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Global value chain dependencies under the magnifying glass

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Policy makers are increasingly grappling with the stability implications of global value chains (GVCs), as widespread supply shortages following the COVID-19 pandemic and the Russian Federation's war of aggression against Ukraine have disrupted the economic recovery and contributed to high inflation. This paper provides a tool to assess vulnerabilities in GVCs by drawing a detailed map of dependencies based on new indicators constructed from the OECD Inter-Country Input-Output tables. The key findings are as follows. First, GVC dependencies increase with both the size of foreign exposures and the length of foreign value chains. Second, in some industries, such as the automotive and ICT industries, vulnerabilities from high GVC dependence are amplified by high geographic concentration of suppliers or buyers. Third, the People's Republic of China is the most critical choke point in GVCs across a broad range of industries, both as a dominant supplier and as a dominant buyer.

Keywords: Global Value Chains, International trade, Resilience

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Executive summary

As widespread supply shortages in the wake of the COVID-19 crisis and, more recently, the Russian Federation's (hereafter, 'Russia') war of aggression against Ukraine have disrupted the economic recovery and triggered high inflation, policy makers are increasingly grappling with the stability implications of global value chains. This paper provides a key input for policy makers to assess global value chain risks by providing a detailed map of global value chain dependencies. The main upshots are as follows:

The indicators in this paper account for the fact that global value chain risk depends both on the size of exposures and the complexity of the value chain.

- Foreign input reliance as a measure of upstream dependencies (on suppliers) increases with both the size of foreign input use in domestic production and the number of times the inputs cross borders before being used.
- Foreign market reliance as a measure of downstream dependencies (on buyers) increases with both domestic input use in foreign production and the number of times the inputs cross borders before being used.

Using the measures of foreign input reliance and foreign market reliance as measures of exposure to global value chain risk reveals that:

- Small open economies are typically most exposed to global value chain shocks.
  - Countries specialised in downstream activities, such as a number of eastern European countries in the automotive industry, are typically most exposed to upstream supply disruptions due to the length of the upstream value chain.
  - Conversely, countries specialised in upstream activities, such as Australia, Chile and Norway in mining, are typically more exposed to downstream demand disruptions.
- For most OECD countries, exposures to global value chain risk are largely intra-regional and intra-OECD.
  - This is especially true in Europe and, to a lesser extent, also in North America.
  - By contrast, in some Asian and South American OECD countries dependencies are to a much larger extent extra-OECD, mainly reflecting large dependencies on the People's Republic of China (hereafter, 'China').

In some industries, exposure to global value chain risk is amplified by high concentration of suppliers and/or buyers.

- For instance, the automotive and ICT & electronics industries (that were both heavily affected by supply disruptions in the wake of COVID-19) are highly dependent on foreign inputs and on geographically highly-concentrated suppliers.

- The mining, chemicals and basic metal industries are significantly exposed to downstream global value chain demand shocks in single buying countries and industries.

High geographical concentration of supply and/or demand raises the risk of single points of failure (choke points).

- Countries and industries can act as upstream choke points when many industries are highly reliant on their inputs.
  - Small resource-rich economies, such as Chile, Kazakhstan and Norway, play an outsize role as upstream suppliers of mining products.
  - China is a dominant upstream supplier in a broad range of industries, including ICT & electronics, chemicals, basic metals and non-energy mining.
  - High-income OECD countries, such as France, Germany, United Kingdom and United States, remain the most critical upstream suppliers of services.
- Downstream choke points, on which many industries are highly reliant as markets, are generally large industries in large economies.
  - This includes most G7 countries, China and India.
  - The Chinese construction industry stands out as a critical buyer of intermediate inputs from a broad range of industries, including mining, manufacturing and services.
- Overall, the indicators in this paper suggest that Chinese industries are the most critical choke point in global value chains, accounting for about half of the top-10 upstream and downstream choke points across broad industry groups.

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1 Introduction

The rapid globalisation of value chains – loosely defined as an increasing share of imported intermediate goods and services in output – has raised productivity and boosted the participation of lower-income countries in international trade (OECD, 2013[1]).[1] But globalised value chains may also expose domestic production to shocks from abroad, including by creating dependencies on a small number of key players (OECD, 2021[2]). Particular concerns arise from dependencies in strategic value chains that are critical to cover peoples' basic necessities, such as food and health, or that serve as critical inputs into a broad range of downstream industries, such raw materials and semiconductors.

This paper provides a key tool to assess vulnerabilities to global value chain (GVC) disruptions by drawing a detailed map of GVC dependencies. Using the latest OECD Inter-Country Input-Output (ICIO) data, it first takes the perspective of countries and industries exposed to GVC disruptions by describing foreign input reliance and foreign market reliance across countries and industries. It then turns to the sources of disruptions by identifying choke points in the GVC network that may act as critical points of failure. The analysis based on OECD ICIO is complemented with case studies that analyse a number of critical value chains in more detail, including food and agriculture (with a focus on supply from Ukraine and Russia), basic metals, and the German automotive industry.

A vast number of studies analyse the effects of the globalisation of value chains on the industrialisation of low-income countries and productivity (Baldwin, 2017[3]; Criscuolo and Timmis, 2017[4]) but only few focus specifically on vulnerability to disruptions (Boehm, Flaaen and Pandalai-Nayar, 2019[5]; Carvalho et al., 2020[6]; Khanna, Morales and Pandalai-Nayar, 2022[7]). The contribution of this paper is threefold. First, it bases the map of GVC dependencies on new indicators of foreign input reliance and foreign market reliance that account for both the size of exposures and the length of value chain. Complementary works shows that these indicators – which were originally proposed by Baldwin and Freeman (2021[8]) – are economically and statistically highly significant in transmitting shocks across countries (Schwellnus, Haramboure and Samek, forthcoming[9]). Second, it complements the indicators of foreign dependencies with measures of geographical concentration of suppliers and buyers and characterises global choke points that can act as single points of failure. Third, the indicators of GVC dependencies developed for this paper will be made publicly available as an extension of the OECD ICIO database.

The main results are as follows. First, small open economies that are specialised in downstream activities (e.g. some eastern European countries specialised in automotive manufacturing) are among the most vulnerable to upstream supply disruptions. Conversely, small open economies specialised in upstream activities such as mining (e.g. Australia, Chile and Norway) are among the most vulnerable to downstream demand disruptions. Second, some industries are not only highly dependent on foreign inputs but also on geographically highly concentrated suppliers, making them particularly vulnerable to supply disruptions. This is, for instance, the case of the automotive and ICT & electronics industries that were heavily affected by supply disruptions in the wake of COVID-19. Third, China is the most critical upstream and downstream choke point in GVCs, accounting for about half of the top-10 upstream and downstream choke points across broad industry groups. Small resource-rich economies play an outsize role as upstream suppliers

of mining products, while high-income OECD countries remain the most critical upstream suppliers of services.

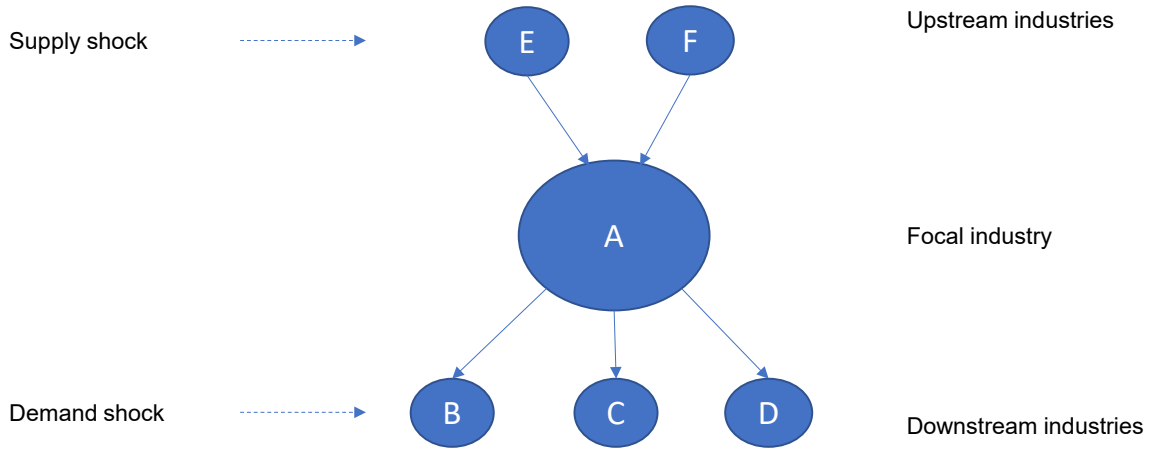
The remainder of the paper is structured as follows. Section 2 describes GVC dependencies from the perspective of countries and industries exposed to supply-side or demand-side disruptions from abroad. Section 3 describes dependencies from the perspective of countries and industries that may be the source of important disruptions, the focus being on upstream and downstream choke points in food and agriculture, mining, manufacturing, and services. The general choke point analysis is complemented with case studies of choke points of particular policy interest: Ukrainian and Russian agriculture; critical minerals for the green transition; as well as the German automotive industry. Section 4 concludes.

2 Setting the scene

Definition of GVC shocks

Upstream supply shocks or downstream demand shocks can affect domestic output by percolating through GVCs (Figure 1).[2] For instance, flooding in Thailand in 2011 disrupted the supply of electronics components (say upstream industry in country E) to Japanese and US carmakers and technology companies (focal industry in country A). By contrast, the global financial crisis of 2008-09 reduced final demand for the output of downstream producers (say downstream industries in country C), which in turn reduced demand for intermediate inputs addressed to upstream producers (focal industry in country A).[3]

Figure 1. The propagation of supply and demand shocks through GVCs



Source: OECD.

Previous key studies on GVC fragilities

While there is ample evidence that GVCs have expanded rapidly over the past four decades, only few recent studies provide a comprehensive picture of dependencies at the country-industry level.[4] Johnson and Noguera (2017[10]) and Baldwin (2022[11]) show that trade in intermediate goods, as measured by the ratio of gross exports to value-added exports, started to increase in the early 1980s, accelerated over the period 1990-2009, and stagnated thereafter. However, the last comprehensive map of GVCs based on OECD TiVA data, covering the years up to 2009, is now outdated (De Backer and Miroudot, 2013[12]).

In recent papers reviewing the evidence on risks in GVCs, Baldwin and Freeman (2021[8]) and Baldwin, Freeman and Theodorakopoulos (2022[13]) provide a number of insights that are relevant to the descriptive

analysis in this paper. First, they emphasise that overall risk exposures can only be assessed by fully accounting for both direct (e.g. through direct suppliers) and indirect (e.g. through the direct suppliers' suppliers) exposures. They point out that this requires data on input-output linkages across countries, either at the level of individual firms or at the level of industries. Second, Baldwin and Freeman (2021[8]) highlight that existing indicators of GVC integration based on trade in value added may not fully account for the risk that disruptions in one part of the value chain may hold up the entire shipment of intermediate inputs. Third, they emphasise that, even though concerns have recently focused on supply disruptions, booms and busts in demand may constitute an important source of GVC risk as well.

