Bank of England

Hidden exposure: measuring US supply chain reliance

Staff Working Paper No. 1,052
November 2023

Richard Baldwin, Rebecca Freeman and Angelos Theodorakopoulos

Bank of England

Staff Working Paper No. 1,052

Hidden exposure: measuring US supply chain reliance

Richard Baldwin,[1] Rebecca Freeman[2] and Angelos Theodorakopoulos[3]

Abstract

Supply chain problems, previously relegated to specialized journals, now appear in G7 Leaders' Communiqués. Our paper looks at three core elements of the problems: measurement of the links that expose supply chains to disruptions, the nature of the shocks that cause the disruptions, and the criteria for policy to mitigate the impact of disruptions. Utilizing global input-output data, we show that US exposure to foreign suppliers, and particularly to China, is 'hidden' in the sense that it is much larger than what conventional trade data suggest. However, at the macro level, exposure remains relatively modest, given that over 80% of US industrial inputs are sourced domestically. We argue that many recent shocks to supply chains have been systemic rather than idiosyncratic. Moreover, systemic shocks are likely to arise from climate change, geoeconomic tensions, and digital disruptions. Our principal conclusion is that concerns regarding supply chain disruptions, and policies to address them, should focus on individual products, rather than the whole manufacturing sector.

Key words: Global supply chains, exposure, input reliance, risk, resilience, globalization.

JEL classification: F10, F13, F14, F60.

---

(1) IMD, CEPR, and NBER. Email: richard.baldwin@imd.org
(2) Bank of England and CEP/LSE. Email: rebecca.freeman@bankofengland.co.uk
(3) Aston Business School. Email: a.theodorakopoulos2@aston.ac.uk

The views expressed in this paper are those of the authors, and not necessarily those of the Bank of England or its committees. This is an early version of the paper prepared for the Fall 2023 Brookings Papers on Economic Activity (BPEA) conference and the final version of this paper will be published in the Fall 2023 BPEA issue. We would like to thank Janice Eberly, Jón Steinsson, Penelopi Goldberg and Benjamin Golub for helpful comments on an earlier draft of this paper that resulted in many improvements. We would also like to thank Thomas Prayer for assistance downloading US trade data from the US Census Bureau.

The Bank's working paper series can be found at www.bankofengland.co.uk/working-paper/staff-working-papers

Bank of England, Threadneedle Street, London, EC2R 8AH
Email: enquiries@bankofengland.co.uk

ISSN 1749-9135 (on-line)

When Harold Macmillan – UK Prime Minister in the turbulent post-WWII years – was asked: "What is the greatest challenge you face?" his alleged reply was: "Events, dear boy, events." Events, termed 'shocks' by economists, have re-emerged as formidable challenges for global leadership, with supply chain disruptions being top of mind. At their May 2023 Summit, for example, G7 leaders stated that "supporting resilient and sustainable value chains remains our priority" (European Council 2023). It was not always like this.

Constructed in a time of stability and hope, today's globe-spanning supply chains propelled efficiency and progress as they became the arteries of the US economy. US administrations supported the internationalization of supply chains with the entry into force of deep trade agreements, like the North American Free Trade Agreement on 1 January 1994, and the establishment of the World Trade Organization on 1 January 1995. At the time, international supply chains were viewed as enhancers of productivity and boosters of prosperity (CEA 2016).

But supply chains are behaving differently in the face of what Mervyn King and John Kay term "radical uncertainty" in their 2021 book of the same name (King and Kay 2021). Today, reverberations of supply chain disruptions echo loud and long, impacting everything from laptop availability and headline inflation to national security and shortages of medicine that affect millions. Empirical studies of these effects are just emerging (Goldberg and Reed 2023; Boehm et al. 2019; Carvalho et al. 2021; Bonadio et al 2021). Most of the economic literature on global supply chains (GSCs) study factors that foster them (Grossman and Helpman 2008; Antràs 2021; Alfaro and Chor 2023), or investigate broader scale trends and in and the landscape of GSCs (World Bank 2020a, 2020b). Economic research on supply chain disruptions is appearing on the theory side (Grossman, Helpman, and Lhuillier 2021; Carvalho and Tahbaz-Salehi 2019; Elliott and Golub 2022; Elliott, Golub, and Leduc 2022; Baqaee and Rubbo 2023) and on the empirical side (Schwellnus, Haramboure, and Samek 2023a; Imbs and Powels 2022).

As this is early days for the economics of supply chain disruptions, there is no consensus on how to organize thinking about the related issues. We propose that the phrase 'supply chain disruptions' inherently directs us toward a three-pillar organizing framework. The first pillar focuses on the 'links' that constitute GSCs, and the second addresses the 'shocks' that disrupt them. This framework, which focuses on understanding supply chain disruptions, is naturally complemented by a third pillar that examines private and public 'taming' measures –

specifically, actions that businesses and governments take to mitigate supply chain disruptions and their economic consequences. This third pillar includes aspects of supply chain resilience and robustness as well as the discussion of situations where policy intervention is warranted. Our paper is organized around these three pillars.

The rest of the paper comes in five sections. Section I looks at how we can measure the links. Section II shows our empirical findings on the links between US manufacturing and its largest supplying nation, namely China. Section III looks at the shocks, and Section IV considers the taming. The final Section presents our concluding remarks.

I. The Links: On the Measurement of Supply Chain Exposure

In US manufacturing companies, supply-chain risk managers have long recognized the importance of knowing their suppliers (Gurtu and Johny 2021). However, the advent of supply chain disruptions on a grand scale, spanning multiple sectors and nations, has elevated this issue from a firm-level concern to a nation-level concern. Identifying where things are actually made, however, is not as easy as it might appear. This section discusses the challenges and solutions, building up to a presentation of the main indicators we employ in the rest of the paper.

I.A. You Can't Fix What You Can't See: Two Ways of Looking at Supply Chains

One cornerstone contribution of our paper lies in the identification of the true origin of the manufactured inputs bought by US manufacturing sectors. We are not the first to tackle the problem. The Biden Administration set up a series of initiatives to address supply chain disruptions (White House 2022). One feature that is common to such initiatives is an effort to improve supply chain transparency and understand where potential 'weak points' lie. These initiatives take a straightforward, business focused approach. Our paper contributes by presenting measures of supply chain exposure that rely on a very different approach.

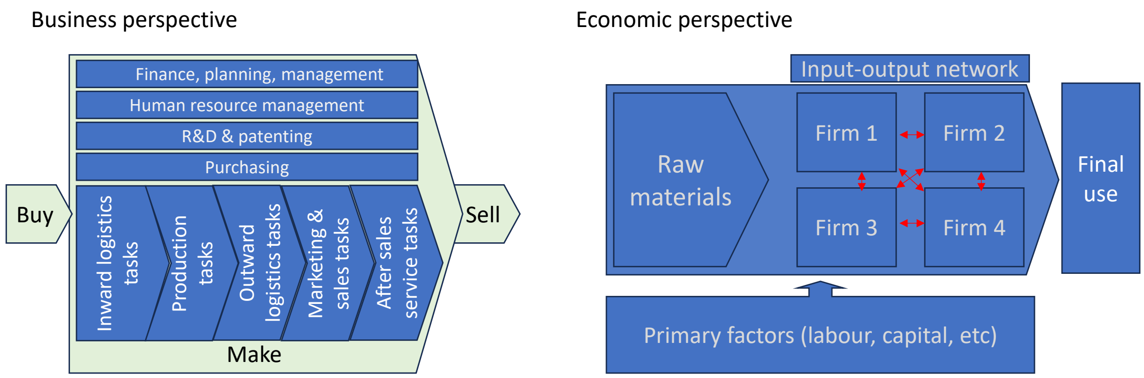
BUSINESS VALUE CHAIN APPROACH VERSUS ECONOMIC APPROACH

Much of the excellent, detailed work on supply chain dependencies has used the business, or 'value chain' approach inspired by Michael Porter (Porter 1985). At its core, this is based on a straightforward view that firms buy things to make the goods that they sell. The natural focus of this buy-make-sell view is on the "what and from whom" questions on the supply side and the "what and to whom" questions on the sales side (Figure 1.1, left panel). This is quite different from the economic approach, as the right panel of Figure 1.1 illustrates.

Economists tend to take a bird's eye view. The buy-make-sell logic of Porter's value chain is recursive, establishing an input-output network of firms selling to firms and eventually to final customers (Figure 1.1, right panel). What looks like a chain from the perspective of a single firm is actually part of a matrix from the economy-wide perspective. In addition, the economic viewpoint introduces a distinction between primary inputs, like labor and capital, intermediate inputs such as parts and components, and final goods.

Each perspective has its advantages.[1] The business view allows much greater attention to detail as the left panel makes clear. By focusing on a single firm, an analyst can delve deep into issues such as logistics, inventory control, and risk management strategies as well as the required administrative tasks ranging from financial planning to purchasing policies (horizontal bars in left panel). Additionally, they can concentrate on corporate relations, partnerships, contracting, and product portfolios. If the ultimate policy goal is to avoid disruption of production of a particular good, say semiconductors, the business approach is the one to take. It is like following a river from its mouth back to the source of all its tributaries. This approach, however, would not have picked up the shock to US car production in 2020 that came when the demand for semiconductors boomed from other sectors, like work-from-home equipment. For that, an economy-wide perspective is necessary.

Figure 1.1: Supply chains perspectives: business value chain versus economic input-output table.



Source: Authors' elaboration of the Porter (1985) value chain (left) and a schematic view of a firm-level input-output table.

[1] At a conceptual level, the two perspectives can also be combined. For instance, drawing upon Feenstra (2010), Fort (2023) presents a framework for firm decisions to engage internationally and outsource tasks.

The core difficulty and the two solutions

The two approaches, while quite different, face a common core difficulty: the massive complexity of modern supply chains. The business approach and the economic approach take very different paths in addressing the core difficulty. An illustration using the auto industry clarifies the two solution paths, each of which involves ignoring certain aspects of the complexity.

The example pertaining to the business approach comes from Lund et al. (2020). This study found that General Motors (GM) had 856 tier-1 (i.e. direct) suppliers, but these 856 suppliers had suppliers themselves, so-called tier-2 suppliers, as did the tier-2 suppliers and so on. The research estimated that GM had a staggering 18,000 suppliers in tier-2 and below. Given that each of these 18,000 suppliers had its own roster of suppliers, an exhaustive cataloging of GM's suppliers would create a sequence that reaches what Buzz Lightyear would call "infinity and beyond."

The business approach keeps the complexity manageable by drawing the line at the number of tiers investigated. It also ignores the fact that each supplier in each tier has multiple tiers of suppliers themselves. The economic approach takes a very different method to the Buzz Lightyear problem, a very different approach to the suppliers of the suppliers, and embraces a very different type of simplifying assumption. The key is an analytic tool is called input-output (IO) analysis, which works at the level of sectors rather than firms. The payoff from this simplification – aggregating all firms into sectors – is that IO analysis can deal fully with the suppliers' suppliers challenge. We illustrate this with the US car industry.

Where US-made cars are made: Economics approach

In the economic approach, there are three levels of answers to the question "Where are Ford cars actually made?"

- The first level is the easiest: Dearborn Michigan.

When a Ford rolls off the assembly line in Dearborn Michigan, we can say that the car is made in Dearborn. This is true, but it is not the whole truth.

- The second level admits that the Dearborn plant buys car parts from other firms.

Many of those parts are not made in Michigan, and many are not made in the US at all. Some are made in Canada, so we can say that some of the Dearborn-made car is actually made in Canada. This is also true, but also not the whole truth.

- The third level digs into the fact that all the parts makers also buy parts that are not made locally.

Canadian car-part makers, for example, may buy some parts from Germany.

The problem is that the third level involves the same sort of Buzz Lightyear never-ending sequence encountered by the business approach. Parts makers buy parts from other parts makers who buy parts from other parts makers, and so on without end. To tackle the issue of infinite recursion, IO analysis employs an approach that diverges radically from the business model's tier-truncation method.

I.B. Measuring Supply Chain Exposure with an Inter-Country Input-Output (ICIO) Table

IO analysis, developed by Nobel laureate Wassily Leontief in the 1950s, facilitates the analysis of how the production of one sector relies on inputs from other sectors.[2] The international version we use in this paper tracks both domestic and foreign sectors. A limitation of IO analysis is that it is conducted at the level of sectors and nations. Additionally, the data does not currently permit disaggregation down to the firm level. Moreover, because the datasets require detailed mapping and harmonization of data from national, regional and international sources for different countries and across many time periods, IO data typically exhibits a larger lag in availability than, say, standard data on direct trade flows. The dataset upon which we rely, the OECD's 2021 release of Inter-Country Input Output (ICIO) tables,[3] is available from 1995 to 2018. There are efforts underway to use 'nowcasting' methods to project IO calculations for the most recent years (even without complete data), but these are experimental at this stage (Mourougane et al. 2023). In our view, the starting date is not a major issue since the expansion of offshoring and the 'new' globalization began in earnest in the 1990s (Baldwin 2016). The end date is also less constraining than one might initially think because the COVID-19 pandemic caused significant disruptions to the global manufacturing and distribution network which are now stabilizing.

The heart of our analysis is the IO table and the distinction between goods that are used as intermediate inputs into the production of other goods, on the one hand, and final goods sold

[2] See Baldwin, Freeman, and Theodorakopoulos (2022) for a fuller discussion of IO analysis.
[3] These tables form the basis for the OECD's Trade in Value Added (TiVA) database. Note that new version of the OECD ICIO data which comprises additional countries and two additional years (OECD 2022) was released after the time that the analysis for this paper was conducted.

to end users, on the other. To put it differently, intermediate sales are business-to-business (B2B) while final sales are business-to-customer (B2C). These B2C sales correspond to the first-level answer to where things are made. The goods produced by US sectors for final sales are clearly made in the US.

The sum of a sector's sales of intermediate goods and final goods is called gross production, to distinguish it from net production, which corresponds to the output of final goods. Roughly speaking, gross production is the sector's total business turnover, or value of total sales. To avoid confusion, it is important to keep in mind that a sector both buys intermediates and sells intermediates. In this paper, we focus on supply-side exposure and note that a single sector's supply chain dependency turns on its purchases of intermediates, not its sales of intermediates. We could also look at the dependency on the selling side and work out a sector's dependence on supply chains for its sales (see Baldwin, Freeman, and Theodorakopoulos 2022 for discussion and calculations).

The IO table also shows the inputs that each sector in each country buys from every other sector in every other country. As such, the IO table has as many columns as rows, with each representing a sector in a particular country. The numbers in the table's cells represent the direct, or face-value purchases by the column sector of inputs from the row sector. These numbers correspond to the second-level answer mentioned above. For example, the column in the IO table corresponding to the US Vehicles sector lists all the sector's purchases from all other sectors in every country. Using the second-level logic, the US Vehicles sector's purchases of inputs from other US sectors would be considered as made in the US.

As it turns out, we can use IO analysis to solve the third-level answer without writing out Buzz Lightyear's never-ending sequence. With a series of simple yet unenlightening calculations, we can transform the IO table into the so-called Leontief matrix (see Box I.B for a more precise explanation that uses matrix algebra.) The elements of the Leontief matrix provide the third-level answer, in other words the full links between all sectors and all nations, fully accounting for the fact that suppliers themselves have suppliers. To give it a name, we call the full accounting links 'look through' exposure.

FACE VALUE VERSUS LOOK THROUGH EXPOSURE

A critical feature of the economics approach is the distinction it makes between the 'face value' exposure of a supply chain and its 'look through' exposure. The face value exposure measures look at the proximate origin of intermediate inputs. This corresponds to the level-2 answer mentioned above that takes the origin of purchased intermediates at face value. For example, if an automaker in the US buys a component from Canada, the face value exposure of the component is only to Canada. By contrast, the look through exposure takes account of the fact that the Canadian producer of the component surely purchased inputs from other nations. In other words, the look through exposure pierces the veil of the supplier network of suppliers supplying suppliers. This allows it to identify the comprehensive link between a purchasing sector in one nation and every supplying sector in every nation.

As we shall see below, there is a substantial difference between supply chain exposure to some economies – especially China – when the exposure is measured on a look through basis versus a face value basis.

Box I.B: Mapping the 3-levels of answers to face value and look through measures

To be more precise about the distinction between face value and look through measures of exposure, we dig into the bit of matrix algebra we glossed over in the main text. In matrix form, the gross output of sectors (all sectors in all nations) are listed in a vector called $\mathbf{X}$. Each sector's gross output is either used for final demand, which we capture with the vector $\mathbf{F}$, or used as intermediate inputs, which we refer to as the matrix $\mathbf{T}$, that is $\mathbf{X} = \mathbf{T\iota} + \mathbf{F}$, where $\boldsymbol{\iota}$ is a vector of 1s for aggregation of inputs into vector form. This is an accounting identity as it is merely categorizing the output of sectors into final or intermediate usage. The intermediate sales to any sector, in turn, are related to the gross production of all sectors, and the technical input-requirement matrix, defined as each element of $\mathbf{T}$ divided by the corresponding country-sector-specific gross output is denoted as $\mathbf{A}$. The $\mathbf{A}$ tells us how much intermediate inputs a single unit in a nation, say the US auto sector, needs from any other sector, say the rubber sector in Brazil. In symbols, $\mathbf{T\iota} = \mathbf{AX}$. Putting together the pieces, $\mathbf{X} = \mathbf{T\iota} + \mathbf{F}$ can be written as $\mathbf{X} = \mathbf{AX} + \mathbf{F}$. Inverting, $\mathbf{X} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{F}$ where $\mathbf{I}$ is the identity matrix. Here, $(\mathbf{I} - \mathbf{A})^{-1}$ is the famous Leontief matrix, more formally known as the Leontief inverse matrix.

Readers versed in matrix algebra will recognize that $(\mathbf{I} - \mathbf{A})^{-1}$ equals the sum of an infinite series. The series is: $\mathbf{I} + \mathbf{A} + \mathbf{A}(\mathbf{A}) + \mathbf{A}(\mathbf{AA}) + \ldots$. In words, the $\mathbf{I}$ is the first-level answer that reflects the production location. The term $\mathbf{A}$ reflects the second-level answer which captures the location of production of the inputs to the final good. The third level answer includes the inputs to the inputs, namely, $\mathbf{A}(\mathbf{A})$, $\mathbf{A}(\mathbf{AA})$, and so on.

In our terminology, the face value exposure is $\mathbf{I}+\mathbf{A}$ (i.e., the second-level answer) and the look through exposure is $(\mathbf{I}-\mathbf{A})^{-1}$, (i.e., the third-level answer).

LIMITATIONS OF INPUT-OUTPUT ANALYSIS

A significant limitation of IO analysis is its omission of elasticities and lack of consideration for substitutability. For instance, the US textile industry heavily relies on imported inputs, many of which either originate in China or are produced using materials from China. At first glance, one might infer that this US sector is susceptible to disruptions. However, it is important to note that numerous countries export textiles and apparel. Consequently, any supply chain disruptions can often be quickly mitigated by switching to alternative suppliers. Additionally, the relatively straightforward nature of these products makes switching suppliers in this sector more straightforward than with more complex components, such as transmissions for trucks.[4]

Recent work, for example by Moll, Schularick, and Zachmann (2023) also highlights how substitutability and agility can help prevent full-blown supply chain crises. Drawing lessons from Germany, they point to the role that the European market played in mitigating gas shortages after Russia curtailed its supply, beginning in 2021, thus preventing full-blown supply chain shutdowns. While there is evidence that elasticities of substitution at the micro-level are known to be smaller than at the macro-level (Houthakker 1955; Jones 2005; Oberfield and Rval 2021), readily available elasticities – especially for intermediates – would allow to study the quantitative links between GSC disruptions and economic outcomes in a more meaningful manner.

