NBER WORKING PAPER SERIES

RISKS AND GLOBAL SUPPLY CHAINS: WHAT WE KNOW AND WHAT WE NEED TO KNOW

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Working Paper 29444
http://www.nber.org/papers/w29444

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
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October 2021

When citing this paper, please use the following: Baldwin R, Freeman R. 2022. Risks and Global Supply Chains: What We Know and What We Need to Know. Annu. Rev. Econ. 14: Submitted. DOI: 10.1146/annurev-economics-051420-113737. We are grateful to Sébastien Miroudot for helpful comments and conversations related to GSC measurement and indicator computation, and to Angelos Theodorakopoulos for useful suggestions and comments overall. Gene Grossman provided invaluable guidance and editor advice. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

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NBER Working Paper No. 29444
October 2021
JEL No. F10,F13,F14,F15,F23

ABSTRACT

Recent supply disruptions catapulted the issue of risk in global supply chains (GSCs) to the top of policy agendas and created the impression that shortages would have been less severe if GSCs were either shorter and more domestic, or more diversified. But is this right? We start our answer by reviewing studies that look at risks to and from GSCs, and how GSCs have recovered from past shocks. We then look at whether GSCs are too risky—starting with business research on how firms approach the cost-resiliency trade-off. We propose the risk-versus-reward framework from portfolio theory as a good way to evaluate whether anti-risk policy is justified. We then discuss how exposures to foreign shocks are measured and argue that exposure is higher than direct indicators imply. Finally, we consider the future of GSCs in the light of current policy proposals and advancing technology before pointing to the rich menu of topics for future research on the risk-GSC nexus.

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1 Introduction

In 2020, explosive growth in demand for Covid-19-related medical supplies teamed up with supply disruptions to produce sudden shortages of personal protective equipment (PPE), testing kits, and medical devices such as respirators. At the same time, shutdowns in the US and European economies generated startling disruptions in the availability of everyday goods ranging from vegetables and eggs to cleaning products and toilet paper. These shocks struck at a time when trade flows had already been stagnating for years, and a political backlash against globalization was well under way (Antràs, 2021; Colantone et al., 2021). These shortages generated headlines which in turn thrust supply disruptions to both the front pages of newspapers and the top of policymakers' agendas. As global supply chain (GSC) pioneer Gary Gereffi put it: "Global supply chains have suddenly become a new buzzword in public consciousness" (Gereffi, 2020).

The buzzword brought with it a narrative that emphasizes risks and vulnerabilities—as illustrated by the title of a widely read March 2020 article in The Atlantic: "The Modern Supply Chain is Snapping: The Coronavirus Exposes the Fragility of an Economy Built on Outsourcing and Just-in-time Inventory" (O'Leary, 2020). Corresponding policy proposals took one of two routes. They either stressed making GSCs shorter and more domestic (through reshoring activity) or more diversified (Javorcik, 2020; Lin and Lanng, 2020).

This risk narrative is new, but internationalized production is far from new. Archaeologists found stone tools in the Levant made of volcanic rock quarried in Turkey and long-distance trade in tin was common during the Bronze Age (Berger et al., 2019). GSCs waxed and waned in the intervening years, but by the 1960s, intermediate goods dominated trade—accounting for over two-thirds of world exports (Johnson and Noguera, 2012*a*; Sturgeon and Memedović, 2010). The importance of GSCs was highlighted in early empirics (Grubel and Lloyd, 1975) and theory (Batra and Casas, 1973; Woodland, 1977). Their importance was underscored every decade since, with important theory contributions starting in the 1980s (Deardorff, 1998; Dixit and Grossman, 1982; Ethier, 1982; Helpman, 1984; Sanyal and Jones, 1982) and the 1990s (Francois, 1990; Hummels et al., 1998; Jones and Kierzkowski, 1990; Venables, 1999).

GSCs have also long been on the policy agenda. The US and Canada, for instance, signed the 1965 Auto Pact to underpin supply chain trade in vehicles. Europe's Common Market, implemented by 1968, went far beyond duty-free trade by embracing the 'four freedoms' (goods, services, workers, and capital) with the explicit intent of internationalizing manufacturing at the European level. At this stage, GSC narratives in the profession and policy circles were largely supportive. Manufactured exports were growing faster than manufacturing GDP, which in turn was growing faster than total GDP; GSCs were associated with industrialization and growth in G7 nations.