An important recent body of work uses network analysis to identify critical points of failure (or choke points) in GVCs. Under perfect diversification of GVCs, negative idiosyncratic shocks in one part of the network should be offset by positive shocks elsewhere, suggesting low risk to domestic production from disruptions abroad (Lucas, 1977[14]). However, if some suppliers or buyers are much more important than others, then disruptions to these important actors can destabilise the entire GVC network (Carvalho and Tahbaz-Salehi, 2019[15]). Network analysis suggests that the importance of a GVC actor can be measured by its centrality, which encompasses both its size and the number of trade links with other actors.

Network analyses based on industry-level input-output data generally reveal large dispersion in centrality across industries, especially in the foreign component of centrality. In particular, using cross-country input-output data from the OECD-TiVA database, Criscuolo and Timmis (2018[16]) show that the foreign part of value chain centrality displays significantly higher dispersion of centrality than the domestic part. This suggests that many countries and industries depend on a small number of influential foreign suppliers or buyers that may act as single points of failure (or choke points) in GVCs. Evidence from firm-level data from Belgium and Japan suggests that centrality is also highly dispersed across firms (Carvalho et al., 2021[17]; Bernard, Moxnes and Saito, 2019[18]), implying that exposure to GVC shocks may not only increase with geographic concentration of suppliers and buyers but also with industry concentration.

Measuring GVC dependencies

Vulnerability to GVC disruptions

In this paper, vulnerability to GVC disruptions is measured using the indicators of foreign input reliance (FIR) and foreign market reliance (FMR) developed by Baldwin and Freeman (2021[8]), where FIR denotes the ratio of foreign output used in domestic production to total domestic gross output, and FMR denotes the ratio of domestic output used in foreign production to total domestic output. These ratios can loosely be interpreted as the share of total domestic output exposed to upstream disruptions in GVCs (FIR) and the share of total domestic output exposed to downstream disruptions (FMR).5 Importantly, gross imports and exports account for both direct and indirect input trade between partner countries by making use of the OECD Inter-Country Input-Output (ICIO) data (Box 1). For instance, the ratio of Chinese output to US gross output accounts for both direct gross imports from China and indirect imports routed through other US trading partners.

Box 1. Vulnerability to GVC disruptions: Foreign input reliance and foreign market reliance

Vulnerability to GVC disruptions is measured by taking the perspective of an industry that faces the risk of an upstream supply disruption or a downstream demand disruption (i.e. the perspective of the focal industry A in Figure 1). Value chain disruptions, such as natural disasters or geopolitical events, typically disrupt the entire shipment of a good rather than only the value added in the disrupted country. Consequently, the preferred definitions of FIR and FMR are based on gross output and are defined as follows:

$$FIR_{c,j} = \sum_{c'=1}^{N} \sum_{j'}^{J} \left(\frac{Foreign\ output_{c,j}^{c',j'}}{Gross\ output_{c,j}} \right) \qquad \text{Equation 1}$$

$$FMR_{c,j} = \sum_{c'=1}^{N} \sum_{j'}^{J} \left(\frac{Domestic\ output\ in\ partner\ gross\ output_{c,j}^{c',j'}}{Gross\ output_{c,j}} \right) \qquad \text{Equation 2}$$

where subscripts *c* and *j* denote, respectively, countries and industries; $Foreign\ output_{c,j}^{c',j'}$ denotes gross output of industry *j'* in country *c'* used in the production of industry *j* in country *c*; and $Domestic\ output\ in\ partner\ gross\ output_{c,j}^{c',j'}$ denotes gross output of industry *j* in country *c* to industry *j'* in country *c'*.[1]

One important property of the numerators in Equation 1 and Equation 2 ($Foreign\ output_{c,j}^{c',j'}$ and $Domestic\ output\ in\ partner\ gross\ output_{c,j}^{c',j'}$) is that they account for both direct and indirect trade links between countries by making use of the OECD ICIO data. For instance, Chinese output in US gross output ($Foreign\ output_{USA}^{CHN}$) accounts for both direct gross imports from China and indirect imports that are routed through other US trading partners.[2] Consequently, FIR and FMR measure ultimate exposure to a partner in the value chain, which accounts for the fact that countries may be exposed to GVC disruptions through higher-tier suppliers (the direct suppliers' suppliers etc.) and higher-tier buyers (direct buyers' buyers etc.).

A second important property of the numerators in Equation 1 and Equation 2 is that value added from a specific partner country may be counted several times. For instance, suppose that a microchip from China is used as an input to the production of a rear view mirror in Mexico, which is, in turn, sent for final assembly of a car to the United States. The Chinese value added embodied in the microchip will be counted twice in $Foreign\ output_{USA}^{CHN}$: once when it crosses the border to Mexico, and once when it crosses the border to the United States. In other words, the numerator of the FIR (foreign output used in domestic production) increases with the length of the upstream value chain. Similarly, the value of the FMR (domestic output used in foreign production) increases with the length of the downstream value chain.

Overall, FIR and FMR can be seen as a combination of (1) the size of exposure to a specific partner in the value chain, and (2) the distance to this partner in the value chain. [3]At a given distance in terms of production stages, a larger size implies higher FIRs and FMRs, in line with the intuition that larger trade links with a specific partner increase vulnerability. At a given size of exposure, greater distance implies higher values of FIR and FMR, in line with the intuition that a larger number of intermediate production

stages between the partner and the destination increases the risk that the shipment is disrupted at some point of the value chain.[4]

Notes:
1. Gross output in the denominator of Equation 1 and Equation 2 encompasses production for intermediate consumption (domestic and foreign), as well as production for final demand (domestic and foreign).
2. In the terminology of input-output analysis, this is achieved by pre-multiplying final demand in the United States with the Leontief inverse, selecting the relevant entry in the resulting vector of gross output.
3. Traditionally, GVC indicators have focused on the measurement of the size of the exposure, e.g. TiVA indicator. A recent indicator by Inomata and Hanaka (2021[19]) captures the complexity of the value chain by measuring the frequency of exposure, i.e. the number of time a product cross a border
4. Note that the denominator in Equation 1 and Equation 2 is domestic gross output, i.e. the sum of value added, domestic intermediate inputs and foreign intermediate inputs. Foreign intermediate inputs are measured as gross output from the last partner in the value chain, i.e. broadly speaking as the sum of value added from all foreign countries (unless there is domestic value added incorporated in foreign intermediate inputs). Given that the numerator of FIR and FMR count value added multiple times when goods or services cross borders multiple times, FIR and FMR can in principle take values above 1.

In contrast to value added-based measures of FIR and FMR, the gross trade and gross output-based FIR and FMR implicitly account for the fact that longer supply chains may involve a higher risk of disruption. This is because gross imports and exports increase each time a good transits through a country so that at any given foreign value added in domestic demand (or domestic value added in foreign demand) a longer value chain will lead to a higher value of FIR and FMR. In other words, the gross output-based FIR and FMR implicitly assume that the entire shipment may be held up at any point of the value chain.[6]

Even though gross output-based and value added-based indicators of GVC dependencies are positively correlated, the use of gross-output based indicators can make a significant difference in some cases (Figure A A.1). For instance, the average GVC dependence on China across countries and industries tends to be larger in gross output terms than in value added terms. This is true for both FIR and FMR and reflects the fact that the ratio of Chinese value added to gross output is comparatively low. By contrast, on average across countries, GVC dependencies on the United States are lower in gross output terms than in value added terms, reflecting its high ratio of value added to gross output.

FIR and FMR can be complemented with measures of geographic and industry concentration. In principle, at any given level of FIR and FMR, risk exposure should increase with the geographic and industry concentration of input suppliers or buyers. High levels of concentration imply that idiosyncratic shocks to single suppliers or buyers – to an industry in a specific country in the case of geographic concentration, or to a firm in a specific industry in the case of industry concentration – may have large downstream and upstream effects on output (Carvalho and Tahbaz-Salehi, 2019[15]).

Sources of GVC vulnerability

Sources of GVC vulnerability are identified as choke points, whose definition is, in turn, based on the concepts of FIR and FMR. As such, they take into account both direct and indirect value chain links. Given that FIR and FMR account for the length of the upstream or downstream value chain, choke points do not only have multiple and large intermediate trade links with their immediate trade partners but their immediate trade partners, in turn, have multiple and large trade links with other partners. An upstream choke point is an important supplier of intermediate inputs, while a downstream choke point is an important buyer of intermediate inputs.

Box 2. Sources of GVC vulnerability: Choke points

The sources of value chain vulnerability are measured by taking the perspective of the industry acting as a potential upstream (i.e. industries E and F in Figure 1) or downstream choke point (i.e. industries B, C and D).

Upstream choke points are defined as the average input reliance across buying industries and countries on a supplying industry in a specific country:

$$UpChoke_{ci}^{Ind} = 1/(C' \cdot I') \sum_{c\prime=1}^{C\prime} \sum_{i\prime=1}^{I\prime} (FIR_{c'i'ci}) \quad \forall i \epsilon Ind$$

Equation 3

where *ci* is the supplying country-industry; *c'i'* is the buying country-industry; *C'* is the total number of buying countries; *I'* is the total number of buying industries; and *Ind* is either a single supplying industry or a broader supplying sector encompassing several industries (e.g. manufacturing or services). For instance, suppose that *Ind* is the manufacturing sector. Then, $UpChoke_{ci}^{Ind}$ measures the importance of each disaggregated manufacturing industry *i* in each country *c* as a supplier to the rest of the economy (including manufacturing industries themselves). The manufacturing industries in the countries with the highest values of $UpChoke_{ci}^{Ind}$ are then considered upstream manufacturing choke points.

The value of $UpChoke_{ci}^{Ind}$ combines the size of dependencies (the average size of *FIR* on the supplying industry conditional on the existence of a value chain link) and the number of dependencies (number of country-industries depending on the supplying industry) of buying industries relative to the supplying industry. At a given number of dependencies, the value of $UpChoke$ increases with the size of *FIR*. Similarly, at a given size of dependencies, $UpChoke$ increases with the number of dependencies. In this sense, the value of $UpChoke$ is similar to measures of forward centrality (Criscuolo and Timmis, 2018[16]). In contrast to forward centrality measures that typically put a lower weight on distant links in the value chain, upstream choke points weigh proximate and distant links equally.[1] The rationale is that the entire shipment may be held up at any point of the value chain.