Furthermore, as mentioned above, an additional limitation of IO analysis is that conducted at the level of sectors and nations. Given the stringent requirements to construct IO tables, the data does not currently permit disaggregation down to the firm (or even detailed

[4] Antràs (2021) and Antràs and Chor (2022) note the 'sticky' nature of supply chains and B2B relationships, which could in principle make it difficult to switch suppliers readily. However, some of the 'stickiness' referred to is precisely generated by lack of alternative suppliers, which is not the case for all sectors, as well as the need for complex, highly specialized parts and components, which are also not required or can more easily be replaced imperfectly for the production of some final goods.

product) level, especially when multiple countries are included. As such, the economic repercussions of supply chain exposure, as it can be measured with the available IO data, may differ depending on the firm-level configuration of the supply chain (Baqaee and Farhi 2019; Elliott and Golub 2022).

II. The Links: Facts on US and Comparator Nation Exposure

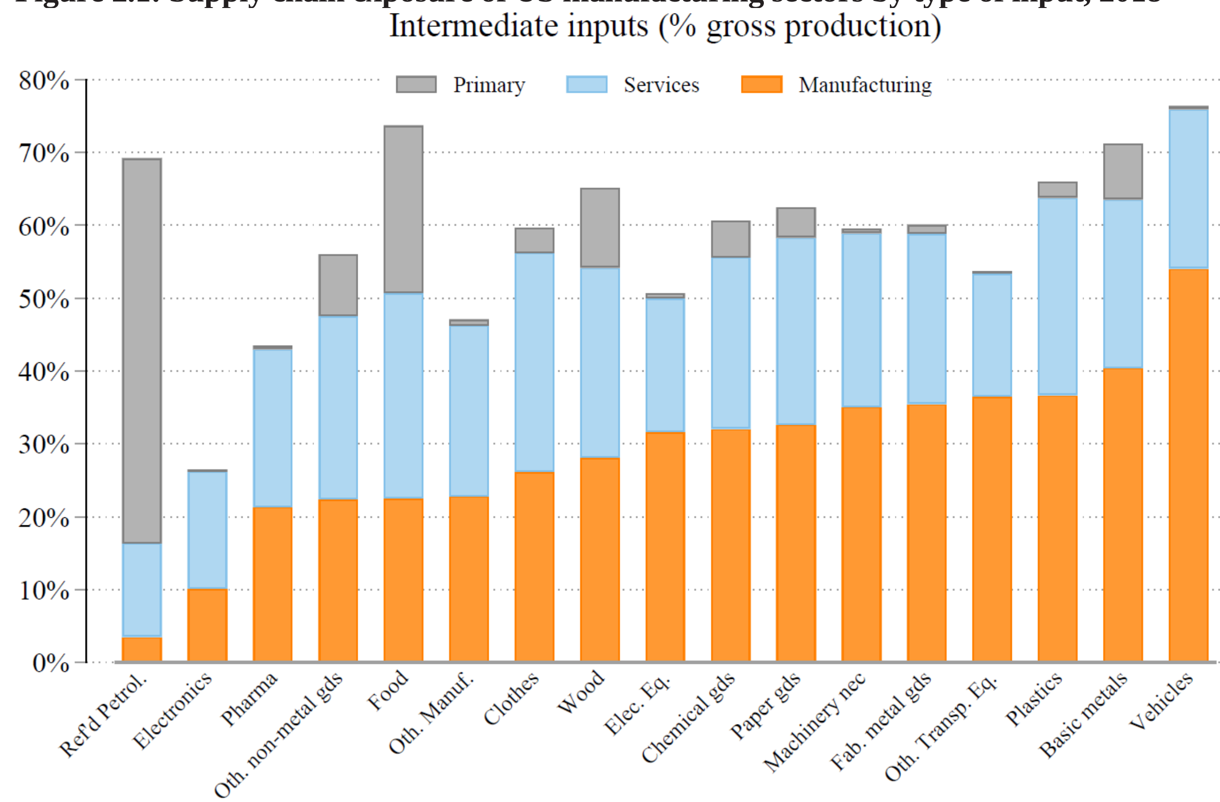
The central focus of our paper is the exposure of US manufacturing sectors to foreign suppliers. To set the context, we begin by examining facts about these sectors that condition our interpretation of the supply chain exposure indicators we present below. The first set of facts addresses the overall supply chain exposure of US manufacturing sectors, which is to say, to inputs from both domestic and foreign sources. As we shall see, some sectors are intrinsically more reliant on intermediate inputs than others. This sets the stage to zoom in on the foreign component of US manufacturing supply chain exposure. We next explore the "hidden exposure" that exists in US manufacturing sectors – by examining differences between face value and look through exposure, and by looking at import concentration using both IO and granular US trade data. Finally, for comparison, we delve into the exposure of the US' largest supplier, China, to the rest of the world and draw out key differences with what is observed for the US.

II.A. Supply Chain Exposure of US Manufacturing Sectors

When considering the US' exposure to supply chain disruptions, a key aspect is the varying dependence of different manufacturing sectors on purchased inputs. The point is that certain sectors, such as the auto sector, are inherently intensive in their use of purchased inputs. Such sectors are more exposed to supply chains and thus intrinsically more vulnerable to supply chain shocks. The concept of face value exposure, which refers to purchases from tier-1 suppliers, is more intuitive than the look through concept. Thus, following the principle of increasing complexity, we start by presenting the facts on a face value basis.

In the data upon which we draw – the 2021 release of the OECD ICIO tables (OECD 2021) – we measure the US' purchased inputs in dollars and standardize each sector's input purchases by its gross production to allow comparisons across sectors and over time. Figure 2.1 presents the data for the year 2018, the most recent year in the dataset. The chart displays stacked columns for each of the 17 US manufacturing sectors identified in the database[5] (see Box II.A for a short description of the products that are grouped into the various sectors.) The total height of each column reflects the importance of the sector's spending on intermediate inputs, counting inputs from all nations including the US itself. The bars within the columns indicate the broad source sectors of the intermediates. For clarity, we use the classic three-way classification of inputs, namely those coming from primary sectors (agriculture, mining, and utilities), services sectors, and manufacturing sectors. The sectors have been arranged in ascending order of their utilization of manufactured intermediate inputs.

Figure 2.1: Supply chain exposure of US manufacturing sectors by type of input, 2018



Source: Authors' elaboration based on 2021 OECD ICIO tables. Note: The numbers shown represent the value of produced intermediates by each US sector, as a share of its total gross production.

---

[5] For convenience, we use shortened sector names as follows: Food products, beverages and tobacco = Food; Textiles, textile products, leather & footwear = Clothes; Wood and products of wood and cork = Wood; Paper products and printing = Paper gds; Coke and refined petroleum = Ref'd Petrol.; Chemical and chemical products = Chemical gds; Pharmaceuticals, medicinal chemical and botanical products = Pharma; Rubber and plastics products = Plastics; Other non-metallic mineral products = Oth. non-metal gds; Basic metals = Basic metals; Fabricated metal products = Fab. metal gds; Computer, electronic and optical equipment = Electronics.; Electrical equipment = Elec.eq.; Machinery and equipment, nec = Machinery nec; Motor vehicles, trailers and semi-trailers = Vehicles; Other transport equipment = Oth. Transp. Eq.; Manufacturing nec, repair and installation of machinery and equipment = Oth.Manuf.

For example, intermediate inputs amount to about 75% of the gross output of the Vehicles sector. How should we think about this 75% figure? One way to approach it is to consider a historical example where the number was close to zero, namely the Ford Company's River Rouge plant in the 1900s. Henry Ford endeavored to produce all necessary intermediate parts for his Model T within this vast facility. The plant spanned 2,000 acres and employed up to 120,000 workers at its peak, which allowed the factory to undertake most production stages. The plant had dock facilities, blast furnaces, steel mills, foundries, a rolling mill, metal stamping facilities, an engine plant, a glass manufacturing unit, a tire plant, and an independent powerhouse for steam and electricity. Ford owned 700,000 acres of forest, iron mines and limestone quarries in northern Michigan, Minnesota and Wisconsin, coal mines in Kentucky, West Virginia and Pennsylvania, and a rubber plantation in Brazil. To avoid outside suppliers of transportation services, Ford owned and operated ore freighters and a railroad company.

All this meant that Ford had very little supply chain exposure even though making cars involved lots of intermediate goods. In today's world, US-based vehicle companies buy many intermediate inputs from independent companies – so much so that about 75% of all their costs are due to purchased inputs. In a nutshell, a nation's industrial organization – in particular the share of manufacturing undertaken by giant, as opposed to small, companies – can influence its supply chain exposure.

More precisely, gross output in our data is measured in dollars and it is defined as the sum of all costs viewing profit as a payment to a factor of production and thus a cost. It can also be defined on the value of output, but ICIO accounting rules mean that the two approaches produce exactly the same answer. Here we use the cost-side definition since it fits in more naturally with discussions of supply chain issues. The second point is that costs can be divided into payments to factors of production (labor, capital, etc.) and purchased inputs, which are also called intermediate goods. The 75% figure means that intermediate goods purchased from suppliers makes up three-quarters of all the cost in the Vehicle sector. That is a very large number, which indicates that the US Vehicles sector is highly exposed to supply chain issues.

An important insight from Figure 2.1 is the pivotal role played by intermediate inputs in the production processes of all 17 sectors. In 14 out of the 17 sectors, spending on intermediate inputs exceeds 50% of the sector's gross output. Even the sector with the lowest dependency, Electronics, still has 25% of its production cost tied up with the direct purchase of intermediates. Moreover, this 25% figure has to be handled with care since it is only for US manufacturers. At the global level, Electronics sector is one of the most intensive users of intermediate goods, but only a narrow range of the goods it comprises (such as computers) are made in the US. Thus, the relatively low dependence on intermediates as presented in Figure 2.1 arises from selection issues, rather than being a ground-level reality of production processes. A similar point applies to the US pharmaceutical industry. In this sector, goods produced in the US rely on intellectual property, which, in the IO table and Figure 2.1, registers as a service sector input.

Much of the recent discussion turns on manufactured inputs purchased by the manufacturing sector, so we zoom in on industrial inputs. Examining each sectors' reliance on manufactured inputs, it is useful to divide the 17 sectors into those with above- and below-median dependence on manufactured inputs. Notably, the sectors with above-median supply chain exposure include Electrical Equipment, Chemical Goods, Paper Goods, Machinery nec, Fabricated Metal Goods, Other Transport Equipment, Plastics, Basic Metals, and Vehicles. At the other end, the sectors that display below-median dependence are Refined Petroleum, Electronics, Pharmaceuticals, Other Non-Metal Goods (glass and ceramic products, construction materials, etc.), and Food.

Another noteworthy observation is the significant presence of intermediate inputs originating from service sectors. While these traditionally aren't seen as potential vulnerabilities, specific services, such as cloud services, might pose significant risks for certain manufacturers. We have recently argued that services trade, particularly trade in intermediate services, is likely to dominate trade in the coming years (Baldwin, Freeman, and Theodorakopoulos 2023). While future work may delve into service supply-chain dependency, given the current interest in the disruption of goods trade, we set aside the consideration of service-sector intermediates for the rest of this paper.

Regarding primary inputs, the observed patterns align with expectations. Primary inputs play a substantial role in only a handful of manufacturing sectors, including Refined Petroleum, Food, and Wood. Surprisingly, the Basic Metals sector, known for producing items like steel girders, aluminum sheets, and copper wire, exhibits a minimal share of inputs from primary sectors. This can be attributed to the fact that, in the US, much of the bulk production of basic metal goods relies on processing scrap metal rather than mining. As the collection and wholesaling of scrap metal are considered services, US Basic Metals production depends less on primary sector inputs than one might assume.

Box II.A: The 17 manufacturing sectors in the OECD ICIO tables

Behind each broad manufacturing industry is aggregated data from detailed product-level trade data. Most categories consist of hundreds of detailed (6-digit) products, carefully mapped to ICIO broad sectors. While some are straightforward—like Vehicles or Clothes—others are more obscure. Other Non-Metal Goods, for example, includes products like glass and ceramic products as well as building materials like bricks and cement. The Wood sector includes various types of wood (oak, beech, maple, etc.) used for fuel, chips, sawdust, and tramway/railway sleepers. It also has wood flooring panels, corks, stoppers, wickerwork, etc. The Electronics sector covers around 270 products, from printing machines to pacemakers. This includes telephones, microphones, loudspeakers, headphones, amplifiers, sound recording devices, radar apparatus, valves, tubes, cameras, navigational instruments, medical appliances, and more.

Turning to the "not elsewhere included" (nec) categories: Machinery nec has 464 products, like chains, engines, pumps, compressors, fans, air conditioners, cranes, machines for printing, textiles, metalworking, and parts such as valves and bearings. Manufacturing nec has nearly 200 items divided into three categories: i) seemingly unrelated items like candles, lighters, and umbrellas; ii) precious materials and jewelry items like diamonds and pearls; and iii) musical instruments, games, and sports equipment. For a full mapping of disaggregate products to ICIO sectors see the OECD Bilateral Trade in Goods by Industry and End-use Category (BTDIxE) conversion key (http://oe.cd/btd).

II.B. Foreign Supply Chain Exposure by Sector at Face Value

This section turns the focus to foreign sources of intermediate inputs – continuing to use the face value concept (i.e. direct purchases). Before looking at the facts, it is important to put the notion of foreign exposure into context, in particular to dispel the idea that somehow foreign suppliers are riskier than domestic suppliers. Indeed, the riskiest thing to do with supply chains is to 'put all your eggs in one basket' (Miroudot 2020b, Baldwin and Freeman 2020a). Otherwise stated, diversification of suppliers both at home and abroad can be a useful buffer against shocks as firms can adjust their production when a disaster occurs.

For example, in 2012 Hurricane Sandy damaged ports, roads, and warehouses in the northeastern states. In the absence of foreign alternatives, this had the potential to be a colossal disruption. However, with ports on the West Coast able to receive goods, and foreign countries able to ship essential products, a complete breakdown of supply chains was avoided (NAS 2014). While foreign suppliers come with their own set of risks, foreign sources can serve as a buffer, contributing to the resilience, rather than the vulnerability, of supply chains (Goldberg and Reed 2023, Miroudot 2020b). In short, the simplistic view that domestic suppliers are safe and foreign suppliers are risky is just that – simplistic.

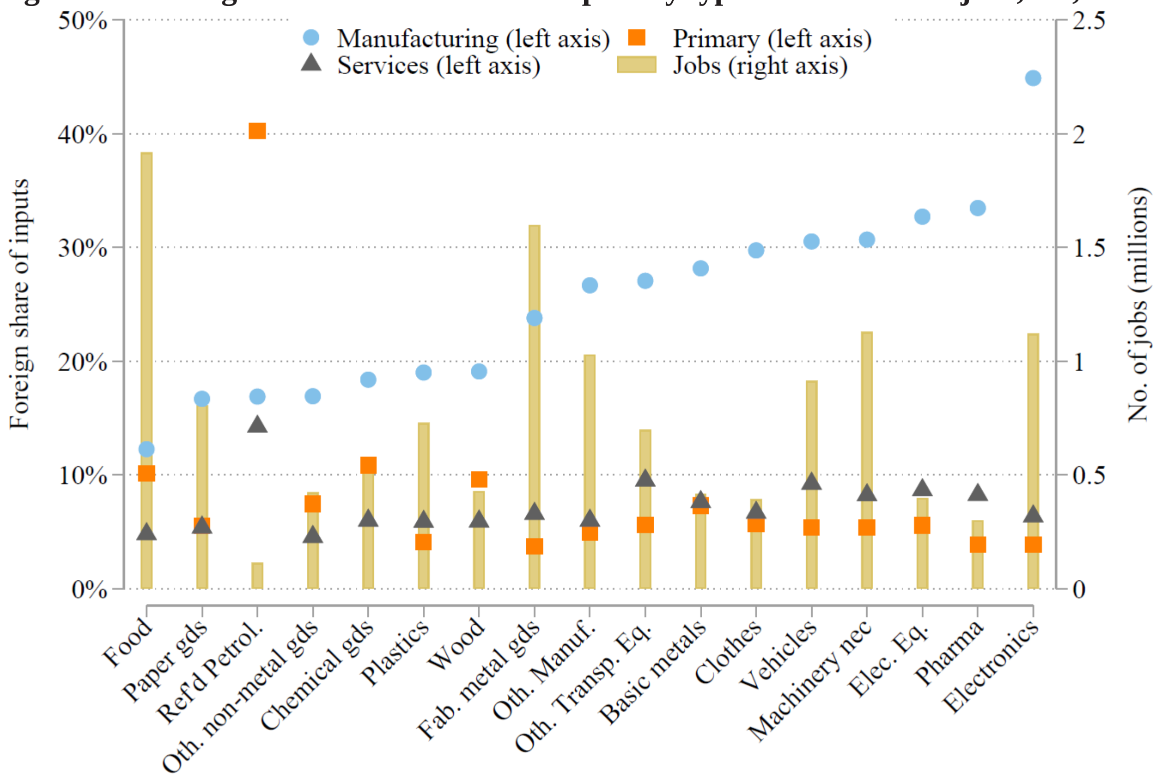
Figure 2.2 unpacks the numbers from Figure 2.1 by displaying the foreign sourcing in each of its stacked bars. For example, manufacturing inputs for the rightmost column in Figure 2.1 shows the share of industrial inputs in the cost of production in the Vehicles sector. The Vehicles point on the line for manufactured inputs in Figure 2.2 indicates that 31% of these inputs are sourced from abroad. The domestic share is naturally the balance between the foreign share and 100%.

The first point to note is that the focus of the recent public debate on industrial inputs – as opposed to, for example, primary inputs – seems justified. Apart from Refined Petroleum, foreign exposure to inputs in the primary and tertiary sectors is rather limited; the foreign share for these types of goods is generally less than 10%. As such, the rest of this paper focuses exclusively on the role of manufactured inputs in supply chains.

A second key fact that emerges from Figure 2.2 is the similarity of the foreign exposure shares when it comes to manufactured inputs. Apart from Electronics, which has a very high foreign share (45%) and Food which has a very low foreign share (12%), US manufacturing sectors source between 17% and 33% of their manufactured inputs from abroad, with the median imported share being 27%. The foreign share is above the median for Other Transport Equipment, Basic Metals, Clothes, Vehicles, Machinery nec, Electrical Equipment, Pharmaceuticals, and Electronics. Nine of the 17 sectors have foreign shares over a quarter.

The fact that the median foreign share is 27% means that most US sectors source the majority of their inputs from domestic suppliers. This is to be expected. As is true of all mega-economies, the US is quite self-sufficient in industrial inputs (Baldwin and Freeman 2022). The explanation is straightforward. Empirical studies show that trade flows are very sensitive to distance; the rough rule of thumb is that bilateral trade flows fall by half when the distance between countries doubles (Head and Mayer 2014). Research also shows that the anti-trade effect – or to put it differently, the localization effect – of distance is even higher for intermediate goods (Miroudot, Lanz, and Ragoussis 2009; Conconi, Magerman, and Plaku 2020). The distance effect is countered by a size effect whereby countries trade more with big economies. It is natural, then, that the US trades mostly with itself. It is, after all, a very large economy that is far from most nations, especially other large nations. Canada and Mexico are exceptions. Figure A1 shows this self-reliance in numbers. For the average US manufacturing sector, about 80% of all intermediates are sourced domestically. Thus, most of the US' supply chain exposure is to itself.

Figure 2.2: Foreign share of intermediate inputs by type and number of jobs, US, 2018



Source: Authors' elaboration based on 2021 OECD ICIO tables and OECD 2021 Trade in Employment (TiM) database. Note: This figure shows the sector's foreign purchased inputs as a share of its total inputs (domestic and foreign) by type of input (left axis) and number of US jobs (right axis).

When thinking about a sector's exposure to foreign suppliers and the implications that such exposure might have for the economy, a second set of important facts is the sector's size. Size, however, can be defined in many ways. In Figure 2.2 we zoom in on jobs, which is an important gauge of how foreign exposure might impact workers in the US economy. In this vein, the columns in Figure 2.2 present data on the number of jobs per sector. The largest sector is Food with almost 2 million employees in 2018. Fabricated Metal Goods is the second largest, with 1.6 million jobs. Three other sectors employ more than a million people (Electronics, Other Manufacturing, and Machinery nec), but the rest of the sectors are comparatively small. Refined Petroleum, Pharmaceuticals, Clothes, Electrical Equipment, Basic Metals, Other Non-Metal Goods, Wood, and Chemical Goods all employ less than a half million workers.

