% of the total value imported by the motor vehicle industry.

[5] See Figure 3 of the paper « Global Value Chain dependencies under the magnifying glass", by Schwellnus et al. (2023[14]).

[6] See Figure 11 in Baldwin et al. (2022[15]). The 40% number is based on their FPEM indicator.

[7] The complete list of ATPs is available here: https://www.census.gov/foreign-trade/reference/codes/atp/index.html.