Downstream choke points are defined as the average FMR across supplying industries and countries on a buying industry in a specific country:

$$DoChoke_{ci}^{Ind} = 1/(C \cdot I) \sum_{c=1}^{C} \sum_{i \epsilon Ind}^{I} (FMR_{cic\prime i\prime})$$

Equation 4

where *ci* is the buying country-industry; *c'i'* is the supplying country-industry; *C* is the total number of supplying countries; *I* is the total number of supplying industries; and *Ind* is either a single supplying industry or a broader supplying sector encompassing several industries (e.g. manufacturing or services). For instance, suppose again that *Ind* is the manufacturing sector. Then, $DoChoke_{ci}^{Ind}$ measures the importance of each downstream industry *i* in each country *c* as a buyer of the output of the manufacturing sector. The downstream industries in the countries with the highest values of $DoChoke_{ci}^{Ind}$ are then considered downstream choke points for the manufacturing sector.

The value of $DoChoke$ is similar to measures of backward centrality (Criscuolo and Timmis, 2018[16]) but with the caveat that proximate and distant value chain links are weighted equally. Moreover, the interpretation of backward centrality by sector or industry is different from downstream choke points. Backward centrality by industry measures the supplying industry's importance as a buyer, whereas the

value of $DoChoke$ measures the importance of downstream industries as buyers of intermediate goods from the supplying industry.[2]

Note:

1. In matrix notation, the upstream choke points indicator is expressed as $\frac{1}{C_{I'}}(I-A)^{-1}I^{foreign}\mathbf{1}$ and foreign forward centrality as $\eta(I-\lambda W)^{-1}I^{foreign}\ \mathbf{1}$, where $\frac{1}{C_{I'}}$ and η are scaling factors, A and W are the matrices of intermediate input flows between industry-country pairs normalised, respectively, by the gross output of the using industry and the total intermediate input of the using industry, $I^{foreign}$ is a matrix of one with zero entries for diagonal domestic blocks, λ determines the rate of decay of higher-order network linkages (direct suppliers will receive a weight of λ^1, while suppliers of suppliers will receive a weight of λ^2, ect ...) and $\mathbf{1}$ is a vector of 1 of dimension ((C*I)*1).
2. Note that the superscript *Ind* in Equation 4 refers to the supplying industry rather than the buying industry.

Figure 1 illustrates the concepts of upstream and downstream choke points with a simple example, where country A would be both an upstream choke point (supplier to countries B, C, D) and a downstream choke point (buyer from countries E and F). Importantly, the downstream choke point value would be lower due to the lower number of buyer-side trade links (with countries E and F) than supplier-side trade links (with countries B, C and D), unless the size of buyer-side trade links is larger.

Data

The primary data source is the OECD ICIO tables that measure the interrelatedness of production across 45 industries and 76 countries from 1995 to 2019 (Martins Guilhoto, Webb and Yamano, 2022[20]).[7] FIR, FMR and choke point indicators are computed using information on gross output; value added; gross output going to final consumption; as well as the origin and destination country of intermediate inputs. Indicators of geographic concentration of production are computed as the share of the top-5 producers in total gross output, and the geographic concentration of intermediate good consumption as the share of the top-5 consumers in total intermediate good consumption.

The OECD ICIO-based indicators of GVC dependencies refer to the year 2019. The use of data referring to 2019 in the OECD ICIO-based analysis ensures that indicators of GVC dependencies are not distorted by temporary disruptions during the acute phase of the COVID-19 pandemic in 2020 but raises the question whether GVC dependencies in 2019 are a good approximation of dependencies in 2022. The reconfiguration of GVCs can at times be abrupt, as illustrated by the rapid substitution of other sources of supply for Russian natural gas in the wake of Russia's war against Ukraine. However, GVC dependencies are generally highly persistent, with the correlation from one year to the next being above 0.9 and the correlation over 3 years being around 0.85 (Figure A A.2). This suggests that abrupt changes in the configuration of GVCs are the exception rather than the norm.

3 GVC dependencies

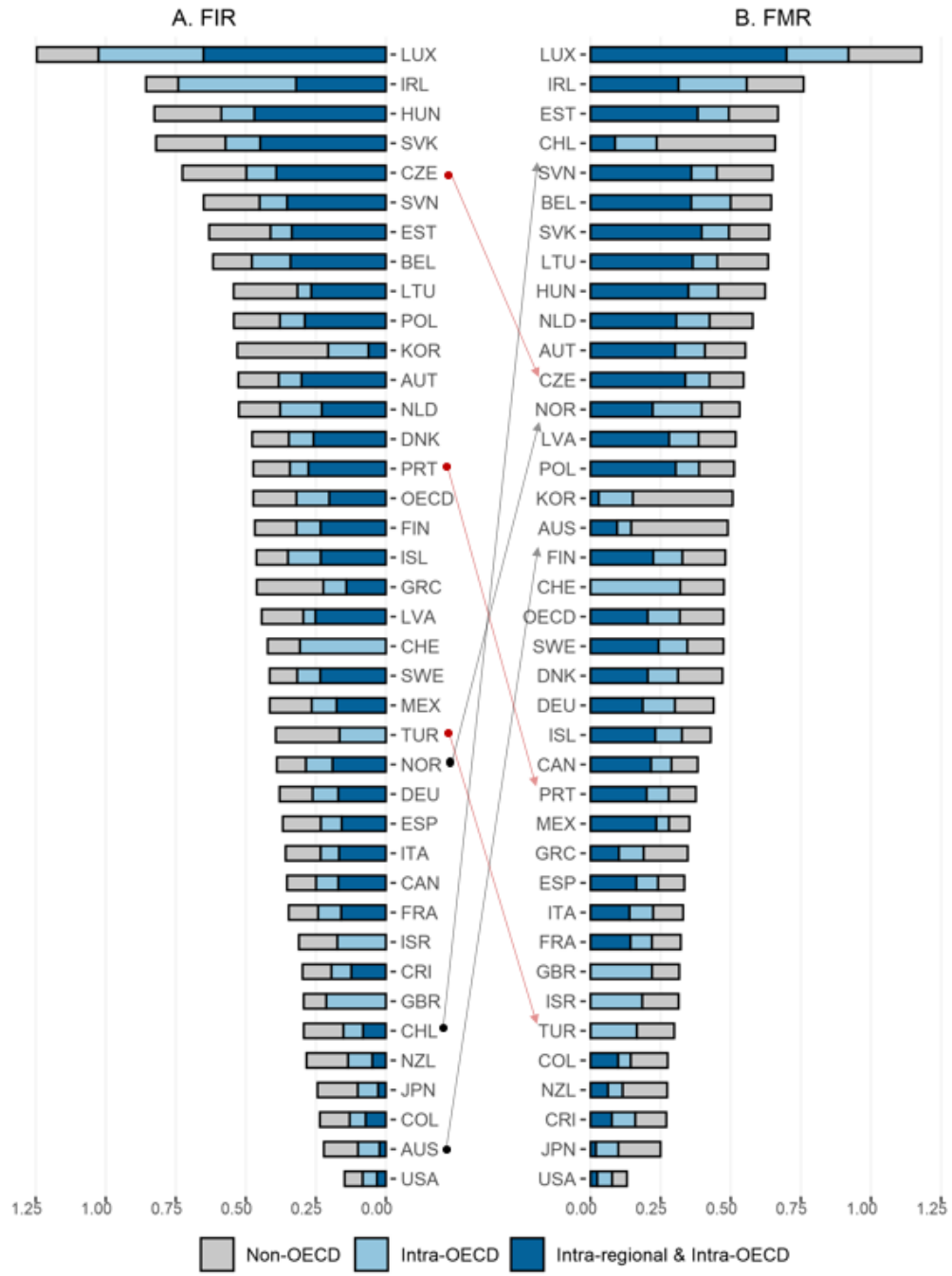
FIR and FMR across countries

On average across OECD countries, both FIR and FMR are about 0.5, implying that about 50% of OECD production is exposed to upstream disruptions in GVCs and 50% to downstream disruptions (Figure 2). FIR and FMR are generally high in small and open economies, such as a number of central and eastern European countries, Ireland and Luxembourg, which reflects small open economies' typically high degrees of integration into GVCs (Figure A A.3). However, some large economies, such as Germany, Italy and Spain, are close to the OECD average in terms of FIR and FMR, reflecting their close integration into European GVCs.

Countries that are specialised in downstream industries tend to be more reliant on foreign inputs, whereas countries that are specialised in upstream industries tend to be more reliant on foreign markets. FIR and FMR do not only account for openness and integration into GVCs but also take into consideration the length of the upstream (FIR) and downstream (FMR) value chain. Consequently, countries that are specialised in downstream industries (e.g. central and eastern European countries in the automotive industry) tend to rank higher on FIR than on FMR. For instance, the Czech Republic is among the top-5 OECD members in terms of FIR but ranks only 12th in terms of FMR. Countries that are highly specialised in upstream industries (e.g. countries with large mining industries, such as Australia, Chile and Norway) tend to rank higher on FMR than FIR. For instance, Chile is the OECD member with the 4th highest FMR but is outside the top-30 on FIR.

FIR and FMR of European Union countries is mostly intra-regional and intra-OECD, whereas it is to a larger extent extra-OECD for North and South American as well as Asian and Pacific OECD members. About 70% of European Union members' FIR is on other members of the European Union or other OECD countries. By contrast, the share of intra-regional and intra-OECD FIR is somewhat lower in North and South American OECD members (around 60%), and especially low in Asian and Pacific OECD members (around 40%). A similar pattern emerges for FMR, with the caveat that extra-OECD FMR is even higher than FIR in Asian and Pacific OECD countries. This is explained by the geographical proximity of Asian and Pacific OECD members to China, as well as the upstream position of Australia and New Zealand in GVCs. Overall, Figure 2 suggests that Asian and Pacific OECD members may be more exposed to GVCs from non-OECD members than their European and American counterparts, making them potentially more vulnerable to geopolitical shocks.

Figure 2. OECD countries account for the major part of foreign dependencies



Note: This figure represents the average FIR (panel A) and FMR (panel B) for OECD countries, as well as a simple average for the OECD group. Individual industries j in each country are aggregated through a weighted average, where the weights are gross industry output ($FIR_c = \sum_j^n (FIR_{c,j} * W_{c,j}^{GO})$, where $W_{c,j}^{GO} = GO_{c,j} / \sum_j^n GO_{c,j}$). A country's FIR/FMR is displayed showing the decomposition of the share of total FIR/FMR between three categories: intra-regional and intra-OECD partners, intra-OECD (extra-regional) partners and non-OECD partners. The regional aggregates taken into consideration are between members of the OECD with intra-regional trade agreements: EEA countries, Asia & Oceania OECD countries and NAFTA+3 countries (including Chile, Colombia and Costa Rica). The composition of country groups is reported in Table A A.1.