One fact that is striking from the supply chain perspective is the relative employment of the Fabricated Metal Goods sector and the Basic Metals sector. The number of workers employed in making Basic Metals is about 400,000, while the Fabricated Metal Goods sector employs four times more workers. This is noteworthy since US trade protections in the form of tariffs and quotas are higher in Basic Metals than in Fabricated Metal Goods, which in turn reduces the competitiveness of the Fabricated Metal Goods sector as it uses Basic Metals as an input (ITC 2023).

Having looked at US supply chain exposure to all sources (domestic and foreign) in Figure 2.1, and the foreign share of that exposure in Figure 2.2, the next step is to look at the exposure by sector and source nation.

II.C. Hidden Exposure: Look Through Versus Face Value Measures

The data presented so far has all been on a face value basis. To focus on the true foreign source of the supply chain exposure, we now switch to supply chain exposure measures on a look through basis, and we focus only on industrial inputs.

Our dataset has 65 economies, but to concentrate on the most important, we show the figures for only the top 15 suppliers to the US. These 15 suppliers account for the lion's share of imported intermediates. Figure 2.3 presents figures for the value of industrial inputs on a look-through basis, with the values standardized by the value of each sector's total purchases of manufactured intermediates from all sources – domestic and foreign. The supplying economies are listed in descending order of importance as a source, as measured by the simple average of the corresponding country's share in each of the 17 manufacturing sectors (see rightmost column). To interpret the figures, note that, for example, the 5.1% in the Vehicles column for the China row indicates that China is the source of 5.1% of all manufactured inputs used by the US Vehicles sector on a look through basis.

China's role as the dominant foreign supplier of industrial inputs to US manufacturing sectors is clear. Looking at the simple average across the 17 sectors (rightmost column) shows a figure of 3.5% for China – close to three times larger than the average for the next closest supplier, Canada. Indeed, China's average share is more than the sum of the three next most important suppliers combined. In eight of the 17 sectors, including Vehicles, Other Transportation Equipment, Plastics, and Fabricated Metal Goods, China is a more important supplier than the next four suppliers combined. In four of those sectors, China's share exceeds that of the next five most important suppliers. In two of these sectors, namely Clothes and Electronics, China's share exceeds that of the other top ten suppliers. This reflects the fact that China is also the top supplier for most of the US' other top suppliers (Baldwin, Freeman, and Theodorakopoulos 2022).

Figure 2.3: Look through exposure of US sectors to foreign manufactured intermediates (%), 2018

	Vehicles	Machinery nec	Basic metals	Elec. Eq.	Oth. Transp. Eq.	Clothes	Fab. metal gds	Plastics	Oth. Manuf.	Wood	Chemical gds	Pharma	Paper gds	Electronics	Oth. non-metal gds	Food	Ref'd Petrol.	Manuf. avg.
China	5.1	4.9	2.9	5.5	4.6	6.3	3.1	3.4	3.8	3.2	2.7	1.4	3.1	4.4	2.6	1.9	1.2	3.5
Canada	2.1	1.4	2.6	1.5	1.2	.6	1.8	1	1	1.6	.9	.4	1.3	.3	.7	.9	1	1.2
Mexico	3.4	1.8	1.7	1.6	1.3	.6	1.3	.7	.9	.7	.6	.2	.7	.8	.6	.6	.4	1.1
Japan	2.6	1.4	.8	.9	1.3	.5	.7	.7	.6	.5	.7	.3	.5	.5	.4	.4	.3	.8
Germany	1.5	1.1	.9	.7	.9	.4	.7	.7	.5	.5	.7	.8	.5	.3	.4	.4	.3	.7
Korea	1.4	.9	.7	.8	.8	.5	.7	.6	.5	.4	.5	.2	.5	.6	.3	.3	.2	.6
India	.4	.3	.3	.2	.2	.8	.3	.4	.4	.3	.3	.5	.3	.1	.2	.2	.1	.3
Taiwan	.5	.4	.4	.4	.5	.3	.4	.3	.3	.2	.3	.1	.2	.4	.2	.2	.1	.3
Italy	.5	.5	.4	.3	.4	.3	.3	.2	.2	.2	.2	.3	.2	.1	.2	.2	.1	.3
Brazil	.3	.3	.7	.3	.4	.1	.5	.2	.2	.3	.2	.1	.3	.1	.2	.2	.2	.3
Ireland	.1	.1	.1	.1	.1	.2	.1	.4	.1	.1	.4	2	.2	.1	.1	.1	.1	.3
France	.2	.2	.2	.2	.9	.2	.2	.3	.2	.2	.3	.2	.2	.1	.1	.1	.1	.2
Russia	.2	.3	.6	.3	.2	.1	.5	.2	.2	.2	.2	.1	.1	.1	.1	.1	.2	.2
UK	.4	.2	.1	.1	.4	.1	.1	.2	.1	.1	.2	.3	.1	.1	.1	.1	.1	.2
Switzerland	.1	.2	.1	.1	.2	.1	.1	.1	.1	.1	.1	1.2	.1	.1	.1	.1	0	.2
RoW	3.1	2.8	3.7	2.9	2.7	2.6	2.9	2.3	2.1	2	2	2	1.9	1.5	1.5	2	1.3	2.3
Foreign	21.9	16.8	16.2	16.1	16	13.8	13.7	11.5	11.2	10.3	10.3	10.1	10.1	9.5	8	7.7	5.9	12.3
USA	78.1	83.2	83.8	83.9	84	86.2	86.3	88.5	88.8	89.7	89.7	89.9	89.9	90.5	92	92.3	94.1	87.7

Source: Authors' elaboration based on 2021 OECD ICIO tables. Notes: Look through exposure is the Foreign Production Exposure: Import Side (FPEM) indicator, as described in Baldwin, Freeman, and Theodorakopoulos (2022) and is computed as the share of manufactured inputs sourced by a given US sector from a given country on a look through basis in total manufactured intermediates across all sources (foreign and domestic) on a look-through basis. RoW stands for Rest of the World. Foreign is the sum of all foreign sources.

Canada is particularly important as a supplier in Vehicles, Basic Metals, and Fabricated Metal Goods. Mexico is the third most important supplier followed by Japan, Germany, and Korea. Once we get beyond the top six supplying economies, the only large suppliers are

Ireland and Switzerland in the Pharmaceutical sector (each accounting for more than 1% of inputs).

To highlight the hidden exposure in US supply chains, Figure 2.4 presents the percentage point difference between look through exposure in Figure 2.3, and the equivalent numbers for face value exposure.[6] The biggest differences are in sectors that are marked by extensive global supply chains. In such sectors, the 'hidden value' gets added at many stages of the globalized production process. The differences are particularly marked in Vehicles, Machinery nec, Electrical Equipment, and Clothes. As far as source-nations are concerned, the biggest hidden value is for nations that are important producers of intermediate goods and extensively involved in global supply chains. This includes the major manufacturing nations, which are (apart from the US), China, Germany, and Japan.

Figure 2.4: Hidden exposure of US sectors to foreign manufactured intermediates (percentage point difference between face value and look through exposure), 2018

	Vehicles	Machinery nec	Basic metals	Elec. Eq.	Oth. Transp. Eq.	Clothes	Fab. metal gds	Plastics	Oth. Manuf.	Wood	Chemical gds	Pharma	Paper gds	Electronics	Oth. non-metal gds	Food	Ref'd Petrol.	Manuf. avg.
China	3.9	3.5	2.2	3.7	3.4	4.2	2.3	2.4	2.6	2.4	2	1	2.3	2.8	1.8	1.6	1.2	2.5
Canada	1	.7	1.1	.6	.6	.3	.9	.5	.5	.7	.4	.2	.6	.2	.4	.5	.9	.6
Mexico	1.4	.7	.7	.6	.6	.3	.6	.4	.4	.4	.3	.1	.4	.2	.3	.4	.4	.5
Japan	1.7	.9	.6	.6	.8	.3	.5	.5	.4	.4	.4	.2	.4	.3	.3	.3	.3	.5
Germany	.9	.6	.5	.4	.6	.3	.5	.4	.3	.3	.4	.4	.3	.2	.3	.3	.3	.4
Korea	1	.6	.5	.5	.6	.4	.5	.4	.3	.3	.3	.2	.3	.4	.3	.3	.2	.4
India	.2	.2	.2	.2	.1	.4	.2	.2	.2	.2	.2	.2	.2	.1	.1	.2	.1	.2
Taiwan	.3	.3	.2	.3	.3	.2	.3	.2	.2	.2	.2	.1	.2	.3	.1	.1	.1	.2
Italy	.3	.3	.2	.2	.3	.2	.2	.2	.1	.1	.2	.2	.1	.1	.1	.1	.1	.2
Brazil	.2	.2	.4	.2	.2	.1	.3	.1	.1	.2	.1	0	.2	0	.1	.1	.2	.2
Ireland	.1	.1	.1	.1	0	.1	.1	.2	.1	.1	.2	.4	.1	0	.1	.1	.1	.1
France	.2	.1	.2	.1	.4	.1	.1	.2	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
Russia	.2	.2	.4	.2	.1	.1	.3	.1	.1	.1	.1	0	.1	0	.1	.1	.1	.1
UK	.2	.1	.1	.1	.2	.1	.1	.1	.1	.1	.1	.1	.1	0	.1	.1	.1	.1
Switzerland	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.5	.1	.1	0	0	0	.1
RoW	2.2	1.8	2.2	1.7	1.7	1.4	1.8	1.4	1.3	1.3	1.3	1	1.3	.9	1	1.4	1.2	1.4
Foreign	13.7	10.3	9.6	9.4	10	8.5	8.5	7.3	6.8	6.8	6.4	4.7	6.6	5.7	5.3	5.8	5.4	7.7
USA	10.3	7.4	9.2	6.3	7.2	6.4	8.3	8.6	5.9	8.5	7.9	4.1	8.5	2.2	6.4	10.2	5.8	7.2

Source: Authors' elaboration based on 2021 OECD ICIO tables. Notes: This figure presents the percentage point difference between the look through exposure (Figure 2.3) and face value exposure (Appendix Figure A1). RoW stands for Rest of the World. Foreign is the sum of all foreign sources.

The hidden exposure is very large. For example, the Vehicle sector's exposure to

[6] See Appendix Figure A1 for the face value equivalent to Figure 2.3

Chinese industrial inputs is four times higher than indicated by the face value measure. In fact, the Chinese look through exposure is more than four times the face value exposure in eight of the 17 sectors. The percentage point differences are, on average, still quite high for Canada, Mexico, Japan, Germany, and Korea, as the rightmost column shows. The only other big hidden exposure numbers are for Ireland and Switzerland in Pharmaceuticals.

II.D. Hidden Exposure Take 2: Rapid Concentration in Foreign Sourcing

The hidden in hidden exposure in the previous section referred to the sourcing of intermediate inputs that was masked behind the Buzz Lightyear spiral of inputs used to make inputs. Here we turn the spotlight on another form of hidden exposure, namely the rapid geographic concentration of supply chain exposure.[7] It could be considered as hidden in the sense that it may have been underappreciated since it happened so fast.

CONCENTRATED SOURCING FROM CHINA

The manufacturing of intermediates has rapidly become geographically concentrated in China. China's ascent as the world's top manufacturer is well documented (World Bank 2020). Less well known is the fact that its production of intermediate manufactured goods has advanced even more rapidly than its production of final goods. Simply put, China has become what might be called "the OPEC of industrial inputs" (Baldwin 2022). This concentration matters since supply chains fundamentally revolve around intermediate goods.

China's rise as the OPEC of industrial inputs

As Figure 2.5 (left panel) shows, as recently as 1995, more than 70% of all intermediate goods were made in developed countries. At the time, the largest single producer – the US – accounted for about 20 percentage points of the 70% figure. By the 2010s, China's production of intermediate goods surpassed one quarter of the whole world's production – a figure that is almost twice as large as the next most important supplier (the US). In 2018, China's manufacturing sector produced a greater value of intermediates than all developed countries combined.

China's rise as a powerhouse of manufactured intermediates production was also rather sudden. At its peak in 2015, China accounted for 42% of world manufactured intermediates production, but just ten years earlier, the figure was 14%. As shown, the rapid rise has

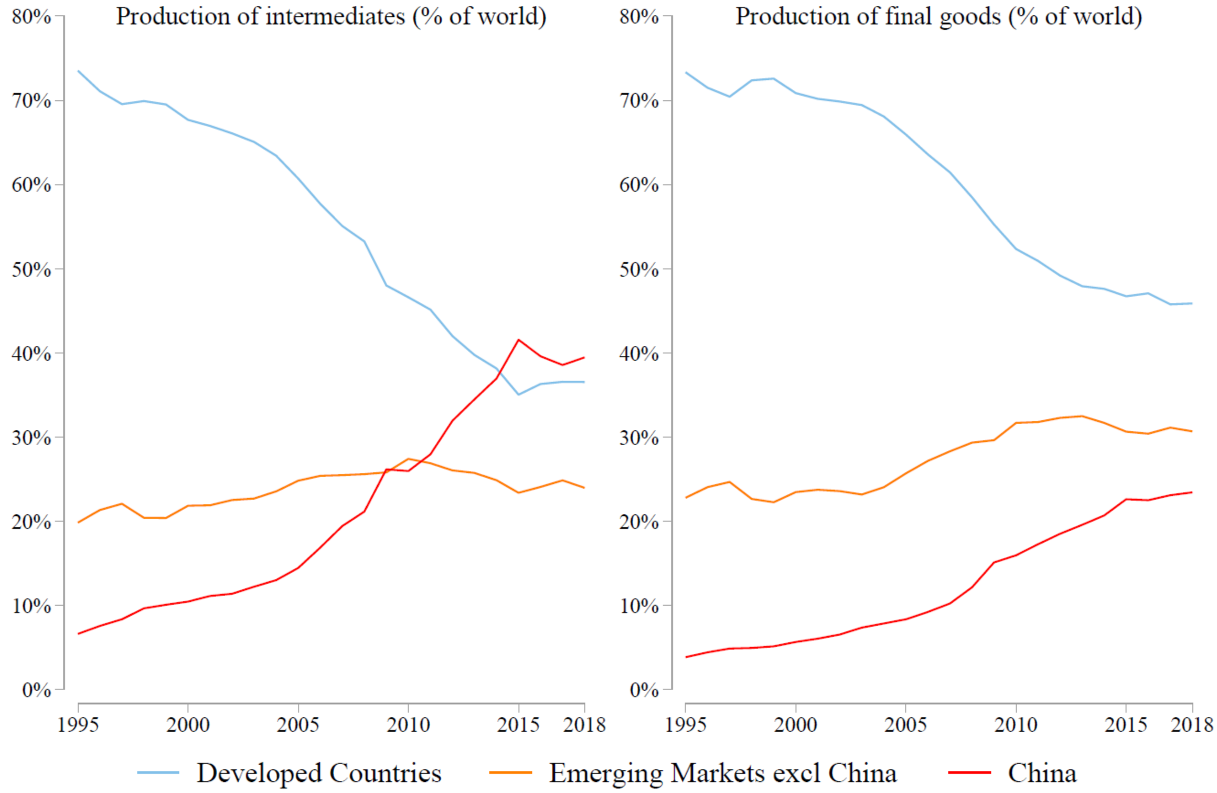
---

[7] In our analysis, we focus on concentration at the country level. However, it is worth noting that concentration can also exist within a given country. Data on the latter are typically not readily available at large scale.

attenuated, and appears to have plateaued, but at a level that implies an astonishing geographic concentration at the world level.

The right panel shows that China's share of global final goods production has been less rapid and less impressive. China's share of world production of final goods and services has also risen compared to 1995 values – seemingly at the expense of developed country production – and is now close to levels for all other emerging markets. It is, however, still more than 20 percentage points below the collective share of developed nations.

Figure 2.5: World production of intermediate and final manufactured goods, 1995-2018



Source: Authors' elaboration based on 2021 OECD ICIO tables. Notes: Developed Countries include the EU, EFTA nations, the United Kingdom, the United States, Canada, Japan, Australia and New Zealand. Emerging Markets excl China includes all other nations (including the rest of world aggregate) except China.

Geographic concentration by sector and source nation

China's rise as the premier foreign provider to US supply chains necessarily reduced the relative importance of other suppliers. Further insight into the concentration of US sourcing can be had by looking at the percentage point changes in the shares between 1995 and 2018 by sector and by source-nation. Since we are interested in the full impact of the changes, we work with the look-through concept that takes account of all the inputs to the inputs.

Figure 2.6 displays the numbers, where shades of red indicate higher exposure and shades of blue indicate lower exposure in 2018 versus 1995. As in the previous heat maps, it includes US sourcing from itself. As noted above, the US, as is true of all mega-economies, supplies most of its own intermediates (as can be seen in the bottom row of Figure 2.3). Figure 2.6 shows that this self-supplying has diminished. All the entries in the bottom row (the change in the US' share of industrial inputs to itself) are negative except for the Electronics sector. The average percentage point (pp) drop across the sectors is 3.4pp, with the figure varying between a +4.2pp for the Electronics sector to -7.5pp in the Vehicles sector. The Pharmaceutical sector is another standout with a drop of 6.2pp. The drop in domestic sourcing is matched by an increase in foreign sourcing.

Figure 2.6: US look through exposure by sector (percentage point differences), 1995 versus 2018

	Vehicles	Machinery nec	Basic metals	Elec. Eq.	Oth. Transp. Eq.	Clothes	Fab. metal gds	Plastics	Oth. Manuf.	Wood	Chemical gds	Pharma	Paper gds	Electronics	Oth. non-metal gds	Food	Ref'd Petrol.	Manuf. avg.
China	4.7	4.6	2.6	5.1	4.3	5.1	2.8	3	3.4	2.9	2.4	1.3	2.8	3.8	2.3	1.7	1.1	3.2
Canada	-.7	-.2	.5	-.1	-.4	-.1	.2	-.2	-.5	-1	-.2	0	-1	-.7	-.3	-.2	.1	-.3
Mexico	2.2	1.1	1.2	.9	.8	.2	.9	.4	.5	.3	.4	.1	.4	-.2	.3	.4	.2	.6
Japan	-1.4	-1.2	-1.2	-1.2	-1.1	-.4	-1	-.7	-.7	-.5	-.7	-.2	-.4	-3.2	-.5	-.4	-.3	-.9
Germany	.4	.1	0	0	0	0	0	0	0	.1	-.1	.4	.1	-.2	0	0	0	0
Korea	.8	.5	.3	.4	.3	-.1	.3	.3	.1	.2	.3	.2	.3	-.7	.2	.2	.1	.2
India	.3	.2	.2	.2	.1	.7	.2	.3	.3	.2	.2	.4	.2	0	.2	.2	.1	.2
Taiwan	-.1	-.1	0	-.1	-.2	-.3	0	-.1	-.1	-.1	0	0	0	-.8	-.1	-.1	0	-.1
Italy	.2	.1	.1	0	.1	-.2	.1	0	-.1	0	0	0	0	-.1	-.1	0	0	0
Brazil	0	0	.1	0	.2	-.1	0	0	0	.1	.1	0	.1	-.1	0	0	.1	0
Ireland	.1	.1	.1	.1	0	.2	.1	.3	.1	.1	.3	1.9	.1	0	.1	.1	.1	.2
France	-.1	-.1	-.2	-.1	0	0	-.1	0	-.1	0	-.1	0	0	-.2	-.1	0	0	-.1
Russia	0	0	-.1	-.1	0	0	0	0	0	0	0	0	0	-.1	.1	0	.1	0
UK	0	-.2	-.2	-.2	-.9	-.1	-.2	-.2	-.1	-.1	-.2	0	-.1	-.3	-.1	-.1	-.2	-.2
Switzerland	0	0	0	0	.1	0	0	0	0	0	0	.7	0	0	0	0	0	.1
RoW	1	.7	.5	.5	.5	.3	.4	.5	.3	.4	.2	1.2	.7	-1.4	.1	.4	0	.4
Foreign	7.5	5.6	3.9	5.3	3.8	5.4	3.5	3.7	3	2.5	2.9	6.2	3.3	-4.2	2	2.2	1.2	3.4
USA	-7.5	-5.6	-3.9	-5.3	-3.8	-5.4	-3.5	-3.7	-3	-2.5	-2.9	-6.2	-3.3	4.2	-2	-2.2	-1.2	-3.4

Source: Authors' elaboration based on 2021 OECD ICIO tables. Notes: This figure presents the percentage point difference between look through exposure in 2018 and look through exposure in 1995. Look through exposure is the Foreign Production Exposure: Import Side (FPEM) indicator, as described in Baldwin, Freeman, and Theodorakopoulos (2022) and is computed as the share of manufactured inputs sourced by a given US sector from a given country on a look through basis in total manufactured intermediates across all sources (foreign and domestic) on a look through basis. RoW stands for Rest of the World. Foreign is the sum of all foreign sources.