Source: OECD, ICIO database

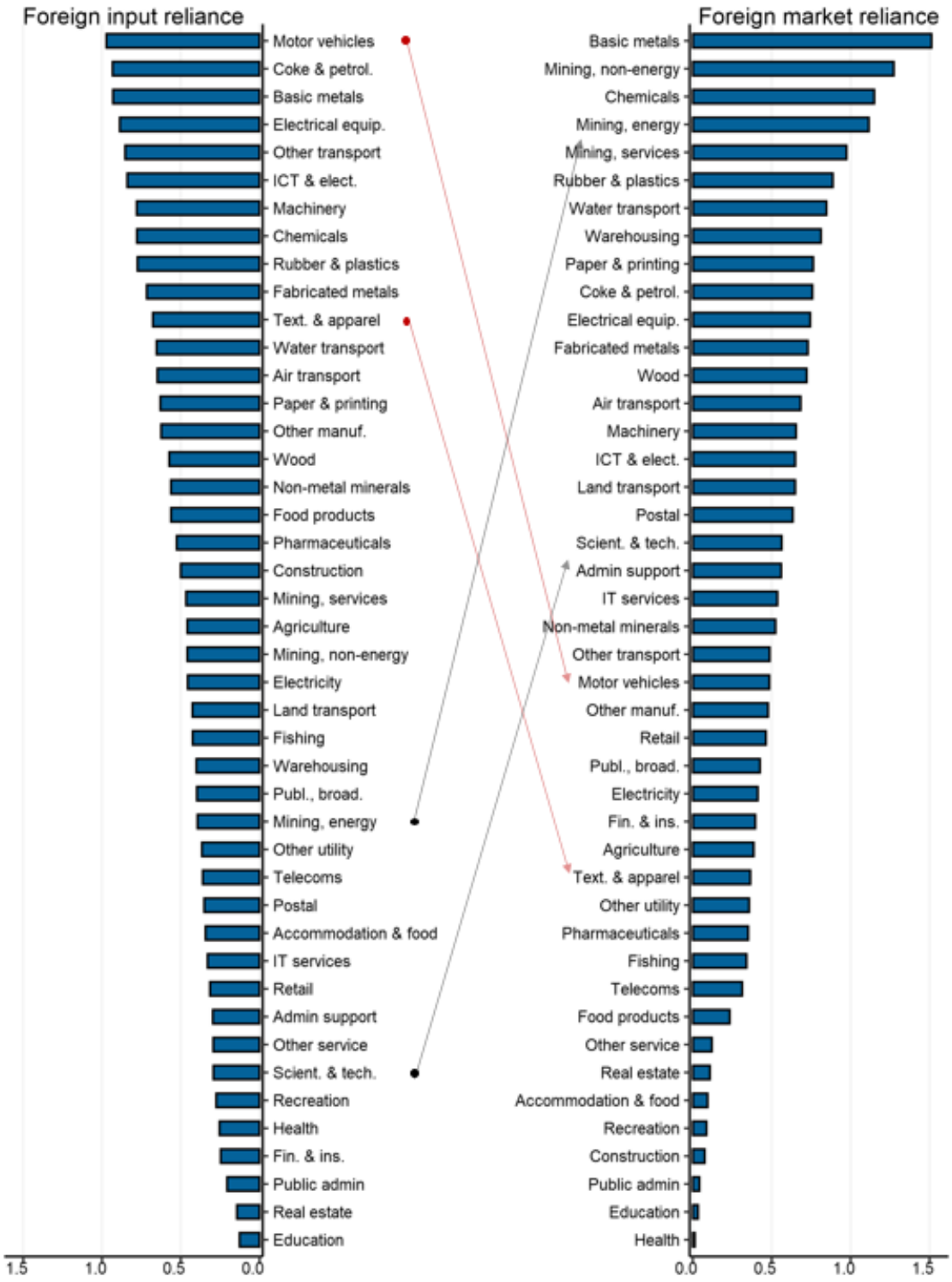
Dependencies by sector

The low values of FIR and FMR for large economies such as China, Japan and United States raise the question why even large economies can be affected by supply chain disruptions. One explanation may be that, even though country-level GVC dependencies may be small, shocks in a few highly GVC-dependent industries may percolate to other industries, thereby triggering broader macroeconomic disruptions.

Openness and the length of the upstream and downstream value chain determine FIR and FMR, with FIR typically being high in downstream industries and FMR being high in upstream industries. For instance, motor vehicles and other transport – which are trade-intensive industries with long upstream supply chains – are top-5 industries in terms of FIR but are not among the top-20 industries in terms of FMR. By contrast, mining industries are all the top-5 industries in terms of FMR but are under the top-20 industry ranking in terms of FIR. This can be explained by the fact that, as an upstream industry, mining is reliant on inputs (domestic and foreign) only to a limited extent but sells its output to a wide range of foreign industries whose output is, in turn, used as intermediate input in a range of other downstream industries.

The industry pattern of FIR and FMR is consistent with the pattern of GVC disruptions observed during and in the wake of the COVID-19 crisis. For instance, motor vehicles and other transport have been among the industries that were the most affected by semiconductor shortages over the past two years. Similarly, health and pharmaceuticals – which rank fairly high on FIR but low on FMR – suffered from supply disruptions during the initial phases of the COVID-19 crisis. A particularly vulnerable industry is the ICT & electronics industry (including semiconductors) that ranks among the industries with both the highest FIR and the highest FMR. Indeed, over the past two years, the industry has simultaneously experienced large positive downstream demand shocks and negative upstream supply shocks that have reinforced each other (Haramboure et al., forthcoming[21]).

Figure 3. FIR is typically higher in downstream sectors and FMR in upstream sectors



Note: This figure represents the average FIR (panel A) and FMR (panel B) for individual industries. Values are an average of OECD and selected (BRIICS) countries ($FIR_j = (\sum_c^n FIR_{c,j}) / n$). The composition of industry groups is reported in Table A A.2.
Source: OECD, ICIO database

Geographical concentration of upstream supply and downstream demand

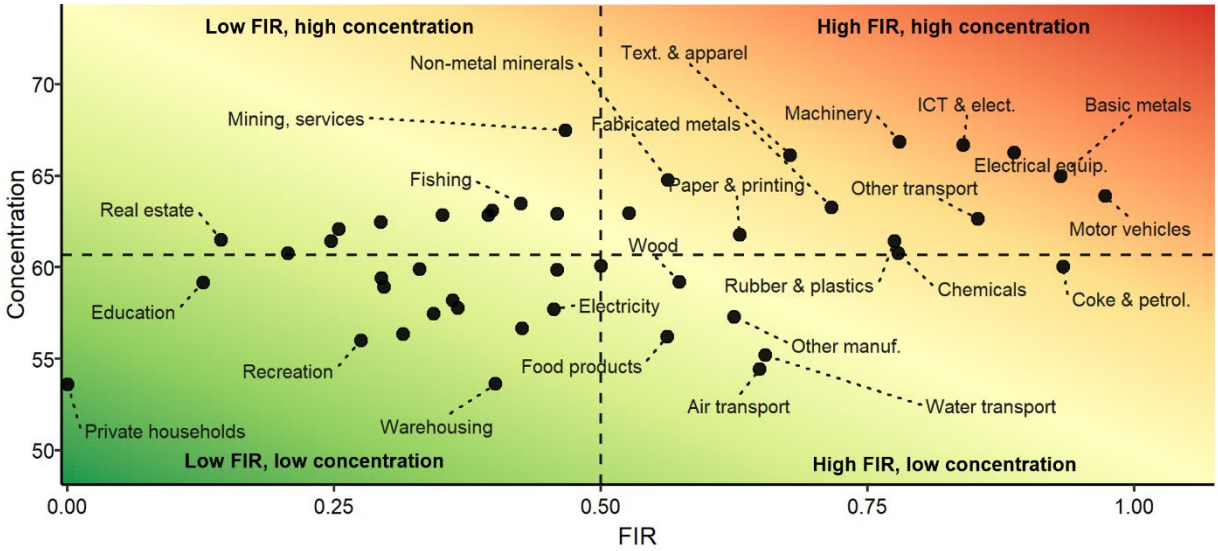
High GVC dependencies typically imply higher risk when upstream suppliers and/or downstream buyers are geographically highly concentrated. The rationale is that when upstream supply or downstream demand are highly geographically concentrated, there are only few alternative suppliers or buyers in case of a shock to a critical country. In other words, the geographic concentration of suppliers and/or buyers may give rise to choke points (single points of failure). For instance, semiconductor manufacturing is highly concentrated in Chinese Taipei, implying that a local shock to semiconductor manufacturing due to geopolitical events or a natural disaster could disrupt the entire GVC (Haramboure et al., forthcoming[21]).

Some downstream industries are both highly dependent on foreign inputs and exposed to high average geographical concentration of their suppliers (Figure 4, Panel A). The motor vehicle industry, for instance, has both one the highest average FIR in the sample and sources its inputs from industries where the average market share of the top-5 producers is around 65% (including the motor vehicle industry itself and basic metals). This suggests that the motor vehicle industry may be among the industries most exposed to disruptions in a single supplying country and industry (the red-shaded area in Figure 4). Other industries in this area include the ICT & electronics industry, machinery, as well as basic metals. Overall, the evidence in Figure 4 is consistent with the pattern of supply disruptions during and in the wake of the COVID-19 pandemic, with the automotive industry and ICT & electronics experiencing large disruptions.