The increase in the share provided by all foreign nations is in the next to last row, and these numbers are all positive except that in the Electronics column. The most remarkable feature of these numbers is the fact that apart from Mexico, a large share of the row entries for all the other major suppliers are negative. The simple averages of the changes are only positive for China, Mexico, Korea, India, Ireland and Switzerland. China's average change is 3.2pp, which is far greater than those of the others upon which the US has become more exposed.

It is notable that China's average share rise is only slightly less than the average share drop in US domestic sourcing. In some of the most supply chain-exposed sectors, like Other Transportation Equipment and Electrical Equipment, China's percentage point gain is similar to the US' percentage point drop. The data cannot shed light on how this change occurred, for example due to offshoring of US intermediate goods production to China, or US deindustrialization, or Chinese industrialization. In other sectors, such as Vehicles, the US decline is significantly greater than the Chinese rise since the supply chain also spread to other foreign suppliers. In the Vehicles sector, we see a moderate decline in Canada's and Japan's share, a big decline in the US' share and an important rise in the shares of Mexico, Korea and, of course, China.

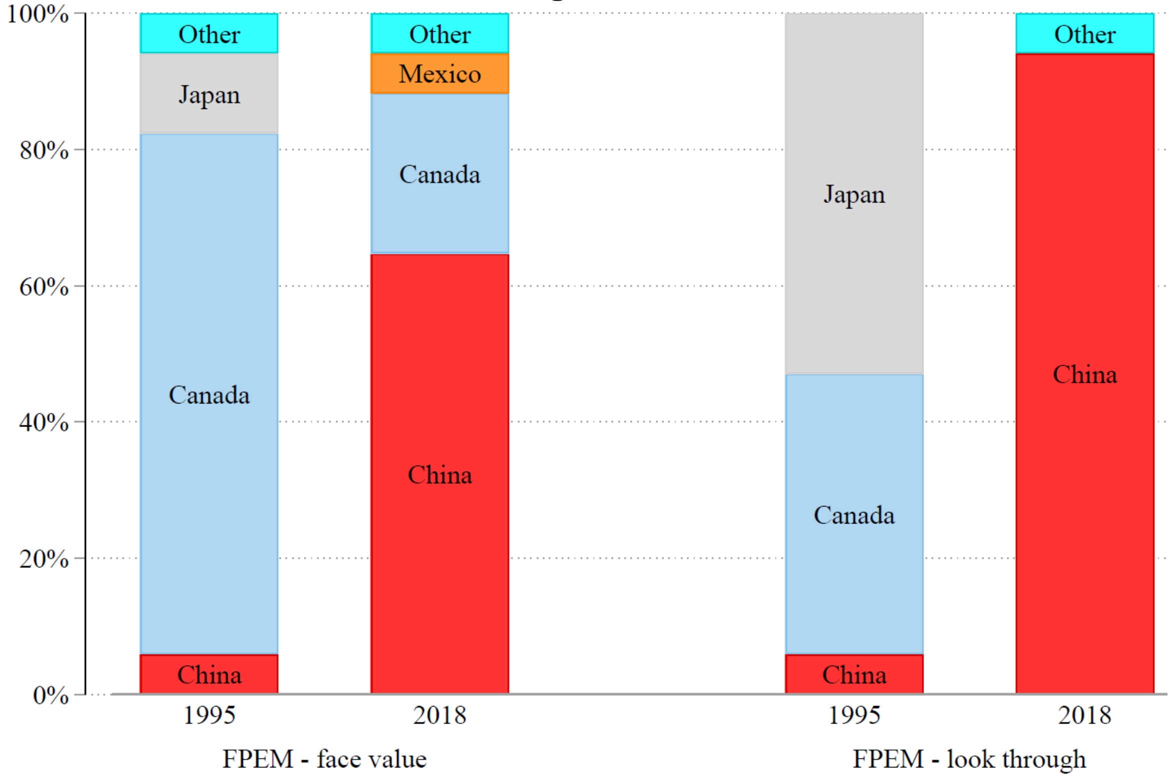
THE TOP FOREIGN SUPPLIER OF INDUSTRIAL INPUTS OVER TIME

The two forms of what we are calling hidden exposure – the look through versus face value measures on the one hand, and the rapid geographic concentration of sources on the other – can be usefully compared and contrasted by examining the nationality of the top supplier to each of the US' 17 manufacturing sectors. Figure 2.7 shows the share of the 17 sectors where the top supplier is China, Canada, Mexico, Japan, or some other nation. The chart also shows how this statistic changed from the beginning of our data, 1995, to the end, 2018. The two left-hand columns use the face value concept to examine the US' top supplier in 1995 and 2018, while the right-hand columns use the look through concept in 1995 and 2018.

When it comes to our second form of hidden exposure, the main takeaway from the chart is that China's role as the top supplier spread rapidly. Turning first to the leftmost pair of stacked columns, we see that in 1995, which was when the new offshoring-oriented globalization was just starting (Baldwin 2006, 2016), China was the top industrial input supplier to about 5% of US manufacturing sectors. By 2018, the share was over 60%. The change is even starker when using the look through measure (rightmost pair of stacked columns). China has shifted from being the top supplier in about 5% of the sectors to the top supplier in all but one sector (Pharmaceuticals).

The chart also shows a different take on our first aspect of hidden exposure. Comparing the two stacked columns for 2018 (the second and fourth columns), we see that while China is clearly dominant using the face value concept, it is much more so on a look through basis.

Figure 2.7: Top foreign supplier of industrial inputs to US manufacturing sectors, 1995 versus 2018, face value versus look through



Source: Authors' elaboration based on 2021 OECD ICIO tables. Notes: This figure shows the share of US manufacturing sectors for which the top supplier is China, Canada, Japan, Mexico or Other. FPEM stands for Foreign Production Exposure: Import Side (See Baldwin, Freeman, and Theodorakopoulos 2022).

The chart also illustrates the fact that Japan was, in 1995, playing a similar role to the one that China is playing today. In 1995, US exposure to foreign industrial inputs was much lower overall since back then the globalization of industrial supply chains was just starting. Most supply chains were domestic. Sticking with the look through concept to take account of direct in addition to all indirect sourcing, we see that among the foreign suppliers, Japan had the most top spots. Japan's role, however, looks much less dominant when viewed from the face value perspective. Comparing the first stacked column (1995, face value) to the third stacked column (1995, look through), we see that the hidden exposure was to Japan back then, not China. This was due to the fact that while the US was sourcing heavily from Canada, Canada was sourcing heavily from Japan. This was to be expected because Japan was the largest producer of intermediate goods outside of the US.

MEASURING GEOGRAPHIC CONCENTRATION WITH STANDARD TRADE DATA

The great advantages of IO analysis are the ability to distinguish face value trade from look through trade and the ability to distinguish between outputs that are used as intermediate goods and those used as final goods. As intermediate goods are what supply chains are set up to acquire, this distinction is critical. The disadvantage that comes with IO analysis is the lack of detail that stems from the very extensive information necessary to estimate the underlying tables, especially at the world (as opposed to single-country) level.

The sorts of supply-chain disruptions that have attracted the attention of heads of state around the world – like in the semiconductor and medical supply sectors – often involve very specific products. Thus, trade data serves as a valuable complement to the IO analysis since it is available at a much more disaggregated level. The US Census Bureau publishes export and import statistics at the 10-digit level following the US Harmonized Tariff Schedule (HTS), which distinguishes over 18,000 different products. To look at the supply-chain vulnerability issue from a different perspective, we next turn to the HTS10 data and look for concentration among source-nations.

A couple of limitations of the 10-digit data are important to keep in mind when thinking about the results we will present. The first is that we know neither which sector is importing the goods nor whether they are intermediate or final products. That is, we only know the type of good that is imported into the US, but we cannot connect the import to a particular purchasing sector. There are some types of imports, like those associated with motor vehicles, where the HTS10 product descriptions allow economists to identify which are intermediate inputs and which are final goods. Moreover, it is reasonable to assume that it is the US auto sector that is purchasing the intermediates. For instance, the product codes 8708305020 for brake drums and 7009100000 for rear-view mirrors are two clear examples. There are other types of imports, such as industrial chemicals, that could be used as inputs in a number of sectors. For these types of imports, we cannot associate geographic concentration with supply-chain exposure of a particular sector. As a fallback, we take the exposure as that of the US manufacturing economy as a whole. The second limitation (beyond not always being sure if a product is an intermediate versus final good) is that the trade data only show the face value exposure. For example, if a car part is imported from Canada, we cannot know how much of the good was actually made in Canada and how much was made in another country.

With these caveats in mind, we turn to using the HTS10 trade data to illustrate the geographic concentration of import sourcing. What we look at is the concentration of import sourcing for the 18,043 products that the US imported in 2018, focusing on imports from a single nation.[8] This is shown in the left panel of Figure 2.8; the far right bar indicates that for about a quarter of all imported products, 80% or more of the value came from a single source-nation. The bars within the column show the frequency with which the single source supplier is China, Canada, Germany, or some other country. In about a third of the products in this top quintile, the single supplier is China. The other stacked columns in the chart are similar, but the bar heights represent goods where the top supplier provides between 60%-80%, 40-60%, 20-40% and 0-20% of all imports, respectively. Thus, each of the 18,043 products is represented in only one of the five stacked columns.

The first salient fact that emerges from the chart is the remarkable geographical concentration of US imports. The leftmost column indicates that for less than five percent of the 18,043 products was the top supplier providing less than 20% of the total import value. Considering the two rightmost columns together shows that for almost half the products, more than 60% of the import value came from a single supplying nation. In short, the chart indicates a remarkably high level of geographic concentration of import sourcing.

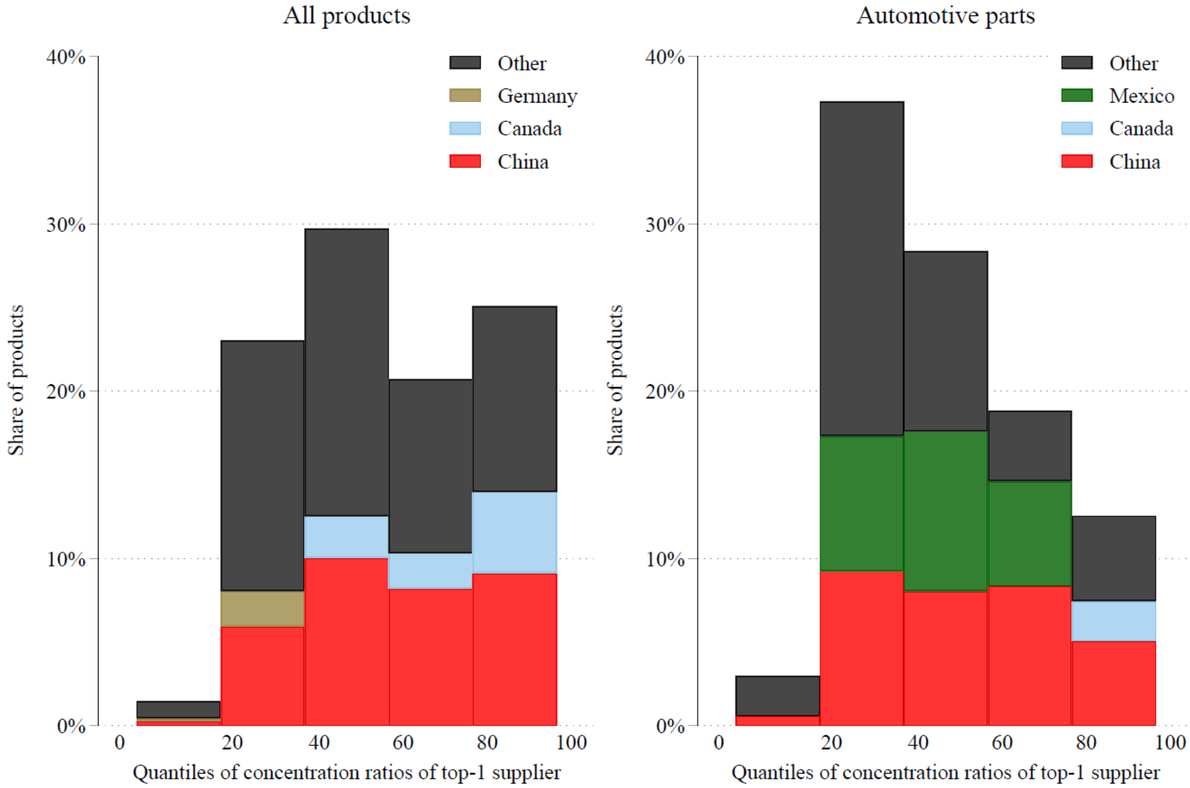
A second noteworthy fact concerns the role of China. In the most concentrated products, for example those underlying the three rightmost columns, China is by far the most important supplier. However, a subtler aspect of this emerges when comparing China's role as top supplier in Figures 2.7 and 2.3. We saw in Figure 2.3 that on a look through basis, China was by far the top supplier in every sector. Its dominance is so great that its share of imported inputs was frequently greater than the sum of the next three largest suppliers combined. Yet the left panel in Figure 2.8 would suggest that China is not as dominant a supplier of US imports. For example, for the rightmost column – the one that shows products where at least 80% of import value originates from a single nation – China is the top-1 supplier in only around a third of the cases.

In other words, if one looks at the direct source of imports, China is important, but not

[8] In line with our concentration analysis with IO data, we focus our attention on a single supplier at the product level. In the absence of firm-level data. We believe that this concentration level reveals particularly high exposure, especially to systemic shocks which have a broad geographical reach.

dominant.[9] However, if one uses IO analysis to determine where the directly imported products were actually made, China's dominant role becomes clear. Of course, the results in Figure 2.3 and Figure 2.8 are not directly comparable, but the contrast is striking. The stark differences are indications of just how much exposure is hidden by failing to look through the veil of inputs into the inputs.[10]

Figure 2.8: Shares of products imported by the US from a single source-nation by quintile of import shares, 2018



Source: Authors' elaboration on US Census Bureau trade statistics. Notes: The left panel shows the quintile distribution of all 18,043 products (intermediate and final) imported by the US in 2018 and the right panel shows the quintile distribution of all 335 automotive parts (intermediates only) imported by the US in 2018.

Given the finer level of disaggregation that is possible with trade data, we use the same type of analysis to take a closer look at the US' imports of automotive parts and components, presumably for the Vehicles sector, where supply chain disruptions are a major issue in the public debate and the distinction between final and intermediate imports is fairly clear. The automotive industry is an interesting case since our IO analysis found it to be one of the most

[9] Evenett (2020) and Goldberg and Reed (2023) note that face value import dependency from China is small in post product categories.
[10] Reconstructing the left panel for the top two suppliers (instead of just the top one supplier) reveals that more than half of all the products that the US imports have over 80% of their value coming from just two suppliers.

exposed to foreign sourcing, and the nature of automobiles allows us to easily distinguish final from intermediate goods in the HTS10 descriptions. The right panel of the figure shows a chart that is similar to the one in the left panel, but focuses solely on the 335 imported products classified as intermediate inputs to the automotive sector by the US Office for Transportation and Machinery.[11]

A comparison of the two panels of Figure 2.8 suggests that the geographic concentration of supply-chain exposure for automotive parts is significantly less marked than it is for the average good (which includes many final goods). The top quintile, for example, covers less than 15% of products. This coverage is significantly lower than the 25% observed for the entire range of imported goods shown in the left panel of Figure 2.8. When considering the top two suppliers, this rises to just over 30%. This finding is in line with the findings from Figure 2.4 where we saw that the top six suppliers each provided more than 1% of manufactured intermediates to the US Vehicles sector.

The last set of facts we present on the issue of supply linkages involve a comparison with the same measures, but taken from the Chinese perspective.

II.E. Comparison with China

The facts for China could hardly be more different than those for the US and the two other major manufacturing countries, Germany and Japan. China's industrialization is quite recent compared to that of the US and other advanced economies and its development journey was quite different. China started its industrialization with processing trade, which involved limited transformation of imported intermediate goods. From there, China built out its industrial base by producing domestically many inputs that had previously been imported. This task was facilitated by its massive and fast-growing internal market and government policy (Cui 2007), foreign investment, and transfers of foreign knowhow (Wen 2016). The result is plain to see in Figure 2.9, which also presents the figures for the US, Japan, and Germany.

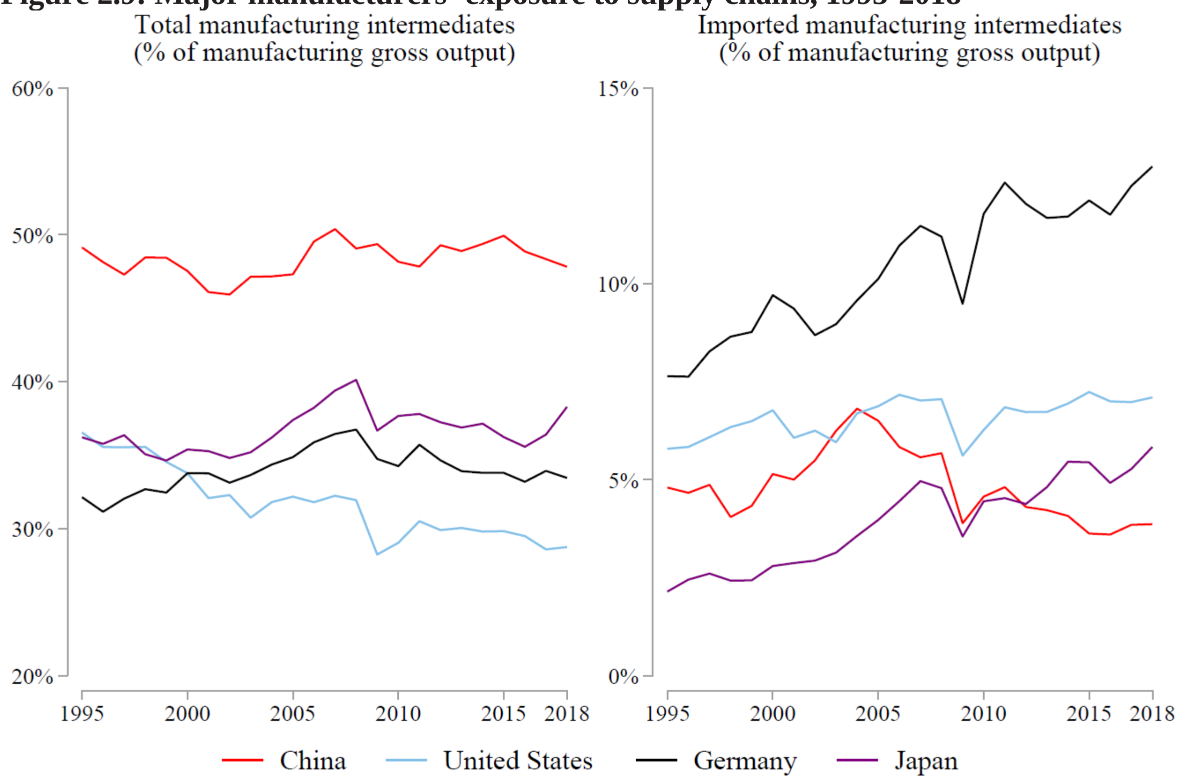
The left panel shows the nations' total usage of manufactured intermediates as a share of their manufacturing gross output. We see that Chinese industry is far more exposed to supply chains – taking domestic and international exposure together – than the other three giants (left

[11] We rely on the US International Trade Association classification of automotive parts, as proposed by the US Office for Transportation and Machinery: https://www.trade.gov/automotive-parts-tariff-codes.

panel). The share of China's manufacturing gross output that is made up of intermediate inputs is about 50% and this figure has been fairly steady since 1995. The corresponding share for the other nations shown is much lower. The right panel, however, shows that Chinese industry is now less exposed to foreign intermediates than the other manufacturing giants. Specifically, China's foreign exposure started in the middle of the pack and rose sharply up to 2005, but has been falling rapidly since. It is now substantially lower in 2018 than the others. The US' exposure to imported manufacturing intermediates is roughly twice, and Germany's is roughly three times that of China.

It is worth noting that all of these "Giant-4" economies are quite self-reliant when it comes to intermediate inputs. The most exposed is Germany, but even then, it sources over 85% of all its manufacturing intermediates from itself.

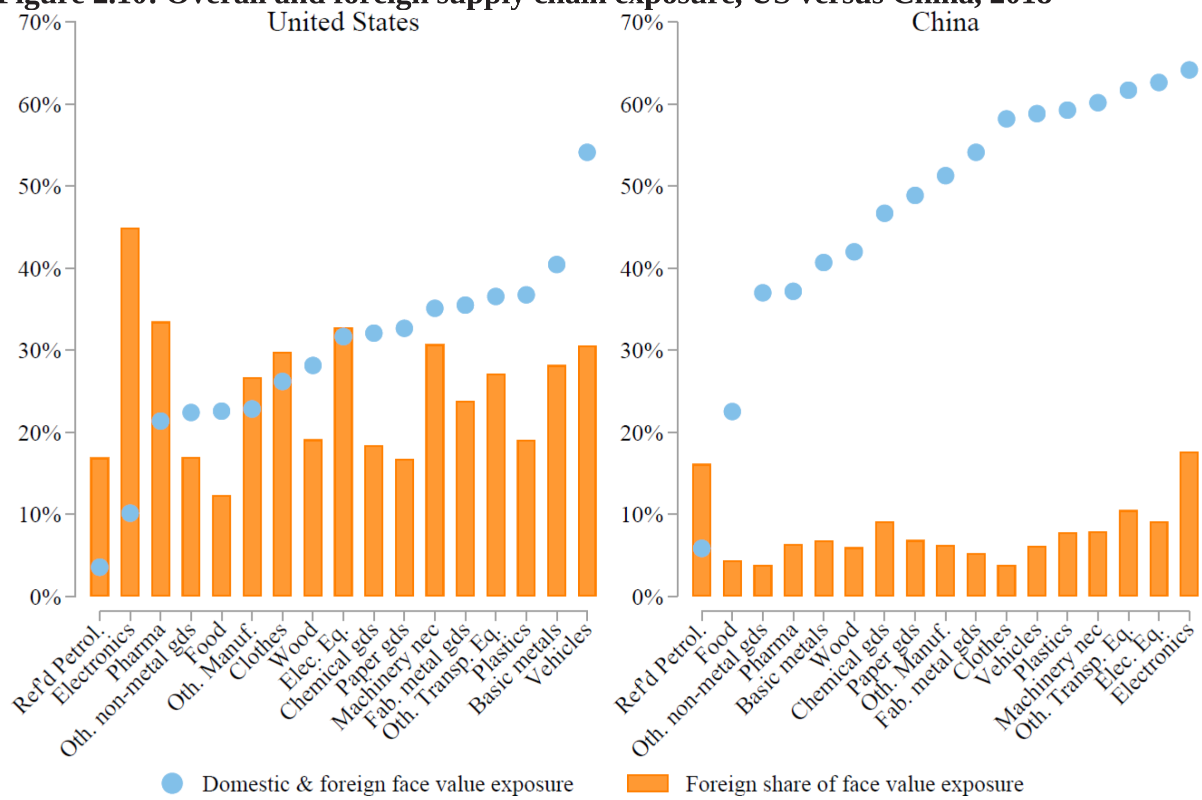
Figure 2.9: Major manufacturers' exposure to supply chains, 1995-2018



Source: Authors' calculations based on OECD 2021 ICIO tables. Notes: The left panel shows manufacturing intermediate inputs as a share of manufacturing gross output. The right panel shows the imported manufacturing intermediates as a share of manufacturing gross output.

Looking closer, Figure 2.10 shows that China's sectors are generally more exposed overall to supply chains (i.e. combining domestic and foreign sources), but much less exposed to foreign suppliers. For instance, China's foreign exposure is below 20% for all sectors, while for the US it is much higher, approaching 30% to 50% in some cases. The opposite holds for the overall (domestic plus foreign) exposure which is much higher for China than it is for the US in every single sector.

Figure 2.10: Overall and foreign supply chain exposure, US versus China, 2018



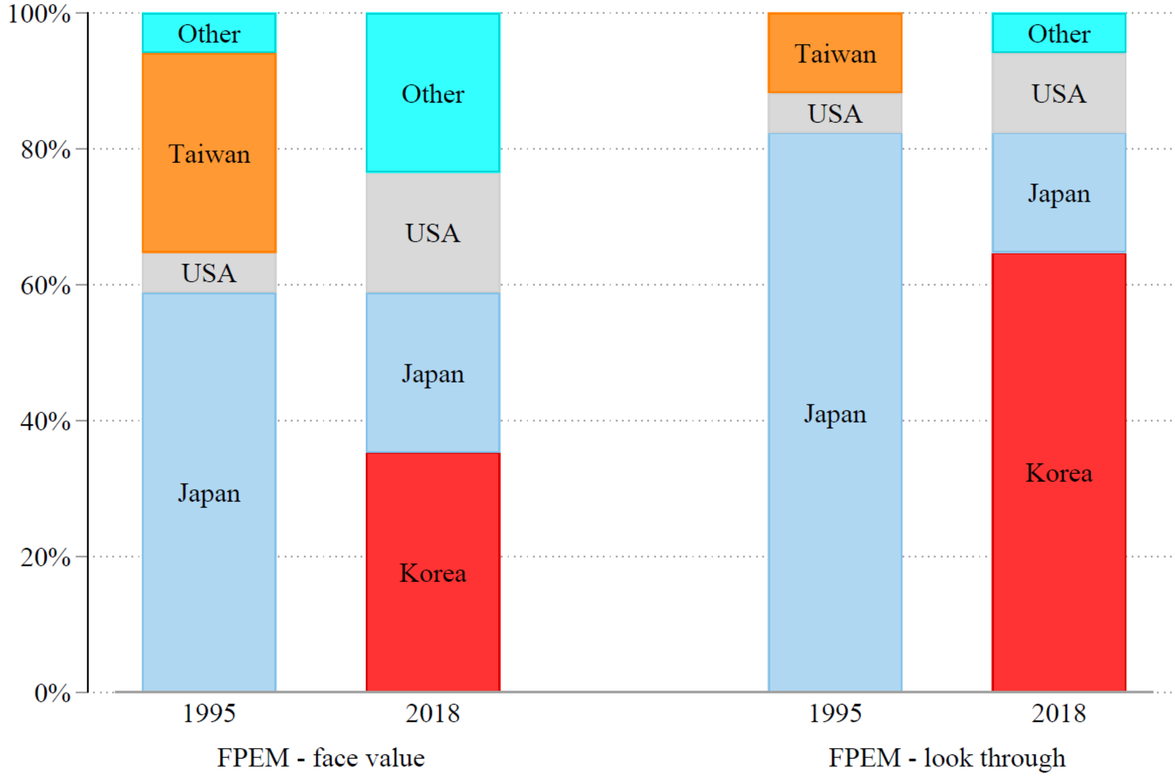
Source: Authors' calculations based on OECD 2021 ICIO tables. Notes: This figure shows total (i.e. domestic and foreign) and imported (i.e. foreign) manufacturing intermediate inputs on a face value basis (as % of a sector's gross output). The blue dots in the United States panel are repeated from Figure 2.1.

In terms of geographic concentration, China is also quite different than the US, as Figure 2.11 shows. This chart, which is comparable to Figure 2.7, shows that China's foreign sourcing is not as concentrated as that of the US. For instance, the far-right column shows that China's top supplier on a look through basis is Korea, but Korea is the top supplier in only about 60% of Chinese manufacturing sectors. Japan, the US, and other nations play a significant role as top suppliers. On a face value basis (second column from the left), Chinese foreign sourcing is even more diversified.

When it comes to rapid changes in geographic concentration, we do see big upward shifts in Korea's top-slot role from 1995 to 2018, but it is not a stark as the shift that the US experienced (Figure 2.7). It is also interesting to note that the big hidden exposure for China in

1995 was to Japanese suppliers. On a face value basis (leftmost column), Japan's role was much lower than it was on a look through basis.

Figure 2.11: Top foreign supplier of industrial inputs to Chinese manufacturing sectors, 1995 versus 2018



Source: Authors' elaboration based on 2021 OECD ICIO tables. Notes: This figure shows the share of Chinese manufacturing sectors for which the top supplier is Japan, Korea, USA, Taiwan or Other. FPEM stands for Foreign Production Exposure: Import Side (See Baldwin, Freeman, and Theodorakopoulos 2022).

III. The Shocks: Recent and Likely Future Shocks

While supply chain disruptions have a long history, we believe that recent disruptions have increased both in scale and complexity. We argue that this shift is partly due to a transformation in the nature of these shocks. Picking up on points made by many (ICC 2023; WEF 2023), we argue that supply chain shocks have become more systemic in the sense that they cover many sectors, many suppliers, and can be longer-lasting than the shocks we were used to before the 2010s. This is a crucial point.

The shocks that emanated from COVID are slowly resolving themselves – at least at the economy-wide level. The Federal Reserve Bank of New York, for example, has developed an index to track the impact of supply chain disruptions (with an eye to their impact on US inflation). This indicator, the Global Supply Chain Pressure Index (GSCPI), spiked at a level that was more than three standard deviations above the historical average in April 2020. The shock faded by October 2020, but then shot up in November 2021 to more than four standard deviations above average. Since then, the GSCPI has fallen.[12] According to the most recent data from July 2023, the GSCPI is a full standard deviation below the index's historical average.

The Bank of International Settlements (BIS), which tracks more classical indicators, comes to roughly the same judgment. Pressures on global supply chains appear to have peaked in late 2021, according to several aggregate indices (Igan et al. 2022). Inventories have begun to normalize, as production has ramped up and aggregate demand has moderated. Freight costs have halved from their peak. Delivery times, particularly in advanced economies, have shortened. Nonetheless, the easing has been slow and uneven across sectors and countries and significant dislocations remain.

Given that the COVID shocks are fading, it is tempting to think that massive disruptions are a thing of the past and that all the attention being paid to supply chain disruptions by governments and firms is akin to "generals preparing for the last war." This is a temptation to resist.

While the pandemic undoubtedly resulted in the largest global supply shock since the 1970s oil shock, COVID was not the first massive shock in recent years. To illustrate this point, and provide examples for our classification of shocks, we start with a quick recap of recent events before making the case that the nature of supply chain shocks has shifted from idiosyncratic to systemic. By idiosyncratic we mean shocks that are isolated and limited in scope; systemic shocks, by contrast, have impacts that affect multiple sectors and regions.

III.A. Brief History of Recent Supply Chain Disruptions

The years 2020-2023 were a wild roller coaster ride for the world's production networks – a journey into uncharted waters of supply chain bottlenecks, unanticipated dependencies, feedback loops, and formerly hidden interlinkages. But, despite the media attention they received, such largescale supply shocks were not a new thing in 2020. Indeed, who could have imagined, back in early 2019, that the grand challenge to global supply chains would arise from a tiny, malevolent ribbon of RNA?

From 2016, the disruption narrative revolved around geoeconomic tensions. These

[12] https://www.newyorkfed.org/research/policy/gscpi.

included tariffs imposed by the US on many of its trade partners and those nations' imposition of retaliatory tariffs (Bown 2017, 2021). The unpredictability of economic policymaking also became a source of disruption. There was also discussion among academics, policymakers, and international organizations about the disruptive possibilities of climate change. These concerns persist today, but their significance was overshadowed by the reach, severity, and lasting impact of the supply chain disruptions caused by the COVID pandemic.

The pandemic took root in late 2019 and surged repeatedly until May 2023 when the World Health Organization officially declared its end (WHO 2023). A byproduct of the disease was that countries very directly, and very expressly disrupted production by imposing stay-at-home measures or reduced-mobility policies that halted factory operations in many sectors worldwide. Other policies also directly disrupted shipping. For example, in an attempt to stall the spread of the virus, many major ports prohibited crew changes without a 14-day quarantine, which had a severe impact on transportation and supply chains (Heiland and Ulltveit-Moe 2020; Bai et al. 2022).

As nations and businesses were adapting to the virus and related health measures, another source of disruption emerged in 2021. Prevented from spending as much as usual on services like food and entertainment, consumers redirected their expenditures toward physical goods, sparking a resurgence in global demand for manufactured goods. Many such goods were made in Asia or with parts from Asia. This shift in spending patterns intensified disruptions stemming from production and transportation disturbances. The scale and duration of this shift exceeded expectations, and supply struggled to meet surging demand. Critical inputs, such as semiconductors, faced shortages. This impacted a range of downstream industries, especially the truck and automobile sectors. The collective effect of these disruptions reveals how fragile and unprepared GSCs were to respond to sudden changes in demand patterns.

An important consequence of this combination of supply and demand shocks was the misplacement of shipping containers due to consumers shifting from in-store to online shopping (Tirschwell 2022). Many of these containers, filled with Asian-manufactured goods, ended up at online fulfillment centers lacking sufficient storage capacity. Furthermore, as the demand surge primarily involved Western demand for goods produced in Asia, trade flows became imbalanced. As containers accumulated in North Atlantic economies, a container shortage emerged in Asia, leading to increased shipping costs and delays. These bottlenecks affected final goods as well as crucial parts and components, ultimately impacting manufacturing in the US and Europe. The pandemic waned and economies reopened in mid-2022, yet global manufacturing remained off-balance. Disruptions persisted due to a 'near-perfect storm' of imbalances. By this, we refer to a convergence of factors—both predictable and unpredictable—that threw supply, demand, and transportation out of equilibrium. The disruptions were so large and so broad that they contributed to an inflationary surge in advanced economies (De Guindos 2023).

The parade of once in a lifetime shocks continued. The Russo-Ukrainian conflict led to sanctions, embargoes, and boycotts, driving commodity and energy prices to soar. This fueled double-digit inflation, which had been absent for decades, introducing macroeconomic disruptions to production-level shocks. Central banks raised interest rates and global growth slowed. But the surprises didn't end there.

A third wave of supply disturbances arose when a new variant of the virus spread to China, triggering severe lockdowns in key centers like Shanghai in Spring 2022. This hampered shipping and the production of intermediate parts, serving as a less intense but no less significant reminder of the evolving nature of supply chain shocks. Then came China's significant policy reversal – shifting from a stance of zero-COVID to almost no policy on COVID. After the wave of infections receded, this unleashed pent-up demand from Chinese consumers. China's policy reversal is significant because it not only influences global supply chains but also reveals how quickly governmental policies can change, adding another layer of unpredictability to supply chain planning.

III.B. Types and Sources of Shocks

To organize thinking and discussions about supply chain shocks, we employ a framework that classifies these shocks into two main categories: idiosyncratic and systemic, as well as three primary sources: supply, demand, and connectivity (Baldwin and Freeman 2020b; Baldwin, Freeman, and Theodorakopoulos 2022). The various combinations are illustrated in Table 3.1

Table 3.1: Taxonomy of sources and nature of shocks, with examples.

	Supply	Demand	Connectivity
Idiosyncratic (isolated, simple)	Factory closure, labor strikes, extreme weather, etc.	Single product demand surge, etc.	Single port closure, single firm cyber-attack, etc.
Systemic (multi-sector, multi-market, complex interactions)	Pandemics, trade wars, large-scale extreme weather, etc.	Sector-wide preference shifts, multi-product, multi-sector boycotts, embargoes, etc.	Massive hurricanes, military conflicts, large-scale hacking, etc.

Source: Authors' elaboration.

We believe the distinction between idiosyncratic and systemic shocks to be pivotal, as it marks one of the most significant shifts in international supply chains since 2016. However, as a review of recent events illustrates, this threefold categorization of shock sources is not entirely foolproof. Some shocks originate from multiple sources, and others may start on the supply side but eventually trigger demand-side repercussions. Further, connectivity shocks (such as port congestion container shortages) can emanate from demand shocks which cause stressed logistics systems, or physical disruptions like the Evergreen ship getting stuck in the Suez Canal, or reduced traffic in the Panama Canal caused by a severe drought (NASA 2023). In a similar vein, Guerrieri et al. (2022) highlight how COVID started as a supply shock, and subsequently led to a demand shock. Nonetheless, the ability to distinguish among the sources of shocks is crucial, as the appropriate remedies typically depend on identifying the source of the disturbance (Baldwin and Freeman 2022). For example, geo-diversifying suppliers will not mitigate unanticipated demand shocks.

TYPES OF SUPPLY CHAIN SHOCKS: SYSTEMIC VERSUS IDIOSYNCRATIC

Leaving aside truly unique events such as the 2008-2009 Global Financial Crisis and the 1970s oil shock, most of the supply chain disruptions before 2016 seemed relatively small, independent, and controllable at the firm level. Notable examples include the floods in Thailand that disrupted auto production, earthquakes in Japan that disrupted the electronics sector, and labor strikes – like the February 2022 blockage of the US-Canada border by truck drivers. Supply chain disruptions seemed to be a topic that could be safely left in the hands of private firms and logistics companies, supply chain management strategists, and operations research specialists. These shocks were idiosyncratic in nature. Other illustrative instances of idiosyncratic shocks encompass the bankruptcy of a solitary supplier, a labor strike confined to one locale, or a fire at an individual factory. While they can wreak havoc on the directly affected entities, their ripple effects to the broader economy are usually minimal.

Systemic shocks, in contrast, are disturbances that resonate across numerous markets, sectors, and products, having a broad geographical and sectoral reach. As such, they are increasingly uncontrollable at the level of individual firms. Notable examples include the Global Financial Crisis, the geopolitical implications of events like Brexit, the US-China geoeconomic tensions, and worldwide pandemics such as COVID.

Fundamentally, the differentiation between systemic and idiosyncratic shocks hinges on the scope of their influence. It may help to think of a systemic shock as a citywide flood affecting an entire urban landscape, both economically and geographically. In contrast, idiosyncratic shocks could be likened to a plumbing failure in a single building, calamitous for its occupants but leaving the broader cityscape largely unaffected.

The three most cited sources of systemic shocks are: geoeconomic tensions; climate change; and digital technology (WEF 2023; MGI 2022). Geoeconomic tensions, for example, have led some actors to use and reshape economic linkages and tools to serve a broader set of strategic goals beyond those which are purely economic, in what some have termed “the weaponization of interdependence” (Farell and Newman 2019; Drenzer, Farrell, and Newman 2021). For instance, the tariffs implemented by the US in 2018 were followed by other countries introducing reciprocal measures raising trade and investment barriers, often citing geoeconoimc and national objectives (York 2023; Bown and Kolb 2023). More recently, the Russo-Ukrainian War has not only elevated concerns about supply chains and national security but also triggered a cascade of systemic shocks. These manifest as trade sanctions, boycotts, embargoes, and cross-border restrictions that reverberate through global supply chains, affecting international flows of goods, services, capital, people and know-how (Goldberg and Reed 2023).