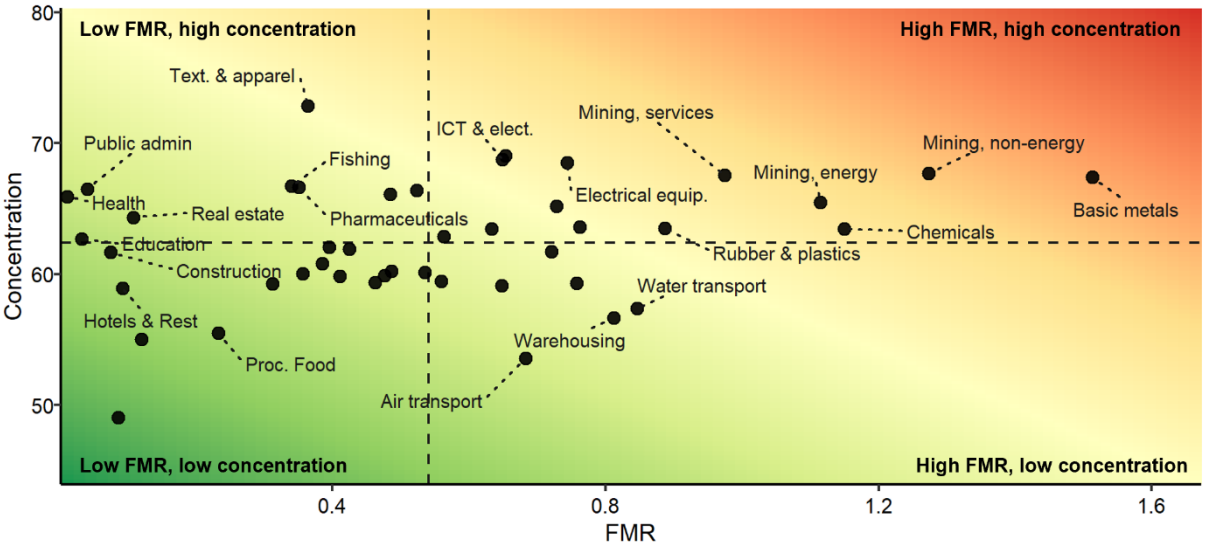
On the side of upstream industries (Figure 4, Panel B), the mining and basic metals industries are both the most heavily reliant on foreign buyers and among the industries where buyers are highly geographically concentrated. In fact, the mining and basic metals industries depend heavily on buying industries that are heavily geographically concentrated in China and the United States, such as refining, construction and motor vehicles. The chemicals industry also appears significantly exposed to downstream GVC demand shocks in single buying countries and industries. Even though the ICT & electronics industry is not among the industries that are most dependent on foreign buyers, it is nonetheless highly exposed to downstream demand shocks through very high buyer concentration, especially in China and the United States. This implies that positive downstream demand shocks in its main markets may amplify supply disruptions and lead to shortages.

Figure 4. Geographical concentration in a number of upstream and downstream industries is high

Panel A: Average concentration of suppliers (%) and average foreign input reliance (index), 2019



Panel B: Average concentration of buyers (%) and average foreign market reliance (index), 2019



Note: For each using industry, average geographic concentration of suppliers is computed as $C_j^{sup} = \frac{1}{N_c} * \sum_{c=1}^{C} \sum_{j=1}^{J} \left(C_j^{prod} * w_{cij} \right)$, where C_j^{prod} in industry *j* is measured as the ratio of gross output in the top-5 producers to global gross output and w_{cij} is the share of supplying industry *j* in total FIR of the using industry *i* in using country c. The average geographical concentration of buyers of a supplying industry *i* is computed using a similar weighted average $C_j^{buy} = \frac{1}{N_c} * \sum_{c=1}^{C} \sum_{j=1}^{J} \left(C_j^{cons} * w'_{cij} \right)$ where C_j^{cons} is the ratio of intermediate consumption of the top-5 consumers to total intermediate consumption and w'_{cij} is the share of buying industry *j* in total FMR of the selling industry in selling country *c*. FIR and FMR of each industry are obtained as the unweighted average across countries. Sample: OECD and selected (BRIICS) countries

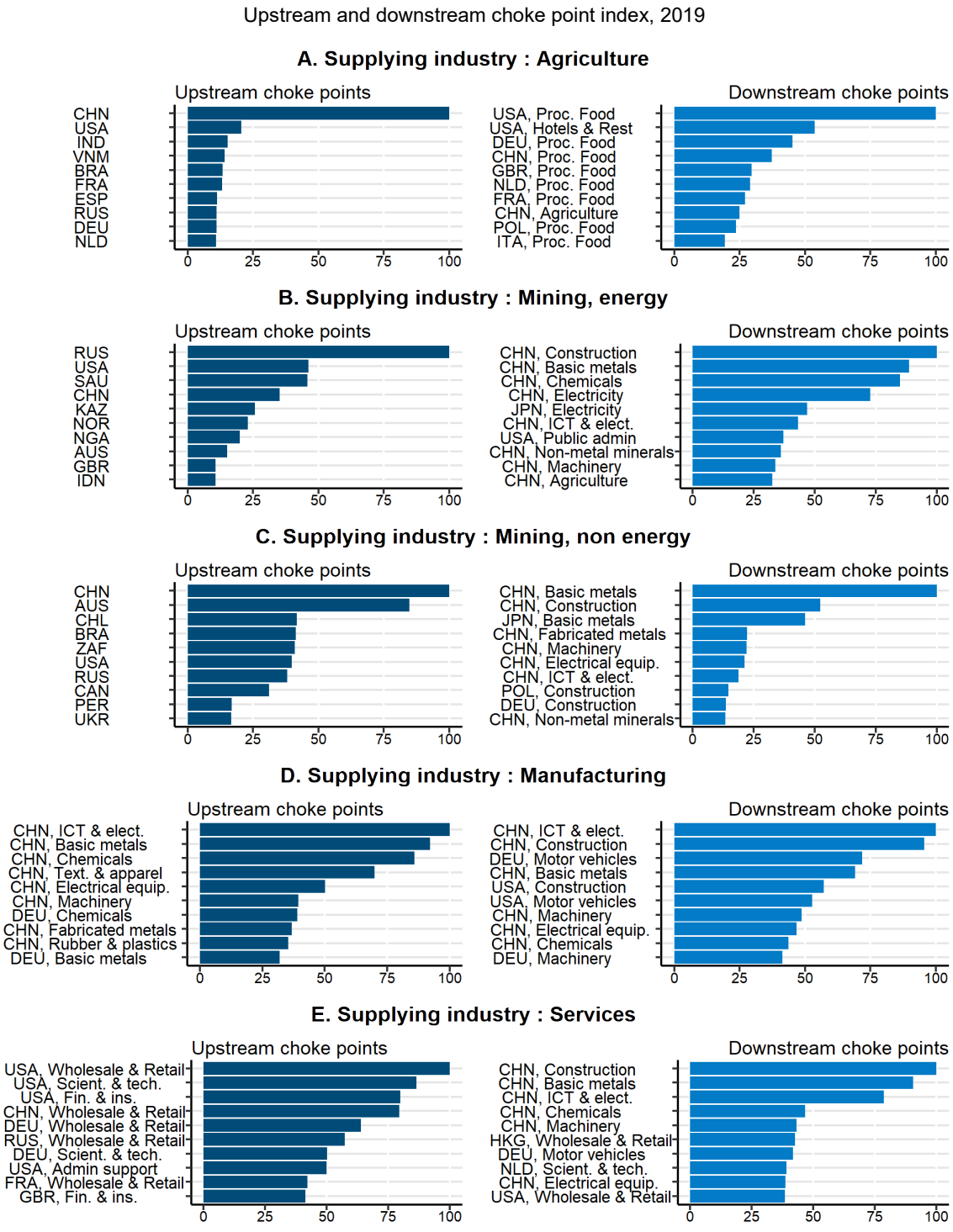
Source: OECD, ICIO database

Choke point analysis

While FIR and FMR describe vulnerabilities from the perspective of countries and industries exposed to supply-side or demand-side disruptions from abroad, this section focuses on the characterisation of the sources of vulnerabilities. For this purpose, it defines as upstream choke points countries and/or industries on which many other countries and/or industries are highly dependent as intermediate input suppliers (see Section 2). Similarly, downstream choke points are defined as countries and/or industries on which many other countries and/or industries are highly dependent as intermediate input buyers. The analysis is conducted at the level of sectors (agriculture, energy mining, non-energy mining, manufacturing and services).

The identification of upstream and downstream choke points by sector has two main objectives. The first is to determine critical suppliers separately for each broad industry. For instance, Russia was the most critical supplier in energy mining in 2019 (Figure 5), suggesting that a supply disruption may have sizeable downstream effects on foreign buyers. The second is to identify the sector's main buyers. For instance, the Chinese ICT and electronics industry was the most critical buyer in manufacturing in 2019. While a positive demand shock may be a boon to manufacturing industries supplying the Chinese ICT and electronics industry, e.g. the semiconductor industry, it may also lead to shortages for other buying industries in manufacturing (e.g. the automotive industry).[8]

Figure 5. China is a critical supplier and buyer in most industry groups



Note: This figure plots for each sector the 10 countries or the 10 country-industry pairs with the highest value of the upstream and downstream choke point index. In each panel, the choke point index is normalised to 100 in the industry with the highest value (see Box 2). The coke and refined petroleum products industry (D19) is dropped from the analysis.
Source: OECD, ICIO database

Agriculture

Upstream agricultural choke points include large economies, such as China, Germany and the United States but also a number of smaller agricultural powerhouses, such as the Netherlands, Spain and Russia (Figure 5, Panel A). China stands out as by far the main upstream agricultural choke point, reflecting its large exports of fruits, vegetables, and rice to a wide range of downstream countries and industries, especially in Asia and the United States. The other agricultural choke points are typically large economies (e.g. Germany) or economies where the agricultural sector accounts for a large share of GDP (e.g. Viet Nam). Moreover, some economies (e.g. the Netherlands) are large hubs for agricultural *entrepot* trade. Many agricultural commodity imports by European Union countries are routed through the large Dutch ports. Even though only little value is added, the choke point index picks up high gross output, consistent with the presumption that a disruption at a major Dutch port could significantly disrupt the European agricultural supply chain.

The fact that Russia is among the top-10 upstream agricultural choke points and Ukraine among the top-20, suggests that Russia's unprovoked, unjustifiable, and illegal war of aggression against Ukraine may have significant consequences for food security around the globe. Dependencies on Russian and Ukrainian agricultural commodities, especially cereals, are particularly high in a few Northern African and Sub-Saharan African countries (Box 3). Moreover, Russia is also a major supplier of fertilisers, which implies that the supply of agricultural commodities, despite not being directly exported by Russia and Ukraine, may be adversely affected by the war.

Box 3. Russia's war against Ukraine is affecting global food security

Russia's war of aggression against Ukraine is the biggest risk to global food security in the short term, with export shortfalls coming at a time when global commodity prices are already peaking. Simulations by the Food and Agriculture Organisation (FAO) suggest that, as a result of the war, the global number of undernourished people could increase by up to 3% to about 750 million people between 2022 and 2023, mostly affecting populations in Sub-Saharan Africa, the Near East and North Africa.[1]

Russia and Ukraine are among the biggest producers of cereals, especially barley, wheat and maize. The two countries combined accounted for around 20% of global barley, 15% of global wheat and 5% of global maize production over 2020-21 (OECD/FAO, 2022[22]). Moreover, combined Ukrainian and Russian production of sunflower seeds accounts for more than 50% of global production and almost 80% of global exports.