The second source, climate change, is perhaps the ultimate example of radical uncertainty, i.e. events whose determinants are insufficiently understood for probabilities to be estimated (King and Kay 2021). Two aspects, however, have clear implications for systemic supply chain disruptions. Extreme weather events have repeatedly knocked production and transportation facilities offline in ways that affect many sectors and many economies (Seneviratne et al. 2021). Hurricane Katrina, for example, knocked the Port of New Orleans offline for months. Likewise, heatwaves and droughts have forced some electric power plants to reduce output in the US and France (Barber 2022). On another note, a very different source of shocks concerns future pandemics. Many public health experts expect climate change to induce the migration of species that results in novel genetic recombination among animals and thus more zoonotic viruses affecting humans (UNEP 2020).

Digital technology is the third source of future systemic shocks. The rapid advance and spread of digital technology in all its manifestations is dialing up the regularity and severity of future shocks in two ways: it is encouraging more activities to shift to the online world where they are vulnerable to accidental and malicious disruptions, and it is boosting the abilities of and incentives for hackers to interrupt normal business activity (Burt 2023). A well-known example is the Colonial Pipeline attack (Easterly and Fanning 2023). In 2021, a criminal hacking group called DarkSide carried out a cyberattack that caused a week-long disruption in the supply of gasoline to the eastern parts of the US. The company that owns the pipeline, Colonial Pipeline, had to shut it down to stop the cyber infection and prevent further damage. Since this pipeline was responsible for delivering almost half of the fuel used on the East Coast, the attack led to widespread panic among consumers and a significant increase in fuel prices. Cybersecurity is continuously improving, but so are the skills of criminal and state-sponsored hackers. In this way, digital technology still poses significant risks to supply chain operations around the world.

SOURCES OF SUPPLY CHAIN SHOCKS: SUPPLY, DEMAND, AND CONNECTIVITY

Starting with supply shocks, which are often the first ones that come to mind, these disruptions result from various interruptions to production. The causes can be immediate and concrete, like natural disasters, worker strikes, industrial accidents, or cyber-attacks. They can also stem from financial troubles like supplier bankruptcies or new competitors entering the market. More broadly, issues such as pandemics, political instability, changes in trade policies, taxes or regulations, government subsidies, or groundbreaking technological advancements fall into this category.

Demand shocks, on the other hand, stem from customer-side changes – be they consumers or businesses. These changes might be due to shifts in individual’s incomes, business bankruptcies, or alterations in consumer preferences. Surprising shifts in how customers view products or a company’s reputation can also lead to demand shocks. Additionally, there are subtler shocks, like currency fluctuations, geopolitical crises, or trade policies, which can act as either demand shocks for some businesses or supply shocks for others, depending on the situation.

Finally, connectivity is the backbone of supply chains, and disruptions here can take various forms and, as described above, even stem from things like demand shocks. These disruptions range from logistical challenges, whether by air, land, or sea, to breakdowns in communication with physical or cyber sources.

It is also worth noting that not all shocks fall neatly into the three bins. The destabilizing influences of shifts in trade, taxation, industrial norms, or regulatory guidelines, for example, often defy clear categorization as they can concurrently impact supply, demand, and connectivity. Moreover, one shock can lead to another. The shortage of new US cars and trucks, for example, was a supply shock, but it also created a demand surge that disrupted the used car market (Helper and Soltas 2021).

The last distinction, which is general and applies to all combinations of shocks listed in Table 3.1, is the difference between 'known unknowns' and 'unknown unknowns.' There exists a spectrum of shocks based on our level of awareness and anticipation. At one end are the known unknowns – events or situations we recognize might occur, but whose timing and exact form are uncertain. For instance, labor strikes at Charles de Gaulle airport can be somewhat predicted, given that such events have historical precedent and observable trends. Preparing for these kinds of shocks is relatively straightforward, as we're aware of their potential occurrence.

At the opposite end of the spectrum are the unknown unknowns – events without forewarning or precedent, and therefore unpredictable in both timing and nature. A fitting example would be the specific characteristics of a future pandemic. While we may anticipate another pandemic based on past occurrences, predicting its exact nature, method of spread, health and economic impacts, and other details is inherently difficult or even impossible.

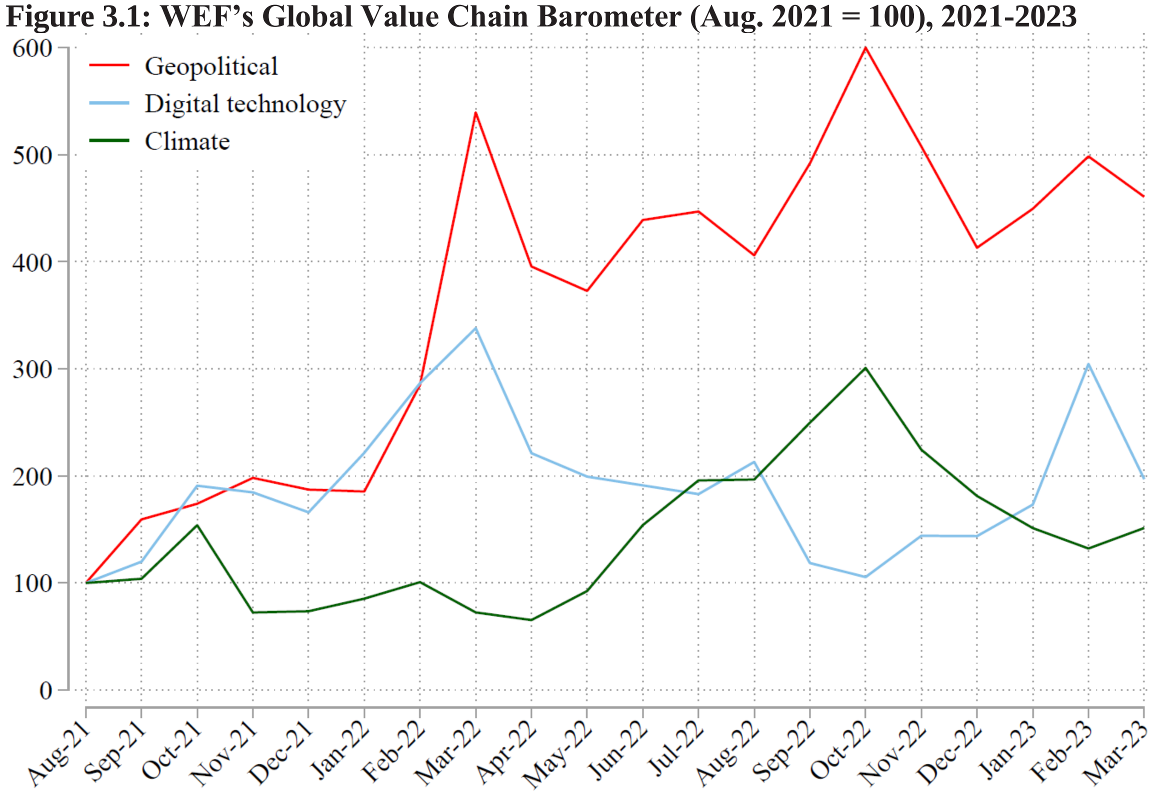
III.C. State of Disruptions

Can we consign the whole 'supply chain disruption thing' to economic history? Or are systemic disruptions a real concern for policymakers? The COVID shock has promoted important efforts to gather better and more timely data on potential shocks. In this section, we review some useful sources that suggest that the 'supply chain disruption thing' is most definitively not fading, although it is not as intense in 2023 as it was in 2021 and 2022.

One survey-based gauge, published quarterly by the World Economic Forum in partnership with the consulting firm A.T. Kearney and utilizing data insights from Everstream

Analytics, is the Global Value Chain Barometer (WEF 2023). In terms of sources of shocks, it focuses on three areas: climate change (especially trade disruptions linked to extreme weather); geoeconomic tensions (especially the Russo-Ukrainian war, realignment of emerging-economy coalitions, and trade policy tools that purposefully disrupt trade and investment flows); and digital technologies (especially cybersecurity related disruption of supply capacities and transportation). After three years of supply disruptions driven by the megatrends of climate change, geopolitical tensions, and technological step-change, disruption levels seem to have stabilized by Q1 2023 compared with Q1 2022, albeit at an elevated level (Figure 3.1). This reflects a combination of a stable trend for new disruptions and firms' improved ability to operate in a higher volatility environment. Overall, this suggests that the three big sources of future shocks are not fading in importance.

Figure 3.1: WEF's Global Value Chain Barometer (Aug. 2021 = 100), 2021-2023



Source: WEF 2021 (data provided to authors upon request). Note: Values indexed to 100 in August 2021.

Another piece of survey evidence regarding current and future supply chain shocks comes from new research by the consulting firm Deloitte, conducted in collaboration with the Federation of German Industries and the International Service Logistics Association. Their survey, titled 'Supply Chain Pulse Check' (Deloitte 2023), reveals that over half of the supply chain managers from over 120 German manufacturing enterprises surveyed report a strong to very strong impact on their performance due to supply chain disruptions. A significant majority – 60% – believe that these disruptions present an even larger problem for the manufacturing sector as a whole. Illustrating the gravity of these supply chain issues – and their potential to worsen – nearly half of the respondents expressed current concerns about a slight to significant increase in the risk of full or partial supply chain failure. These concerned respondents outnumbered those who held the opposite view. Notably, small to medium-sized enterprises indicated a higher level of concern about supply chain disruption and failure compared to large companies.

Regarding expectations for future shocks, the survey findings were not optimistic. Almost 60% of respondents anticipate no change in the current trend of supply chain disruption. Half of them expect a slight improvement in the medium to long term, but over one-fifth foresee the problems becoming slightly or significantly worse in the future.

A similar exercise was undertaken by the Business Continuity Institute (BCI) involving over 200 supply chain risk management professionals in 58 nations and across 17 sectors (BCI 2023). The study found that reported supply chain disruptions are still more than twice as high as pre-pandemic levels. Almost half of respondents experienced these issues with their closest suppliers at tier-1, while a quarter saw more disruptions with their tier-2 suppliers. Both of these figures exceeded those in the last report in 2021.[13] Interestingly, the respondents expected cyberattacks and data breaches to be the top threat to supply chains over the coming years.

III.D. How Firms Manage the Risks

Another way of gauging whether supply chain shocks will continue is to look at the behavior of the economic actors who are closest to the problems, namely firms that manage extensive supply chains. Here we review some of the key recent firm-level adjustments undertaken as firms revamp their approaches to sourcing inputs and producing output.[14] There

[13] The 2023 report notes that these high results are partly due to more analysis being undertaken on the performance analytics of supply chains.

[14] Initiatives to support supply chain resilience are also being undertaken at the intra- and inter-country level. For instance, on 31 May 2023, 14 partners of the Indo-Pacific Economic Framework for Prosperity (IPEF) concluded negotiations on a Supply Chain Agreement aimed at "increasing the resilience, efficiency, productivity, sustainability, transparency, diversification, security, fairness, and inclusivity of their supply chains" (US Department of State 2023). To achieve this aim, the IPEF has established three bodies. The Supply Chain Council will develop sector-specific action plans for critical sectors and key goods. The Supply Chain Response Network will establish an emergency communications channel for partners to seek support during supply chain disruptions/facilitate information sharing during a crisis. The Labor Rights Advisory board will support the

is no database on adjustments that firms are making in response to recent supply chain events, but the importance of the issue has led several organizations to undertake surveys that reveal important trends. The McKinsey Global Institute (MGI), for example, surveyed over 100 supply chain managers across various industries (MGI 2022). The survey results showed that 90% of respondents aimed to further increase resilience, and almost three-quarters of them planned to spend more on pro-resilience initiatives.

The most common change in supply chain risk management involved a rise in the level of inventories of inputs and final goods (80% increased inventories in 2022). Diversification of suppliers was almost as popular. Over 80% of respondents switched to dual sourcing. A trend towards shortening distances was also common. The survey for 2022 reported that 44% of firms were regionalizing their supply networks to counter disruptions. This was an increase from the 25% figure reported in the survey for 2021. Improving the transparency of supply chains was an important part of resiliency efforts, with 67% of respondents saying they set up digital dashboards to provide information on their supply chains. Likewise, the survey found that most companies invested more in digital supply chain management tools to allow them to plan better and react to shocks. The measures were reported as working. More than 83% of the firms stated that their new resilience tactics helped them minimize the impact of 2022 supply chain disruptions.

A second set of insights into firms' current adaptations comes from the World Economic Forum's "Resiliency Compass" (WEF 2021). The analytic framework synthesizes contributions from over 400 supply chain experts spanning the corporate, governmental, and academic sectors. As such, the compass serves as an indicative representation of how the private sector is strategically approaching and mitigating supply chain shocks. The Compass has eight 'compass points' grouped into demand-, supply-, and logistic-oriented.

The first strategy suggests that firms adopt a simplified product portfolio, thereby affording companies the capacity to substitute components and adapt production methodologies when encountering obstacles. The second strategy recommends a customer-centric orientation, utilizing technological advances to integrate consumer preferences into the product design stage. In terms of adaptability, adaptive information systems allow firms to recalibrate manufacturing schedules to accommodate evolving customer requirements. It also helps to

promotion of labor rights throughout IPEF members' supply chains.

anticipate demand shocks. These are the main recommendations on the demand side.

The third compass point emphasizes the critical need for transparency with respect to the financial viability of suppliers all along the supply chain. The goal here is to anticipate shocks emanating from firm-level bankruptcies or financial turmoil. The fourth strategic dimension focuses on fostering a diversified customer distribution network. Here the objective is to establish a distribution infrastructure with sufficient versatility to meet demand through multiple avenues, encompassing wholesalers, retailers, and digital sales channels. These are supply-side strategies; the next strategy addresses shocks that may arise from the connectivity links in the supply chain.

The fifth recommendation prescribes the establishment of agile and transparent logistics systems, enhancing visibility, control, and coordination across the supply chain by means of collaborative engagement with logistics partners. The subsequent strategy accentuates the centrality of manufacturing adaptability, advocating for a resiliently designed production network with an emphasis on flexibility in both locational and product aspects. The seventh strategy encourages a balanced approach to supplier diversity, harmonizing the need for risk mitigation with the imperatives of forming strategic partnerships with key suppliers. The last compass point underscores the necessity for advanced planning methodologies, promoting investments in emergent technologies and analytical tools to enable real-time responsiveness to market shifts in both supply and demand across the entire operational continuum.

A third notable contribution to the MGI and WEF findings is from the Deloitte 'Supply Chain Pulse Check' survey described above (Deloitte 2023). Importantly, the survey results in terms of measures that German companies are either currently implementing or have in their strategic planning to enhance supply chain resilience exhibit a high degree of concordance with those of the MGI survey. Specifically, the report finds that respondents are augmenting inventory levels and embracing additional logistical routes to mitigate the disruptions presently affecting supply chains. A notable 43% have already initiated these tactics, while an additional fifth are in the preparatory stages. Moreover, 38% of respondents are actively working to diversify their supplier base.

Taken together, the evidence from these surveys clearly suggests that firms do not believe that supply chain disruptions are a thing of the past.

IV. The Taming: Robustness and Resiliency in Supply Chains

As mentioned in Section I, many of the policy-driven efforts to address supply chain disruptions are based on the firm-centric business approach pioneered by Michael Porter (Porter 1985). Thus far, we have aimed to illustrate how economists, utilizing IO analysis, can enhance our comprehension of supply-chain interconnectedness. In this section, we explore how the broader, more macroeconomic perspective of the economic approach to supply chains can offer insights that could be valuable in formulating policies to reduce, avoid, or mitigate supply chain disruptions.

We start with a critical distinction that is pervasive in the logistics and supply chain management literature (Brandon-Jones et al. 2014), but largely absent from the recent economic literature (Miroudot 2020a is a notable exception), namely underscoring the difference between robustness and resiliency when it comes to supply chain risk management.

IV.A. Adjusting to Risk: Robustness Versus Resilience

Businesses and governments have always been aware of the potential risks of disruption. As the surveys discussed in the previous section showed, firms have put into place adaptive strategies that draw from two vital concepts: robustness and resiliency (Brandon-Jones et al. 2014). These words have very similar meanings in English and in fact are sometimes used interchangeably or in tandem in the public discourse surrounding supply chains. To clarify, we start with an example that helps spotlight the differences. The example concerns strategies to address the challenges created by electric power outages.

Most households and businesses understand that the power will occasionally go out and embrace pro-resilience strategies such that they are minimally affected when outages occur. Otherwise stated, they know the shock will hit and they know operations will be disrupted, but they arrange things to reduce the disruptions and bounce back quickly after the disruption subsides.

In contrast, most large hospitals adopt very different strategies, namely pro-robustness strategies (FEMA 2019). They have multiple alternative electricity sources including batteries and generators to ensure that they can continue operating despite the power outage. In a nutshell, the goal of robustness is to have backups that allow the show to go on whilst the disruption is occurring. The goal of resiliency is to get the show back on the road as soon as possible, minimizing a business's "time to recovery" (Simchi-Levi et al. 2014, Simchi-Levi 2015). At one level of abstraction, both seek to reduce the duration of production disruptions, but for robust production systems, the duration is zero.

ROBUSTNESS VERSUS RESILIENCE

A supply chain is robust when it continues to operate despite shocks. This is often achieved by engineering supply chains to include fail-safes, redundancies, and geo-diversified supply sources, along with maintaining appropriate inventories of critical inputs. On the sourcing front, robustness signifies cultivating a diversified array of suppliers poised to deliver identical inputs, thereby immunizing the business process against disruptions originating from a single supplier. Within the company's own production sphere, robustness entails maintaining multiple manufacturing sites for in-house inputs and finishing of final goods. In all scenarios, amassing substantial inventory levels and buffer stocks throughout the supply chain, as well as relying on standardized inputs from multiple suppliers, enhances robustness (Sánez and Revilla 2014). As the survey data discussed in Section III reveal, the strategy of stockpiling more inventories resonates with the majority of manufacturing firms in their response to the pandemic.

Resilience relates to the system's capacity for rapid recovery post-crisis, and as such it is a more dynamic concept. The goal is for the supply chain to bounce back from disruptions in a manner that is both efficient and expedient. The essence of resilience lies in flexibility and adaptability, which could take the form of swiftly switching suppliers, adjusting production schedules on the fly, or tweaking products as required (Martins de Sá et al. 2019, Miroudot 2020b).

Robustness and resilience are not binary options. They are two sides of the same coin in the risk management world. For instance, relying on standardized inputs in a production process (a robustness strategy) could also be a resilience strategy insofar as it would allow flexibility and adaptability in the face of a shock. To summarize, a robust supply chain offers a buffer that can soak up a certain degree of disruption without significant operational impact, buying the system time to respond. In tandem with this, resilience enables the system to adapt, recover, and thus minimize long-term negative impacts.

TRADE-OFFS IN BUILDING ROBUSTNESS AND RESILIENCE

Building robustness and resiliency into supply chains involves distinct sets of strategies.

When the shocks come from the supply side, this requires some form of redundancy. This could manifest in a broad and geo-diversified portfolio of suppliers for inputs, multiple production sites, or large inventories. Setting up and maintaining these redundancies necessitates higher immediate operational costs. Indeed, it can be expensive to manage relationships with many suppliers, especially when the input requires extensive checking and certification for quality and fits with the rest of the production process. Further, the spreading out of orders among multiple suppliers may dilute buying power and elevate costs associated with contract supervision and enforcement.

As mentioned, one of the most direct means of establishing robustness is to hold substantial inventories of parts and components, but this can be expensive and even impractical (for example if warehouse space is not available). One example was the well-anticipated, post-Brexit uncertainty that British carmakers faced when the end of their frictionless trade with the EU was looming, but they did not really know how well the new system would work. Holding inventory was an obvious idea, but the problem lay in the scale of the challenge. Today's cars are made up of tens of thousands of parts, ranging from nuts and bolts to engines, transmissions, and electronics. Beyond the financial costs of maintaining extensive inventories, the logistical challenge of storing such a wide range of components is formidable.