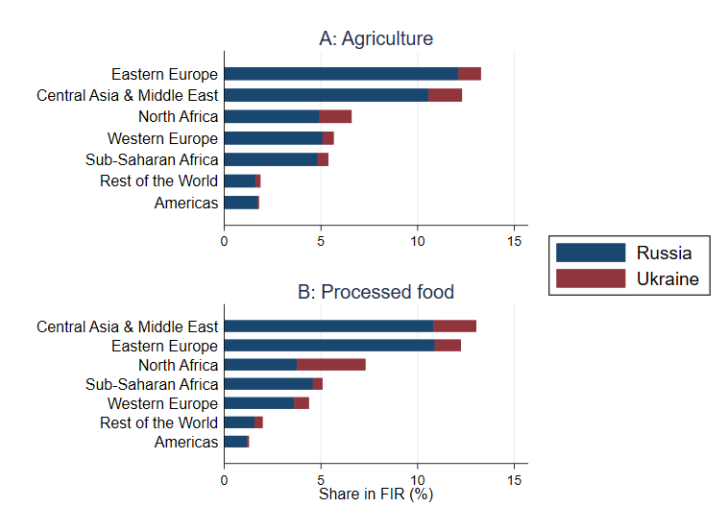
Russia is also among the world's top exporters of fertiliser, accounting for more than 15% of global fertiliser exports in 2020 (UNCTAD, 2022[23]). Higher input prices translate into rising production costs, and may therefore not only affect food security in countries that are directly dependent on Russian and Ukrainian agricultural exports but also in countries that are highly dependent on Russian fertiliser. For instance, rice prices have already started to increase as a result of rising fertiliser prices, jeopardising the affordable supply of a global staple food over the next year.

Regional dependencies on Russian and Ukrainian agricultural products and fertiliser is illustrated in Figure 6. Agriculture shows a high reliance on Russian inputs in Eastern Europe, Central Asia and the Middle East, reflecting Russia's dominant role in fertiliser production and these regions' close geographic proximity to Russia (Panel A). The regional ranking is similar for the processed food industry that is highly dependent on agricultural inputs (Panel B). Strikingly, North African countries are highly dependent on agricultural inputs from Ukraine, which can be explained by the fact that cereals are a

main staple food in this region. Given that many of the agricultural products and fertilisers exported by Ukraine and Russia are effectively traded in global markets, disruptions may have repercussions even for countries which are not directly dependent on Ukrainian or Russian imports.

Figure 6. High dependence on Russia and Ukraine in some regions

Share of Russia and Ukraine in FIR, 2019



Note: Economies are grouped as follows: 1) Americas: ARG, BRA, CAN, CHL, COL, CRI, MEX, PER and USA; 2) Eastern Europe: BLR, BGR, CZE, HUN, POL, ROU, RUS, SVK and UKR; 3) Western Europe: AUT, BEL, CHE, DEU, DNK, ESP, EST, FIN, FRA, GBR, GRC, HRV, IRL, ISL, ITA, LTU, LUX, LVA, MLT, NLD, NOR, PRT, SVN and SWE; 4) Central Asia & Middle East: CYP, ISR, JOR, KAZ, SAU and TUR; 5) North Africa: CMR, EGY, MAR and TUN; 6) Sub-Saharan Africa: CIV, NGA, SEN and ZAF; 7) Rest of the World: AUS, BGD, BRN, KHM, CHN, HKG, IND, IDN, JPN, KOR, LAO, MYS, MMR, NZL, PAK, PHL, ROW, SGP, TWN, THA, VNM and TiVA's RoW.
Source: OECD, ICIO database

Note:
[1] For more details on the scenario settings, please see section 2.2. of FAO's report on the importance of Ukraine and Russia for global agricultural markets and the risks associated with the war (FAO, 2022[24]).

Given the level of aggregation of industry data in the OECD ICIO data, upstream agricultural choke points can only be disaggregated by country. By contrast, downstream agricultural choke points – the critical buyers of agricultural commodities – can be disaggregated by country and industry. Doing so suggests that the critical buyers of agricultural commodities are the processed foods industries in China and a number of major OECD economies. For instance, a positive demand shock in the processed foods industry in the United States – by far the largest buyer of agricultural commodities – could percolate up through the global agricultural value chain, leading to demand pressures on producers and possibly to price increases or shortages for other buyers.

Mining

Upstream choke points in mining include the world's major oil, gas and coal producers, such as Russia, Saudi Arabia, United States, as well as other large raw material producers, such as Australia, Chile and

China (Figure 5, Panels B and C). Given that both energy mining and non-energy mining are highly geographically concentrated (Figure A A.4), a disruption in production in a single country may have large negative effects on downstream industries. Indeed, Russia's war of aggression against Ukraine has led to large increases in energy prices, with adverse consequences on inflation and output in many countries and industries, especially in Europe.

The relatively high level of aggregation in the OECD ICIO data masks the fact that geographic concentration of supply specific parts of the mining value chain may be even higher than suggested by Figure A A.4.For instance, the transition to carbon-neutral production will critically rely on minerals that are highly geographically concentrated (Box 4).

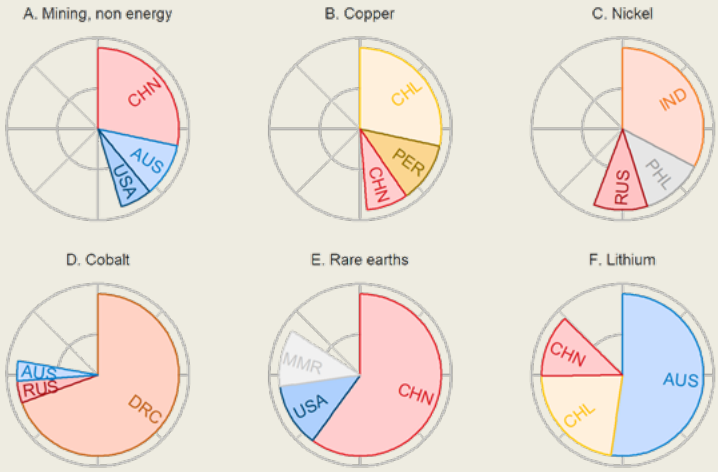
Box 4. Concentration of the supply of minerals critical to the green transition is high

A handful of minerals will be at the heart of the low-carbon energy transition. This includes cobalt, nickel and lithium contained in the battery of electric vehicles; rare earths that are critical for the manufacturing of wind turbines; and copper that is essential to all clean technologies (e.g. photovoltaic systems, bioenergy, wind turbines, or electric cars). According to the International Energy Agency, in order to meet the Paris Agreement goals, required increases in critical minerals supply range from 7-fold for rare earths to 42-fold for lithium by 2040 (IEA, 2021[25]).

Securing the supply of those minerals is a priority for all OECD governments, particularly because extraction is currently highly geographically concentrated (Figure 7). At the same time, no country appears to dominate in the extraction of all minerals. Key producers vary significantly across minerals, suggesting that dependencies at the disaggregated critical minerals level may differ from dependencies at the more aggregated industry level in the OECD ICIO data. For instance, China is the top upstream choke point in the aggregated mining non-energy industry (Panel A) but appears to be dominant only in the extraction of rare earths at the disaggregated minerals level (Panel E) and is not a key player in the extraction of nickel and cobalt (Panels C and D).

Figure 7. The extraction of minerals critical to the clean energy transition is highly concentrated

Share of top three producing countries in the production of selected minerals, 2019



Note: The pie chart for non-energy mining represents the share of the top three producers in total gross output. The five mineral-specific pies represent the share of the top three countries in the total extraction of each mineral.
Source: OECD, ICIO database, IEA (2021[25])

China's limited role in critical minerals extraction underestimates its dominant role in the value chains of clean energy minerals. First, over the past 20 years, China has pursued an ambitious policy to gain control over strategic minerals abroad (Foreign Policy, 2019[26]; Renneboog et al., 2022[27]).[1] As the data presented above only reflects the location of extraction, operations by Chinese-controlled companies abroad are not considered. Second, China is the undisputed leader in the processing of critical clean energy minerals as opposed to the extraction, ranging from 35% of the world's production of processed nickel to 87% of processed rare earths (IEA, 2021[25]). To some extent, this is reflected in the high upstream choke point value of China in chemicals (processed minerals are partly classified as chemicals) and the high downstream choke point value of China in the basic and fabricated metals industries (processed minerals are partly classified as basic and fabricated metals) (Figure 5).

Note:
1. For example, China owns or has influence over half of cobalt production in the Democratic Republic of Congo (Foreign Policy, 2019[26]).

At the same time as global mining is highly geographically concentrated in terms of production, it is also highly geographically concentrated in terms of demand (Figure 4 and Figure 5, Panels B and C). Chinese industries, including construction, basic and fabricated metals, as well as a number of manufacturing industries, are among the main buyers of both energy and non-energy mining inputs from abroad. China's dominant role as a downstream buyer of foreign mining products implies that shocks to specific industries, such as boom and bust cycles in construction, may have outsize effects on global demand and prices. Strikingly, the United States does not figure among the major downstream choke points in mining despite its large market size, which reflects the fact that the United States satisfies a large proportion of its demand through domestic production.

Manufacturing

China emerges as the key manufacturing upstream choke point in GVCs. The output of its ICT & electronics, basic metal and chemicals industries serves as input across a broad range of downstream industries and countries. Only the German chemicals industry plays a comparable role as a single point of failure.

China also plays a dominant role as a downstream buyer of manufacturing products. Many Chinese manufacturing industries that act as upstream choke points also act as downstream choke points, including ICT & electronics, basic metals and chemicals industries. This suggests that Chinese manufacturing industries play a major role in both upstream and downstream production stages, with disruptions both a risk to downstream buyers and upstream suppliers in the GVC. Apart from Chinese manufacturing industries, the Chinese construction industry also appears to play a prominent role as a buyer of last resort of manufacturing inputs from abroad, especially from the chemical and basic metals industry.

In contrast to upstream manufacturing choke points, some large OECD manufacturing industries are among the downstream manufacturing choke points. This includes the US construction and motor vehicles industries, and the German machinery and motor vehicles industries. In fact, the German motor vehicles industry is a major of European manufacturing and figures among the top-3 global downstream and the top-15 upstream manufacturing choke points (Box 5).

Box 5. China and the United States are large buyers of German motor vehicles output

The German motor vehicles industry holds a central position both in national and international markets. In 2019, motor vehicles accounted for around 4½ percent of German value added. Moreover, being the largest manufacturing industry in Europe and among the top-20 worldwide, it is a large player both in terms of supply and demand of intermediate goods and services. About one-fifth of the German motor vehicles industry's output in 2019 consists of imported intermediate inputs, and a similar share is used as intermediate input in regional and global value chains.

The geographic composition of upstream suppliers to the German motor vehicles industry differs from its downstream buyers. As in many other manufacturing industries across the world, China plays a key role both as an upstream supplier and a downstream buyer. However, the German motor vehicles industry is less reliant on extra-European Union countries upstream than downstream, with China, United Kingdom and the United States being large buyers of inputs from the German motor vehicles industry. Moreover, the downstream side is also more geographically concentrated, with the three main partners accounting for around one-third of the industry's FMR.

Overall, this suggests that an adverse demand shock in extra-European Union countries, especially China and the United States, may have sizable effects on the German motor vehicles industry. At the same time, a disruption of German supply may adversely affect not only to European buyers but also non-European ones.

Figure 8. Downstream demand for intermediate inputs is skewed toward extra-European Union countries

Share of supplying countries in FIR and buying countries in FMR, 2019

Note: This figure portrays the total FIR and FMR for the German motor vehicles industry (29 in ISIC Rev.4) by supplying and buying country, respectively. Top countries representing approximately the top 40% of the sector's FIR/FMR are displayed in order of their FIR/FMR value.
Source: OECD, ICIO database

Services

Upstream choke points in services include the wholesale & retail, finance & insurance, as well as science & technology sectors of major OECD economies. The key role of the wholesale & retail sector in China and major OECD economies as an upstream choke point is mainly explained by its large size. Strikingly, the smaller Russian retail sector also figures among the major upstream choke points, reflecting its importance as a supplier of many downstream industries in Eastern Europe and Central Asia. The US and UK finance & insurance industries are major financial hubs that provide financial services to a wide range of downstream industries abroad, while the US and German science & technology sectors are innovation powerhouses that export their services worldwide.

Downstream choke points in services include a large number of Chinese industries, including the construction, basic metals and ICT & electronics industries. This reflects these industries' large size and heavy reliance on transportation and warehousing services from abroad. Among the other downstream choke points for services are large industries, such as the German motor vehicles industry and the US retail sector, but also smaller industries, such as the Dutch science & technology sector and the Hong Kong retail sector. The Dutch science & technology sector is a large buyer of postal & courier services, while the Hong Kong retail sector is a large buyer of postal & courier, warehousing and transport services, reflecting its outsize role as a hub for *entrepot* trade from China.

4 Conclusions

This paper has reported a set of new indicators of GVC dependencies based on OECD ICIO data for the year 2019. The FIR and FMR indicators – which were originally proposed by Baldwin and Freeman (2021[8]) – account for dependencies on direct suppliers and buyers and for indirect ones (through the direct suppliers' suppliers and the direct buyers' buyers), allowing to trace the ultimate source of GVC dependencies. They further account for both the size of dependencies and the length of the value chain by allowing for double counting of value added each time an input crosses an international border. The presumption is that, at any given size of dependencies, vulnerability to GVC disruptions increases with the length of the value chain.

The new indicators of FIR and FMR suggest that GVC dependencies are mostly intra-regional and/or intra-OECD, limiting' exposure to geopolitical risk. Nonetheless, a significant share of OECD countries' exposure to GVC risk is extra-OECD, implying that GVC disruptions in non-OECD economies, including due to geopolitical events, may have significant upstream and downstream effects. FIR is typically larger in industries that are closer to final demand, such a motor vehicles, transport and ICT & electronics. By contrast, industries far from final demand, such as mining and basic metals, are typically more reliant on foreign markets.

In some downstream industries, such as motor vehicles, machinery and ICT & electronics, vulnerability related to high FIR is amplified by high average geographic concentration of suppliers. In upstream industries, such as mining, basic metals and ICT & electronics, vulnerability related to high FMR is, in turn, amplified by high average concentration of buyers. The high vulnerability of ICT & electronics to both upstream supply disruptions and downstream demand cycles is in line with developments in the wake of the COVID-19 crisis, when the interplay of supply disruptions and booming demand led to large shortages (Haramboure et al., forthcoming[21]).

The new indicators further suggest that Chinese industries are the most critical choke points in GVCs, both upstream as suppliers and downstream as buyers, accounting for about 50% of the top-10 choke points across sectors. Its role as an upstream supplier is particularly salient in manufacturing while the Chinese construction industry is particularly important as a buyer of intermediate inputs from abroad. High-income OECD countries, such as France, Germany, United Kingdom, and United States, remain the most critical upstream suppliers of services. However, small resource-rich economies, such as Chile, Kazakhstan, and Norway, play an outsize role as upstream suppliers of mining products.

The new indicators provide a plausible map of dependencies in GVCs but are on their own insufficient to establish that dependencies imply the transmission of risk to domestic economic outcomes. For instance, high foreign input dependency on a specific supplying country may not be risky if the dependent industry can easily switch to alternative suppliers. To this end, a companion paper estimates econometrically whether the transmission of shocks from abroad is significantly related to the indicators of GVC dependencies related in this paper (Schwellnus, Haramboure and Samek, forthcoming[9]). Quantifying the relation between supply shocks abroad, the indicators of GVC dependencies developed in this paper and domestic output also allows quantifying the benefits from a reconfiguration of GVCs, including diversification of input supply and the partial onshoring of production.

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Endnotes

[1] In this paper, the term GVCs denotes the use of foreign inputs in domestic production, irrespective of whether the production satisfies domestic or foreign demand.

[2] Supply shocks include disruptions, such as natural disasters, cyber-attacks, labour unrest, supplier bankruptcy and changes in policies (e.g. increases in import tariffs). Demand shocks include recessions, buyer bankruptcy and changes in policies (e.g. export restrictions).

[3] In theory, upstream demand shocks and downstream supply shocks may also affect domestic production, e.g. if a sudden increase in demand for the upstream supplier's output from other countries reduces availability for domestic producers. However, empirical studies typically find that transmission of these shocks through GVCs is much weaker than the transmission of upstream supply and downstream demand shocks (Acemoglu, Akcigit and Kerr, 2016[29]).

[4] Schewellnus et al. (forthcoming[9]) reviews the rapidly expanding body of work analysing the propagation and amplification of shocks through GVCs.

[5] The interpretation is loose because, in principle, the ratios can take values above 1 (Box 1). In practice, this is not an issue at the level of aggregation used in the remainder of the paper.

[6] Inomata and Hanaka (2021[28]) develop a method to decompose total value chain risk into volume and a frequency part.

[7] Other countries are grouped in a rest of the world category.

[8] Reporting choke points separately by broad industry group also has the advantage that it allows identifying critical points of failure in industries that supply only a small part of other industries' inputs but are nonetheless critical for production (e.g. critical minerals).

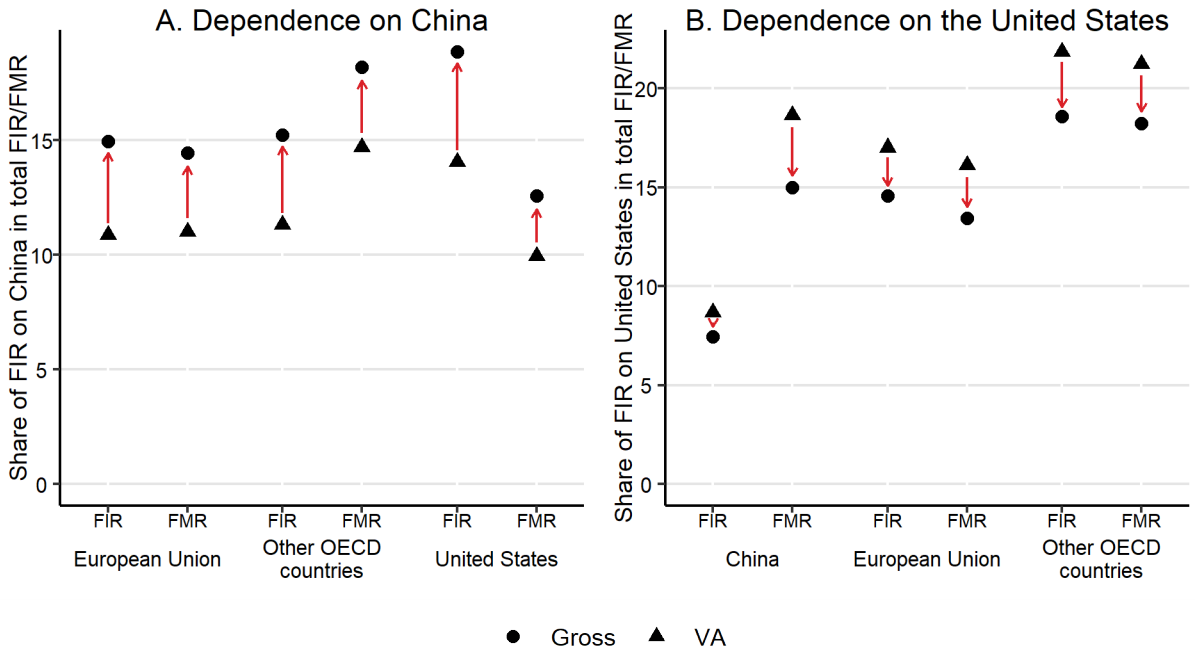
Annex A. Supplementary figures and tables

Comparison between gross output and value added-based measures of vulnerabilities

Gross output-based and value added-based measures of GVC dependencies are positively correlated. In contrast to gross output-based measures, value added-based measures ensure that foreign value added embodied in foreign intermediate inputs is not counted multiple times when an input crosses borders several times. The value added-based indicator corresponding to the FIR defined above is foreign value added embodied in final demand while the value-added based indicator corresponding to the FMR is the share of domestic value added used in foreign production. Depending on the level of aggregation, correlations between gross output-based and value added-based indicators range between 0.6-0.9. However, in some cases, such as dependencies on China and the United States, the use of gross output-based rather than value added-based indicators of GVC dependencies can make a significant difference (Figure A A.1).