Moreover, when it comes to highly specialized parts and components, the costs of ensuring that these products meet quality standards and integrate smoothly into the existing production process can make it prohibitively expensive to engage with many suppliers. In such cases, the buyer may have to strive for resiliency rather than robustness. This is why single-sourcing and long-term partnerships often emerge as risk management tactics. While such a strategy might compromise robustness if the supplier encounters risks, the benefits include avoiding the sunk costs of switching suppliers, and securing investments from the existing supplier in facilities and practices that can abbreviate disruptions. Even though a serious shock to a single supplier may disrupt overall production, the buyer may choose to put plans in place for quick recovery.

Constructing resilience could involve fostering the ability to adjust production schedules, and modify products as required (Miroudot 2020b). As resilience is likely to involve actions that were not anticipated, off-contract trust among suppliers and buyers (or direct control via ownership) is important in boosting resilience (Martins de Sá et al. 2019; Dubey et al. 2017;

Bode et al. 2011). In the extreme, resiliency may require buyers to functionally control the suppliers, or at least maintain long-term relationships that foster sufficient trust. As usual as it is in economics, the choice is not between risk diversification and reliance on lower-cost, higher-quality inputs; it's about finding the right balance. The extra costs today of diversification must be weighed against the expected future benefits of having a supply chain that can carry on in the face of shocks. The possibility that public authorities may have a different evaluation of the trade-off is a key justification for supply chain policy.

IV.B. Do We Need Policy? The Wedge Between Private and Public Risk Evaluation

Baldwin and Freeman (2022) introduce an analogy to discuss the public-private evaluation of supply chain risk. They base this analogy on the standard portfolio model, highlighting the potential existence of a Pigouvian wedge between public and private risk evaluations. While firms are concerned about risks, they also value cost savings, which may involve relying on fragile 'just in time' supply chains. A societal appraisal of this trade-off might prioritize risk reduction or consider the externalities arising from the cost-saving initiatives by firms.

EXAMPLES OF PUBLIC-PRIVATE WEDGES IN RISK PERCEPTION

What are some examples of these public-private wedges? It is useful to turn to two industries where most governments actively intervene to make the supply chain more resilient: the food sector and the military equipment sector. In the food sector, farmers use various tactics to protect crops from shocks like pests, diseases, and uncertain rainfall. But while the cost to an individual farmer of a bad harvest is limited, a general failure may lead to famine and social upheaval. The wedge here exists because market prices do not fully reflect the social cost of famine, or hunger. The classic pro-resiliency government policies in this case are to subsidize production, control prices, and maintain sufficient inventories.

In the realm of military equipment, many governments systematically favor domestic production. While there may be protectionist motives behind such policies, one rationale focuses on the ability to maintain armament production even during wartime. The societal risks associated with a lack of military equipment are even harder to quantify than those in food production. An inability to produce arms and military supplies could lead to loss of territory, loss of life, or loss of sovereignty. In a general way, it is natural to assume that private firms, who are primarily profit-driven, will underappreciate these social costs of supply disruptions.

Protection of basic metal sectors, and steel in particular, is often justified on national security grounds.

In both the farms and arms cases, we could say that governments knew that the private sector cared about risk, but their caring was mostly limited to their bottom line while the societal cost of major disruptions could be much higher, encompassing factors like social upheaval and loss of life. Another way to rationalize the near-universal intervention of governments in the farms and arms supply chains is the prospect theory of Kahneman and Tversky (1973). This theory explains how humans tend to act in seemingly irrational ways in the face of uncertainty. It stresses the role of present-biased reference points, pervasive loss aversion, and the importance of framing effects.

In the financial sector as well, governments seldom entrust risk management entirely to private entities. The justifications for the interventions are wide-ranging, but many are rooted in information asymmetry, inadequate information, or some agents' inability to process information correctly. These range from investor protection and transparency rules to market stability policies.

Elements of the justifications from these three examples are clear in the recent spate of risk-management policies put forth by the Biden Administration (White House 2021). The Executive Order asserts that structural weaknesses in American supply chains have long existed, but it took the COVID pandemic to bring them into the mainstream. The document notes the need to "prioritize strengthening critical supply chains and revitalizing the US industrial base." The Biden administration's policy has focused on four sectors that share some of the characteristics of the food and military supply sectors, on the one hand, and the financial sector on the other. These are: semiconductors and advanced packaging; large-capacity batteries; critical minerals and materials; and pharmaceuticals and related active pharmaceutical ingredients.

Semiconductors and batteries have become critical to the production of many manufactured goods, including a wide range of armaments. The justification for public policies may thus be linked to those that apply to the arms industry. The advanced packaging concern came to light when the US rollout of COVID vaccines was delayed by a lack of glass vials with the necessary quality. The inclusion of pharmaceuticals can be thought of as akin to the justifications for intervention in the food sector. While individual producers are aware of risks, and take active measures to reduce them, they do not fully incorporate the social costs of severe supply shortages into their business models.

THE WEDGE DIAGRAM

Every economics student learns that policy interventions can potentially rectify market outcomes when there is a wedge between the private and public evaluation of the consequences. This happens when there is a gap between private and societal risk assessments, or when collective action challenges cause information gaps, leading firms to operate without full information. Figure 4.1, presented in Baldwin and Freeman (2022), illustrates these points.

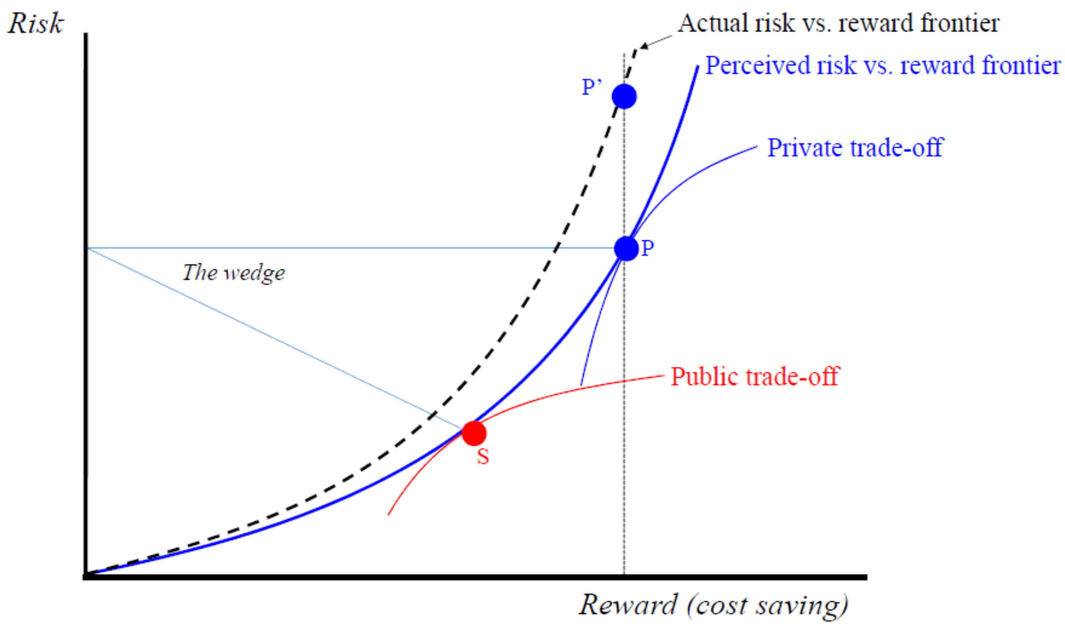
The central idea that the diagram illustrates concerns a trade-off between cost savings and risk. That is, firms can lower costs by centralizing production in cost-efficient areas. However, this cost-saving approach increases the risk associated with centralizing all production. The diagram illustrates this trade-off with the upward-sloped curve that is bowed outward. This curve simply asserts that additional cost savings come with heightened risks. The risk-reward frontier curves upward, indicating that the risks-versus-cost-savings trade-off steepens as costs fall.

The downward-curving private-evaluation curve is an indifference curve. It reflects the trade-off firms face on the economic side. That is to say, while firms dislike risk, they like cost savings. The 'Private trade-off' curve depicts this relative evaluation. This indifference curve is bowed downward since we assume that firms worry more about risk as the risk level rises. In other words, firms need ever greater increments in cost savings to justify ever higher risk.

The diagram also plots the public evaluation of the risk-reward trade-off, which is drawn assuming that the government is more risk-averse than private firms. Various reasons – such as those discussed above in the farms and arms sectors – can justify this discrepancy. For instance, companies might overlook the broader macroeconomic ramifications of supply disruptions, focusing solely on their own performance. Disruptions at one supply chain point could result in losses downstream, but upstream entities might not factor in these potential losses.

As mentioned, such a gap between public and private risk perceptions is easy to envision in critical sectors like medical supplies, food production, or other "strategic" inputs like semiconductors. As illustrated, private entities, in the pursuit of their private goals, might be willing to embrace more risk (as shown by point P) than would be socially optimal (point S). This difference between societal and private preferences creates a discernible gap and hence a market inefficiency. This inefficiency, in turn, suggests a rationale for policy interventions that reduce supply chain risk.

Figure 4.1: The risk-reward wedge and public policy.



Source: Figure 1 in Baldwin and Freeman (2022). Note: This diagram is entitled "The public-private wedge analysis of GSC risks" in Baldwin and Freeman (2022).

The diagram also sheds light on another possible reason for policy action: information problems. As discussed in Section II, firms often have incomplete information about their supply chains due to their sheer complexity. The MGI's estimate that GM had over 18,000 suppliers serves as a telling example; monitoring all these suppliers would be nearly impossible (Lund et al. 2020). Moreover, the same study found that nearly half of the companies that were assessed either had no detailed information on their supply chains or only had information on their immediate, tier-1 suppliers. With such a complex web of suppliers, it's hardly surprising that firms may inadvertently expose themselves to more risks than they assume. In other words, the actual risk landscape might be far more perilous than perceived, leading firms to make choices that unknowingly expose them to undue risks.

V. Concluding remarks

Our paper looks at the three fundamental elements of supply chain disruptions: the links that create the possibility of disruption; the shocks that create the disruptions; and measures aimed at taming or avoiding the disruptions. Here in the concluding remarks we put forward some conjectures on the implications of our discussion of the three elements.

Starting with the links element, a core message of our paper is that the US exposure to foreign supply chains is much bigger than it appears at face value, but it is not that big on the macro level. There are two distinct points in this bigger-but-not-big finding.

First, by any measure, the US buys at least 80% of all industrial inputs from domestic sources. Thus, at an aggregate level, its foreign exposure is hardly alarming. However, while this may be reassuring, it is important to note that supply chain disruptions rarely occur at the macro level. The 80% figure was not relevant when the US auto sector shuttered factories due to a lack of semiconductors, or when buying home office electronics became problematic due to a demand surge and logistic snarls. This observation serves to provide some perspective on the recent public debate on foreign supply chains. Concerns about foreign exposure should be directed to particular products, not US manufacturing as a whole (more on this below). This is our conjecture as to what the ‘not big’ part of our results means. The ‘bigger’ part of bigger-but-not-big suggests a very different conjecture.

US supply chain exposure to some foreign suppliers is much higher than it appears to be using standard trade statistics. We calculate that this is especially true for China. By any measure, China is the US’ largest supplier of industrial inputs. But taking account of the Chinese inputs into all the inputs that American manufacturers buy from other foreign suppliers – what we call look through exposure – we see that US exposure to China is almost four times larger than it appears to be at face value.[15] A second aspect of hidden exposure arises from the fact that China’s dominance of the US’ imports of industrial inputs came rather suddenly. This might help explain why the basic point was not brought to the fore until recently.

Combining the two points from our ‘links’ results, in conjunction with the fact that all major economies are also highly reliant on Chinese inputs to their inputs[16] – suggests that an

[15] The same hidden exposure point holds for Taiwan and Korea. Their look-through exposure is 3.5 times larger. For Japan the figure is 3.1. Nonetheless, these countries have a much smaller absolute face value and look through exposure overall.

[16] While not explored in depth in this paper, our look through measure also tells us that it is not just the US which is heavily dependent on China for industrial supplies. Baldwin, Freeman, and Theodorakopoulos 2022, for example, showed that every major manufacturing nation in the world sourced at least 2% of their industrial intermediates from China.

across-the-board decoupling of the US and Chinese manufacturing sectors is unlikely to be cheap, quick, or even feasible. More research is needed to quantify this point, but recent studies all point to the fact that a US-China decoupling is likely to be very damaging economically to the US and the world as a whole (Góes and Bekkers 2021; Freund et al 2023; Métivier et al. 2023; Aiyar et al. 2023).

Moreover, taking the face value versus look through distinction to heart suggests that the latter measure is more relevant in assessing whether policies aimed at reducing US exposure to Chinese manufacturing will have their desired effect. For instance, simply substituting away from imports from China to, say, Vietnam may do little to reduce the look-through dependence on Chinese production if the Vietnamese exports to the US depend on Chinese inputs. This important point is made empirically by Alfaro and Chor (2023).

Turning to the second element of supply chain disruptions, the shocks, our discussion suggests that the US is facing a new reality when it comes to supply chain shocks. We argue that the nature of shocks has shifted. While idiosyncratic shocks continue to produce challenges for manufacturers around the world, many of the recent and likely future shocks will be systemic. Here idiosyncratic shocks are those that are isolated and limited in scope, while systemic shocks have impacts that affect multiple sectors and regions and may be long lasting. In addition to these two types of shocks, we underscore that the source of supply chain shocks can be either demand-driven, supply-driven, or affect connectivity – and that these three categories are often interconnected.

While there is no way to predict future shocks – and in particular those that are systemic in nature – evidence gathered from surveys of supply chain risk managers coupled with the costly, long-lasting adjustments that firms are making to their supply chain organization, is evidence that the nature of shocks has shifted. These surveys highlighted three central sources of future shocks: climate change, geo-economic tensions, and accidental and malicious digital disruptions.

Laying our findings on shocks end-to-end with our findings on links leads to a very clear policy message. Concerns about supply chain disruptions should not be overblown, but they should be taken seriously since they are likely to be with us for many years to come.

The final element of our paper concerns policies that are aimed at reducing the impact of supply chain disruptions. As an essential background to policy considerations, we highlighted here the need to think hard about rationales for public policy interventions. A second bit of essential background that we touched upon is the non-trivial distinction between robustness and resiliency in supply chains, which is taken as critical in supply chain risk management research. The need for a policy intervention rationale if market failures are present is clear, but the nature of the rationale is different in supply chain management than it is in the traditional situation that focuses on Pigouvian wedges.

Because firms actively choose the risk level of their supply chains (to the extent that they have visibility of their suppliers and suppliers' suppliers), any public policy intervention should be based on the presence of a public-private wedge in the tradeoff between cost-savings and disruption risk. Given the vast diversity in supply chains, we argued this point by analogy, drawing attention to sectors where most nations have chosen to interfere with the private sector's optimal combination of low-cost sourcing and concentration of supply chain risk. In the farms and arms sectors, for example, governments have long implemented expensive policy interventions to encourage domestic production and diversified sources. In these sectors, the public-private wedge arises from many underlying factors, but often they involve the fact that serious disruptions can create largescale societal problems. As the private sector has little incentive to fully internalize such problems, it is easy to imagine that the wedge is large in these sectors.

Do the sectors that have recently been the focus of government supply chain policy fit this bill? In the US, Europe, and Asia, semiconductors seem to have slipped into the same category as farms and arms in the sense that governments around the world have decided that they cannot rely solely on the private sector to control supply chain risks. In the US, the Biden administration has also put some pharmaceutical products, as well as large-capacity batteries into the farms and arms category. Without detailed simulations of the economic and social costs of disruptions in these products, it is impossible to comment precisely on the merit of these governmental choices. But, given the lack of incentives for firms to consider the broader societal costs of extreme events, it is easy to think that there are wedges that would justify intervention in these sectors.

V.A. Directions for Future Research

It is plain that there is much, much more that could be done to shed light on the exposure of US supply chains to future shocks. One direction would be to explore the use of granular data, such as firm-specific transaction-level data and/or fine-grained geographic data.[17] In particular, it would be very helpful to have more disaggregated ICIO tables at the country and industry dimensions to gain a deeper understanding of supply chain vulnerabilities and the propagation of disruptions in further detail. It would also be useful to more fully document how supply-chain exposure became so concentrated geographically. Adding econometric investigation would be also an important contribution. The OECD, for example, has used some of the look-through measures we developed in our earlier work to demonstrate that they provide a robust empirical accounting for the transmission of shocks than do face value measures (Schwellnus, Haramboure, and Samek 2023a, 2023b). The last point we mention is the extension of the entire face value versus look through distinction to an evaluation of the exposure of US manufacturing sectors on the sales side, that is to say the exporting side.

[17] To be sure, additional measures of supply chain exposure are being developed, in particular using product-level data. For instance, concerned primarily with the possibility of supply disruptions, European Commission (2021) and Arjona, Connell, and Herghelegiu. (2023) recently proposed a methodology for measuring the EU's strategic dependencies and vulnerabilities at the detailed product-level which relies upon relies on the computation and use of three indicators relating to the concentration of EU imports from non-EU sources, the importance of non-EU imports in total demand, and the substitutability of non-EU imports with EU production.

References

Aiyar, Mr Shekhar, Mr Jiaqian Chen, Christian Ebeke, Mr Christian H. Ebeke, Mr Roberto Garcia-Saltos, Tryggvi Gudmundsson, Ms Anna Ilyina et al. *Geo-economic fragmentation and the future of multilateralism*. International Monetary Fund, 2023.

Alfaro, Laura, and Davin Chor. *Global Supply Chains: The Looming "Great Reallocation"*. Jackson Hole Symposium August 2023.

Antràs, Pol. 2021. *De-Globalisation? Global Value Chains in the Post-COVID-19 Age*. 2021 ECB Forum: "Central Banks in a Shifting World" Conference Proceedings. 2021.

Antràs, Pol, and Davin Chor. "Global value chains." *Handbook of international economics* 5 (2022): 297-376.

Arjona, Román, William Connell, and Cristina Herghelegiu. *An enhanced methodology to monitor the EU's strategic dependencies and vulnerabilities*. No. WP2023/14. Chief Economist Team at the Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, 2023.

Bai, Xiwen, Ming Xu, Tingting Han, and Dong Yang. "Quantifying the impact of pandemic lockdown policies on global port calls." *Transportation Research Part A: Policy and Practice* 164 (2022): 224-241.

Baldwin, Richard. *Globalization: The great unbundling(s)*. Helsinki: Economic Council of Finland, 2006.

Baldwin, Richard. *The great convergence: Information technology and the new globalization*. Harvard University Press, 2016

Baldwin, Richard. *The peak globalisation myth: Part 1*. VoxEU.org, 31 August 2022. https://cepr.org/voxeu/columns/peak-globalisation-myth-part-1.

Baldwin, Richard, and Rebecca Freeman. "Risks and global supply chains: What we know and what we need to know." *Annual Review of Economics* 14 (2022): 153-180.

Baldwin, Richard and Rebecca Freeman (2020a). *Supply chain contagion waves: thinking ahead on manufacturing 'contagion and reinfection' from the COVID concussion*. VoxEU.org, 1 April 2020. https://voxeu.org/article/covid-concussion-andsupply-chain-contagion-waves.

Baldwin, Richard, and Rebecca Freeman (2020b). *Trade conflict in the age of Covid-19.* VoxEU.org, 22 May 2020. https://voxeu.org/article/trade-conflict-age-covid-19.

Baldwin, Richard, Rebecca Freeman, and Angelos Theodorakopoulos. *Horses for courses: measuring foreign supply chain exposure*. NBER Working Paper No. 30525, 2022.

Baldwin, Richard, Rebecca Freeman, and Angelos Theodorakopoulos. "Deconstructing Deglobalization: The Future of Trade is in Intermediate Services." Asian Economic Policy Review 19(2023): 1-23.