Figure A A.1. Dependence on China is larger in gross terms than in value added terms

Share of China and United States in FIR and FMR, %, 2019



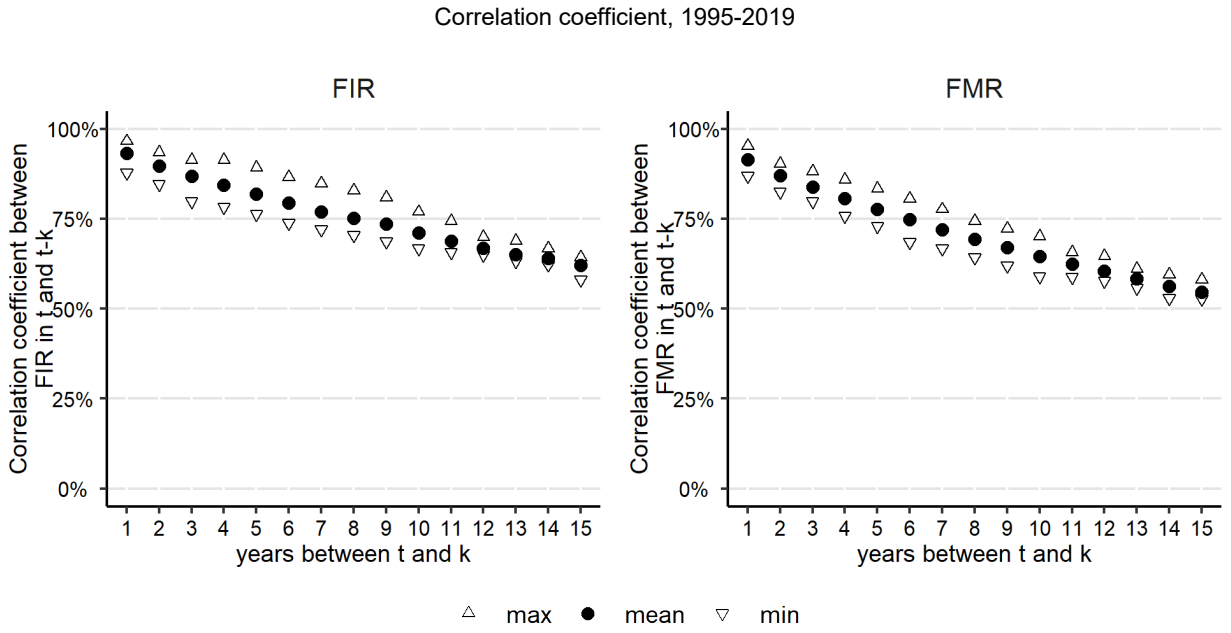
Note: The chart represents the share of China and the United States in total FIR and FMR using a value added and gross output-based definition of FIR and FMR.

Source: OECD, ICIO database

Persistence of GVC dependencies over time

In the short term, upstream and downstream GVC dependencies are very stable, as illustrated by the high autocorrelation of the FIR from one year to the next (Figure A A.2). This suggests that rapid reconfigurations of GVCs, such as the rapid reduction of some European countries' dependencies on Russian oil and gas are the exception rather than the rule. Looking beyond the average correlation suggests that persistence is high even in times of great upheaval. For instance, the correlation in the wake of the 2008-09 economic and financial crisis is around 0.85, only marginally lower than in normal times. Moreover, even over a horizon of 10-15 years past dependencies remain highly predictive of current dependencies. Hence, the results presented in this paper that are based on data from 2019 are likely to be highly representative of current GVC dependencies despite the upheaval of the COVID-19 crisis.

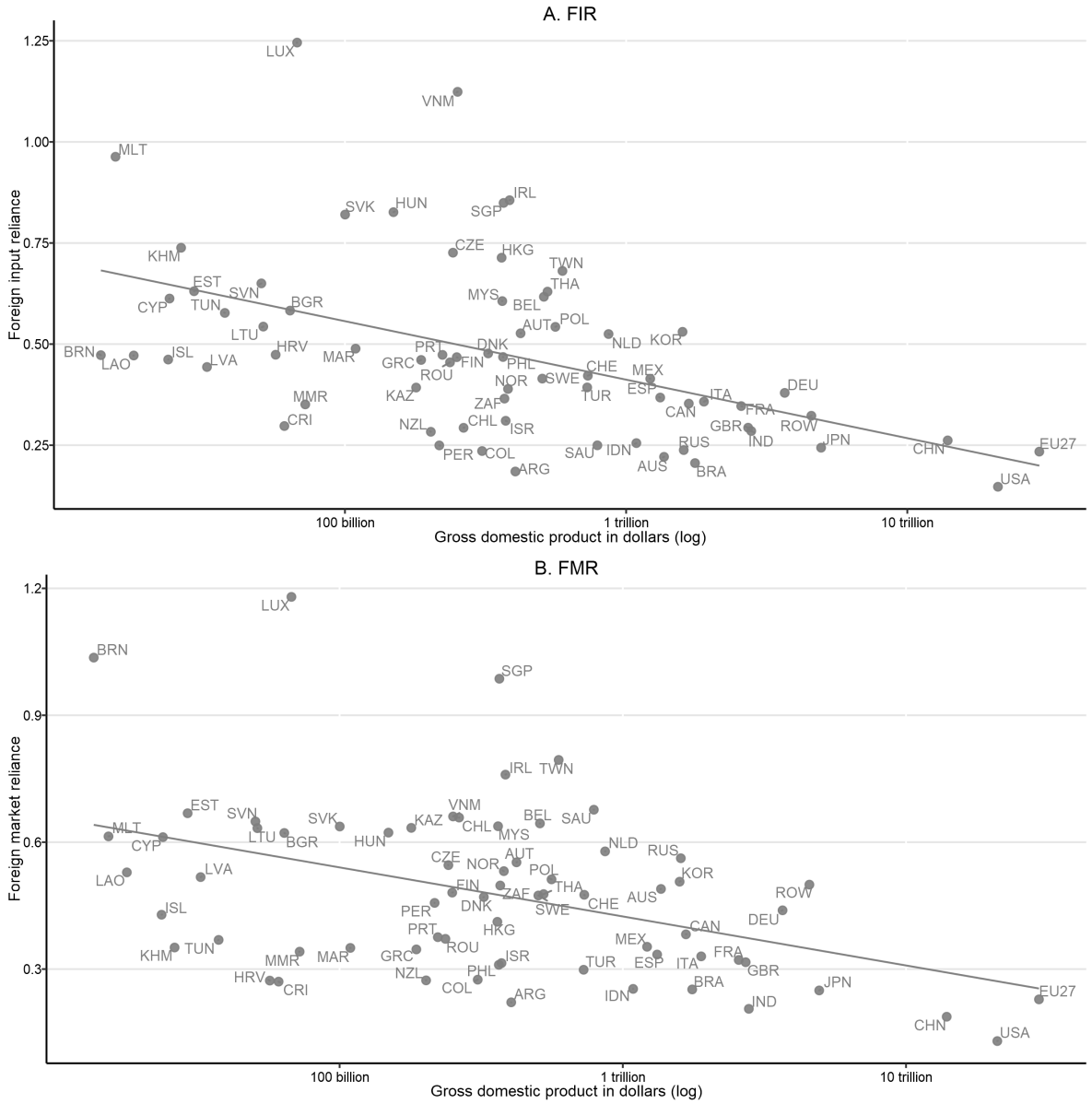
Figure A A.2. Upstream and downstream dependencies change only gradually over time



Note: The left panel plots the maximum, minimum and average correlation coefficient between FIR in year t ($FIR^{t}_{ici'c'}$) and the corresponding FIR in year t-k ($FIR^{t-k}_{ici'c'}$). The coefficient is computed separately for all 0<k<15, t and t-k ∈ $[1995; 2019]$. The right panel is obtained through a similar procedure replacing FIR by FMR.
Source: OECD, ICIO database

The relation between country size and GVC dependencies

Figure A A.3. Small open economies are more reliant on foreign inputs and foreign markets



Note: The average FIR (panel A) and FMR (panel B) are computed by aggregating an economy's industries' FIR and FMR. Individual industries j in each economy e are aggregated through a weighted average, where the weights are gross industry output ($FIR_e = \sum_j^n (FIR_{e,j} * W_{e,j}^{GO})$, where $W_{e,j}^{GO} = GO_{e,j} / \sum_j^n GO_{e,j}$). EU27 is an aggregation treating the European Union as a single economy, therefore excluding intra-regional flows from the calculation of average FIR and FMR.
Source: OECD, ICIO database

Country and industry groupings in Figures 2 and 3

Table A A.1. Countries and Regions

Country and regional groupings employed in Figure 2

Grouping	ISO Country codes/Regions
Asia & Oceania OECD members	AUS, JPN, KOR, NZL
European Economic Area (OECD members)	AUT, BEL, CZE, DEU, DNK, ESP, EST, FIN, FRA, GRC, HUN, IRL, ISL, ITA, LTU, LUX, , LVA, NLD, NOR, POL, PRT, SVK, SVN, SWE
NAFTA+3	CAN, CHL, COL, CRI, MEX, USA

Table A A.2. Industries

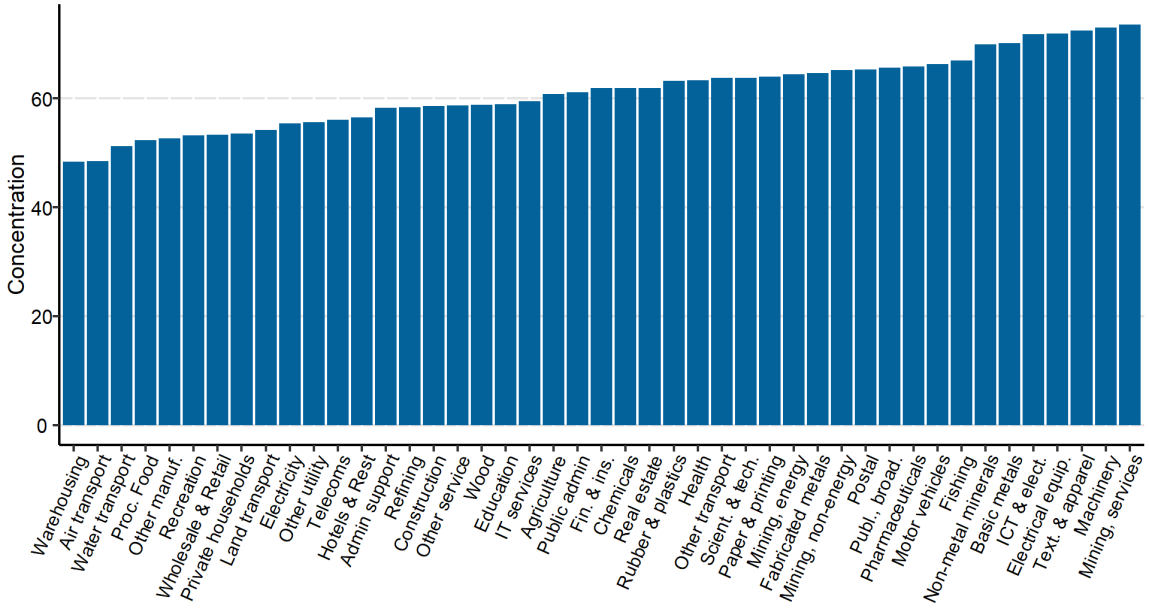
Industry groupings used in Figure 3

Grouping	ISIC Rev.4
Agriculture	01-03
Mining	04-08
Manufacturing	10-33
Services (broad definition)	45-98 (traditional services); 41-43 (construction); 35-39 (utilities); 09 (supporting services to mining activities)

Geographical concentration of production

Figure A A.4. Concentration of production

Share of top-5 countries in total gross output by industry, 2019, %



Note: Output of the top-5 country and total gross output does not include output produced by country in the rest of the world category of the ICIO database.
Source: OECD, ICIO database