Baqaee, David Rezza, and Emmanuel Farhi. "The macroeconomic impact of microeconomic shocks: Beyond Hulten's theorem." *Econometrica* 87, 4 (2019): 1155-1203.

Baqaee, David, and Elisa Rubbo. "Micro Propagation and Macro Aggregation," *Annual Review of Economics* 15(2023): 91-123.

Barber, Gregory. *Nuclear Power Plants Are Struggling to Stay Cool*. Wired.com, 21 July 2022. https://www.wired.com/story/nuclear-power-plants-struggling-to-stay-cool/.

BCI. *Supply chain resilience report 2021*. Business Continuity Institute, 2021. https://www.thebci.org/uploads/assets/e02a3e5f-82e5-4ff1-b8bc61de9657e9c8/BCI-0007h-Supply-Chain-Resilience-ReportLow-Singles.pdf..

Bode, Christoph, Stephan M. Wagner, Kenneth J. Petersen, and Lisa M. Ellram.

"Understanding responses to supply chain disruptions: Insights from information processing and resource dependence perspectives." *Academy of Management Journal* 54, no. 4 (2011): 833-856.

Boehm, Christoph E., Aaron Flaaen, and Nitya Pandalai-Nayar. "Input linkages and the transmission of shocks: Firm-level evidence from the 2011 Tōhoku earthquake." *Review of Economics and Statistics* 101, no. 1 (2019): 60-75.

Bonadio, Barthélémy, Zhen Huo, Andrei A. Levchenko, and Nitya Pandalai-Nayar. "Global supply chains in the pandemic." *Journal of International Economics* 133 (2021): 103534.

Bown, Chad P. 2017. *Trump's Attempted Takedown of the Global Trade Regime?* In: The Future of the Global Order Colloquium, The University of Pennsylvania, Fall 2017. https://global.upenn.edu/sites/default/files/go-trumps-attempted-bown.original.pdf.

Bown, Chad P. "The US–China trade war and Phase One agreement." Journal of Policy Modeling 43, no. 4 (2021): 805-843.

Bown, Chad P. and Melina Kolb. *Trump's Trade War Timeline: An Up-to-Date Guide*, Peterson Institute for International Economics. 1 June 2023 https://www.piie.com/sites/default/files/documents/trump-trade-war-timeline.pdf.

Brandon-Jones, Emma, Brian Squire, Chad W. Autry, and Kenneth J. Petersen. "A contingent resource-based perspective of supply chain resilience and robustness." *Journal of Supply Chain Management* 50, no. 3 (2014): 55-73.

Burt, Andrew. "The Digital World Is Changing Rapidly. Your Cybersecurity Needs to Keep Up." *Harvard Business Review*, 16 May 2023.

Carvalho, V. M. and Alireza Tahbaz-Salehi. "Production Networks: A Primer." *Annual Review of Economics* 11 (2019): 635–663

Carvalho, Vasco M., Makoto Nirei, Yukiko U. Saito, and Alireza Tahbaz-Salehi. "Supply chain disruptions: Evidence from the Great East Japan earthquake." *The Quarterly Journal of Economics* 136, no. 2 (2021): 1255-1321.

CEA. *Economic Report of the President*. Council of Economic Advisers. Washington, DC: U.S. Government Publishing Office, 2016. https://www.whitehouse.gov/wp-content/uploads/2021/07/2016-ERP.pdf.

Conconi, Paola, Glenn Magerman, and Afrola Plaku. "The gravity of intermediate goods." *Review of Industrial Organization* 57 (2020): 223-243.

Cui, Li. "China's Growing External Dependence." *Finance and Development, International Monetary Fund* 44, no. 3 (2007).

De Guindos, Luis. *The inflation outlook and monetary policy in the euro area*. Keynote speech at King's College London. 7 July 2023. https://www.ecb.europa.eu/press/key/date/2023/html/ecb.sp230707~8f8f9debc6.en.html.

Deloitte. *New risks for the supply chain and the industry location Germany: Supply Chain Pulse Check.* Deloitte, Spring 2023.

Drezner, Daniel W., Henry Farrell, and Abraham L. Newman, eds. *The uses and abuses of weaponized interdependence*. Brookings Institution Press, 2021.

Dubey, Rameshwar, Angappa Gunasekaran, Stephen J. Childe, Thanos Papadopoulos, Constantin Blome, and Zongwei Luo. "Antecedents of resilient supply chains: An empirical study." *IEEE Transactions on Engineering Management 66*, no. 1 (2017): 8-19.

Easterly, Jen and Tom Fanning. 2023. *The Attack on Colonial Pipeline: What We've Learned & What We've Done Over the Past Two Years*. U.S. Cybersecurity and Infrastructure

Security Agency blog. 7 May 2023. https://www.cisa.gov/news-events/news/attack-colonial-pipeline-what-weve-learned-what-weve-done-over-past-two-years.

Elliott, Matthew, and Benjamin Golub. “Networks and economic fragility.” *Annual Review of Economics* 14 (2022): 665-696.

Elliott, Matthew, Benjamin Golub, and Matthew V. Leduc. “Supply network formation and fragility.” *American Economic Review* 112, no. 8 (2022): 2701-2747.

European Commission. *Strategic dependencies and capacities*. Staff Working Document. 2021. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021SC0352.

European Council. *G7 Leaders' Statement on Economic Resilience and Economic Security*. 20 May 2023. https://www.consilium.europa.eu/en/press/press-releases/2023/05/20/g7-leaders-statement-on-economic-resilience-and-economic-security/.

Evenett, Simon J. "Chinese whispers: COVID-19, global supply chains in essential goods, and public policy." *Journal of International Business Policy* 3 (2020): 408-429.

Farrell, Henry, and Abraham L. Newman. "Weaponized interdependence: How global economic networks shape state coercion." *International Security* 44, no. 1 (2019): 42-79.

Feenstra, Robert C. *Offshoring in the global economy: microeconomic structure and macroeconomic implications*. MIT Press, 2010.

FEMA. *Healthcare Facilities and Power Outages: Guidance for State, Local, Tribal, Territorial, and Private Sector Partners*. Federal Emergency Management Agency. 2019.

Fort, Teresa C. “The Changing Firm and Country Boundaries of U.S. Manufacturers in Global Value Chains.” *Journal of Economic Perspectives*, 37, no. 3 (2023): 31-58.

Freund, Caroline, Aaditya Mattoo, Alen Mulabdic, and Michele Ruta. *Is US Trade Policy Reshaping Global Supply Chains?* Paper presented at the IMF Conference on Fragmentation and Reconfiguration of Global Value Chains, Washington DC, 23-24 May 2023.

Góes, Carlos and Eddy Bekkers. *The Impact of Geopolitical Conflicts on Trade, Growth, and Innovation*. World Bank Policy Research Working Paper No. 9719. 2021

Goldberg, Pinelopi K., and Tristan Reed. *Is the Global Economy Deglobalizing? And if so, why? And what is next?* NBER Working Paper No. 31115, 2023.

Grossman, Gene M., and Esteban Rossi-Hansberg. “Trading tasks: A simple theory of offshoring.” *American Economic Review* 98, no. 5 (2008): 1978-1997.

Grossman, Gene M., Elhanan Helpman, and Hugo Lhuillier. *Supply chain resilience: Should policy promote diversification or reshoring?*. NBER Working Paper No. 29330, 2021.

Guerrieri, Veronica, Guido Lorenzoni, Ludwig Straub, and Iván Werning. “Macroeconomic implications of COVID-19: Can negative supply shocks cause demand shortages?” *American Economic Review* 112, no. 5 (2022): 1437-1474.

Gurtu, Amulya and Jestin Johny. “Supply chain risk management: Literature review.” Risks 9, no. 1 (2021): 1-16.

Head, Keith, and Thierry Mayer. "Gravity equations: Workhorse, toolkit, and cookbook." In *Handbook of international economics*, vol. 4, pp. 131-195. Elsevier, 2014.

Helper, Susan and Evan Soltas. *Why the Pandemic Has Disrupted Supply Chains*. Council of Economic Advisors, White House, 17 June 2021. https://www.whitehouse.gov/cea/written-materials/2021/06/17/why-the-pandemic-has-disrupted-supply-chains/.

Houthakker, Hendrik S. “The Pareto distribution and the Cobb-Douglas production function in activity analysis.” *The Review of Economic Studies* 23, no. 1 (1955): 27-31.

ICC. *Trade report: A fragmenting world*. International Chamber of Commerce, 6 April 2023. https://iccwbo.org/news-publications/policies-reports/icc-2023-trade-report-a-fragmenting-world/.

Igan, Deniz, Phurichai Rungcharoenkitkul, and Koji Takahashi. *Global Supply Chain Disruptions: Evolution, Impact, Outlook*. BIS Bulletin No. 61, 28 September 2022.

Imbs, Jean M. and Laurent Pauwels. *Measuring Openness*. CEPR Press Discussion Paper No. 17230.

ITC. *Economic Impact of Section 232 and 301 Tariffs on U.S. Industries*. International Trade Commission Investigation No. 332–591, 2023.

Jones, Charles I. "The shape of production functions and the direction of technical change." *The Quarterly Journal of Economics* 120, no. 2 (2005): 517-549.

Tversky, Amos, and Daniel Kahneman. "Availability: A heuristic for judging frequency and probability." *Cognitive psychology* 5, no. 2 (1973): 207-232.

King, Mervyn, and John Kay. *Radical uncertainty: Decision-making for an unknowable future*. Hachette UK, 2020.Lund, Susan, James Manyika, Jonathan Woetzel, Ed Barriball, and Mekala Krishnan. *Risk, resilience, and rebalancing in global value chains.*McKinsey Global Institute, 6 August 2020. https://www.mckinsey.com/business-functions/operations/our-insights/risk-resilience-and-rebalancing-in-global-value-chains.pdf.

Martins de Sá, Marcelo, Priscila Laczynski de Souza Miguel, Renata Peregrino de Brito, and Susana Carla Farias Pereira. "Supply chain resilience: the whole is not the sum of the parts." *International Journal of Operations & Production Management* 40, no. 1 (2019): 92-115..

Métivier, Jeanne, Marc Bacchetta, Eddy Bekkers, and Robert Koopman. *International Trade Cooperation's Impact on the World Economy*." WTO Staff Working Papers Economic Research and Statistics Division, 2023.

MGI. *Taking the pulse of shifting supply chains*. McKinsey Global Institute, 2022. https://www.mckinsey.com/capabilities/operations/our-insights/taking-the-pulse-of-shifting-supply-chains.

Miroudot, Sébastien. "Reshaping the policy debate on the implications of COVID for global supply chains." *Journal of International Business Policy* 3 (2020a): 430-442.

Miroudot, Sébastien. "Resilience versus robustness in global value chains: Some policy implications." In Baldwin, Richard and Simon J. Evenett (eds), *COVID and trade policy: Why turning inward won't work* (2020b): 117-130.

Miroudot, S., R. Lanz and A. Ragoussis. *Trade in Intermediate Goods and Services*, OECD Trade Policy Papers, No. 93, 2009.

Moll, B., Schularick, M., and Zachmann, G. *The power of substitution: The great German gas debate in retrospect.* Paper prepared for Brookings Papers for Economic Activity Fall 2023 Conference, 2023.

Mourougane, Annabelle, Polina Knutsson, Rodrigo Pazos, Julia Schmidt, and Francesco Palermo. *Nowcasting trade in value added indicators.* OECD Statistics Working Papers, No. 2023/03, 2023.

NAS. *Chapter 4 - Case Study: Response to and Recovery from Superstorm Sandy.* In: Making U.S. Ports Resilient as Part of Extended Intermodal Supply Chains. National Academies of Sciences, Engineering, and Medicine. The National Academies Press, 2014.

NASA. *Panama Canal Traffic Backup*. NASA Earth Observatory, 18 August 2023. https://earthobservatory.nasa.gov/images/151778/panama-canal-traffic-

backup#:~:text=While%20some%20weather%2Drelated%20delays,waiting%20to%20make%20the%20transit.
OECD. OECD Inter-Country Input-Output Database, http://oe.cd/icio, 2021. Accessed on 03 August 2022.
OECD, OECD Inter-Country Input-Output Database, http://oe.cd/icio, 2022.
Porter, Michael E. *The Competitive Advantage: Creating and Sustaining Superior Performance*. NY: Free Press, 1985
Oberfield, Ezra, and Devesh Raval. "Micro data and macro technology *Econometrica* 89, no. 2 (2021): 703-732.
Sáenz, María Jesús, and Elena Revilla. "Creating more resilient supply chains." *MIT Sloan management review* (2014).
Schwellnus, Cyrille, Antton Haramboure, and Lea Samek. *Policies to strengthen the resilience of global value chains: Empirical evidence from the COVID-19 shock*. OECD Science, Technology and Industry Policy Papers, No. 141 (2023a).
Schwellnus, Cyrille, Antton Haramboure, Lea Samek, Ricardo Chiapin Pechansky, and Charles Cadestin. *Global value chain dependencies under the magnifying glass*. OECD Science, Technology and Industry Policy Papers, No. 142 (2023b).
Seneviratne, Sonia I., Xuebin Zhang, Muhammad Adnan, Wafae Badi, Claudine Dereczynski, Alejandro Di Luca, Sergio M. Vicente-Serrano, Michael Wehner, and Botao Zhou. *Chapter 11: weather and climate extreme events in a changing climate*. Intergovernmental Panel on Climate Change Sixth Assessment Report, 2021.
Simchi-Levi, David. "Find the weak link in your supply chain." *Harvard Business Review* (2015).
Simchi-Levi, David, William Schmidt, and Yehua Wei. "From superstorms to factory fires: Managing unpredictable supply chain disruptions." *Harvard Business Review* 92, no. 1-2 (2014): 96-101.
Tirschwell, Peter. 2022. *Container Shipping: Supply Chains Will Remain Disrupted Well into 2022*. S&P Global Market Intelligence, 4 April 2022. https://www.spglobal.com/marketintelligence/en/news-insights/research/container-shipping-supply-chains-will-remain-disrupted-well-into-2022.
Heiland, Inga, and Karen Helene Ulltveit-Moe. "An unintended crisis in sea transportation due to COVID restrictions." In Baldwin, Richard and Simon J. Evenett (eds), *COVID and trade policy: Why turning inward won't work* (2020):151-163.
UNEP. *Preventing the Next Pandemic: Zoonotic diseases and how to break the chain of transmission.* United Nations Environment Programme (2020)
US Department of State. *Press statement on the substantial conclusion of IPEF supply chain agreement negotiations.* 31 May 2023. US Embassy Jakarta Press Release https://id.usembassy.gov/press-statement-on-the-substantial-conclusion-of-ipef-supply-chain-agreement-negotiations/.
WEF, *The resiliency compass: Navigating global value chain disruption in an age of uncertainty*. World Economic Forum White Paper, July 2021. https://www3.weforum.org/docs/WEF_Navigating_Global_Value_Chains_Disruptions_2021.pdf.
WEF. *Navigating global disruption: Introducing the Global Value Chain Barometer*. World Economic Forum https://www.weforum.org/agenda/2023/01/davos23-global-value-chain-barometer/.

Wen, Yi. *China's Rapid Rise: From Backward Agrarian Society to Industrial Powerhouse in Just 35 Years*, St. Louis Fed blog, 11 April 2016. https://www.stlouisfed.org/publications/regional-economist/april-2016/chinas-rapid-rise-from-backward-agrarian-society-to-industrial-powerhouse-in-just-35-years.

White House. *Building resilient supply chains, revitalizing American manufacturing, and fostering broad-based growth. 100 day reviews under Executive Order 1407*, June 2021. https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf.

White House. *Fact Sheet: Biden-Harris Administration Announces New Initiative to Improve Supply Chain Data Flow*. White House Briefing Room Statements and Releases, March 2022. https://www.whitehouse.gov/briefing-room/statements-releases/2022/03/15/fact-sheet-biden-harris-administration-announces-new-initiative-to-improve-supply-chain-data-flow/.

WHO. WHO Director-General's opening remarks at the media briefing - 5 May 2023 (2023). https://www.who.int/news-room/speeches/item/who-director-general-s-opening-remarks-at-the-media-briefing---5-may-2023.

World Bank. *World development report 2020: Trading for development in the age of global value chains*. The World Bank, 2020a.

World Bank. *Global Value Chains and Economic Development: An Overview*. World Bank, 2020b.

York, Erica. *Tracking the Economic Impact of U.S. Tariffs and Retaliatory Actions.* Tax Foundation, Washington DC, 7 July, 2023.

VI. Appendix: Face Value Exposure

This appendix presents the face value exposure equivalent of Figure 2.3.

Figure A1: Face Value Exposure of US Sectors to Foreign Manufacturing Intermediate Inputs (%), 2018

	Vehicles	Machinery nec	Basic metals	Elec. Eq.	Oth. Transp. Eq.	Clothes	Fab. metal gds	Plastics	Oth. Manuf.	Wood	Chemical gds	Pharma	Paper gds	Electronics	Oth. non-metal gds	Food	Ref'd Petrol.	Manuf. avg.
China	1.2	1.5	.7	1.8	1.2	2	.8	1	1.2	.9	.7	.4	.8	1.5	.8	.3	0	1
Canada	1.1	.7	1.5	.9	.6	.3	.9	.5	.5	.9	.4	.2	.7	.2	.3	.3	.1	.6
Mexico	2	1.1	.9	1.1	.7	.3	.7	.3	.5	.3	.3	.1	.3	.6	.3	.2	0	.6
Japan	.9	.5	.3	.3	.5	.1	.2	.2	.2	.1	.2	.1	.1	.2	.1	.1	0	.2
Germany	.6	.5	.4	.3	.3	.2	.3	.3	.2	.1	.3	.4	.2	.1	.1	.1	0	.3
Korea	.4	.3	.2	.3	.2	.1	.2	.2	.1	.1	.2	.1	.1	.2	.1	0	0	.2
India	.1	.1	.1	.1	.1	.5	.1	.2	.2	.1	.1	.3	.1	0	.1	.1	0	.1
Taiwan	.1	.1	.1	.1	.2	.1	.1	.1	.1	0	.1	0	.1	.1	0	0	0	.1
Italy	.2	.2	.1	.1	.2	.1	.1	.1	.1	.1	.1	.1	.1	0	.1	0	0	.1
Brazil	.1	.1	.3	.1	.2	0	.2	.1	.1	.1	.1	0	.1	0	.1	0	0	.1
Ireland	0	0	0	0	0	.1	0	.2	.1	0	.2	1.6	.1	0	0	0	0	.2
France	.1	.1	.1	.1	.5	.1	.1	.1	.1	.1	.1	.1	.1	0	.1	0	0	.1
Russia	0	.1	.3	.1	.1	0	.2	.1	0	0	.1	0	0	0	0	0	.1	.1
UK	.2	.1	0	0	.2	0	0	.1	0	0	.1	.2	.1	0	0	0	0	.1
Switzerland	0	.1	0	.1	.1	0	0	.1	0	0	.1	.7	0	.1	0	0	0	.1
RoW	.9	1	1.5	1.2	1	1.1	1.1	.9	.9	.7	.8	1.1	.7	.6	.5	.5	.1	.9
Foreign	8.1	6.6	6.6	6.6	6	5.2	5.2	4.3	4.3	3.5	3.8	5.4	3.5	3.8	2.7	1.9	.5	4.6
USA	67.8	75.8	74.6	77.6	76.8	79.8	78	79.9	83	81.1	81.8	85.8	81.4	88.3	85.6	82.1	88.3	80.5

Source: Authors' elaboration based on 2021 OECD ICIO tables. Note: The numerator of the face value exposure is the technical coefficients of the **A** matrix, as described in Box I.B. In order to ease comparison with Figure 2.3, this is normalized with total manufactured intermediates across all sources (foreign and domestic) on a look-through basis. RoW stands for Rest of the World. Foreign is the sum of all foreign sources.