The literature and narrative changed course as the nature and impact of GSCs changed from around

1990 (Baldwin, 2006; Taglioni and Winkler, 2016). From the 1980s, Information and Communication Technology (ICT) made it feasible to unbundle manufacturing processes and offshore some stages to low-wage nations. This intensified trade in intermediates and spurred foreign direct investment (FDI), but the big change came from elsewhere. The ICT revolution enabled firms in G7 countries to send their firm-specific know-how to low-wage nations along with the offshored production stages to ensure quality and compatibility. This created a new high-tech-low-wage combination in manufacturing that transformed the competitive landscape (Baldwin, 2016). The result was the industrialization of a handful of emerging market economies at a historically unprecedented pace—far faster, e.g., than that of the so-called 'newly industrializing economies' Hong Kong, Singapore, South Korea, and Taiwan (Birdsall et al., 1993). The G7's share of world manufacturing fell from two-thirds in 1990 to less than half in 2010, with all of the G7 share-loss offset by share-gains for a handful of rapid industrializers—above all China.

The new impact called for fresh theorizing related to vertical specialization, production fragmentation, multinationals, and other facets of firm behavior in the 2000s (Antràs et al., 2006; Antràs and Helpman, 2004; Grossman and Rossi-Hansberg, 2008; Hummels et al., 2001; Kohler, 2004; Markusen, 2005; Yi, 2003), and more recently (Antràs and Chor, 2013; Antras et al., 2017; Baldwin, 2013; Baldwin and Venables, 2013; Bernard and Moxnes, 2018; Grossman and Helpman, 2021; Halpern et al., 2015; Johnson and Noguera, 2012*b*; Koopman et al., 2010, 2014). Further, the heightened policy importance resulted in massive data efforts on the part of governments, international organizations, and academia to produce new databases and measurement approaches (such as value-added trade) for many countries and sectors (Lenzen et al., 2012; OECD, 2019; Timmer et al., 2016, 2015; see Johnson, 2018 and Antràs and Chor, 2021 for an overview of data sources).

Yet, while the academic debate gravitated towards the productivity and welfare-enhancing benefits of GSCs to international firms (Amiti and Konings, 2007; Grossman and Rossi-Hansberg, 2008; Halpern et al., 2015; Topalova and Khandelwal, 2011) as well as firms along the domestic supply chain (Blalock and Veloso, 2007; Merlevede and Theodorakopoulos, 2021), the GSC narrative in policy circles tended towards highlighting risks rather than rewards (Bown, 2021). Hints of a shift appeared when Autor et al. (2013) found large and persistent adjustment costs in the US caused by trade with low-wage nations—with much of this being within GSCs.[1] This widely publicized finding, together with social dislocation in the US driven by technological changes (Autor, 2015), were factors behind the sharp change in US trade policy from 2016—especially with respect to China (Rodrik, 2018).

Such phenomena have also been linked to a wave of populism in the US and Europe, with several influential studies documenting that perceivable rises in trade exposure, and associated distributional consequences, can be tied to a political backlash against globalization (Colantone et al., 2021; Rodrik,

[1] These results were later echoed by Pierce and Schott (2016) and Amiti et al. (2019), among others.

2021).[2] More generally, Eichengreen (2018) argues that globalization and declining US manufacturing were important in driving the 2016 US presidential election, which broadly highlighted an anti-trade and anti-GSC rhetoric. On top of this, a series of widely covered natural disasters in the 2010s contributed to the view that nations were too reliant on foreign suppliers (Abe and Ye, 2013).

The culmination of shocks made many realize how far interdependence had gone in many industrial goods. Evenett and Fritz (2021) survey various policies that governments have used to reduce import dependence on a single nation—usually China. These include changing tariffs/border barriers to redirect investment, providing local production subsidies, and adopting policies on FDI such as limits on foreign ownership or outright bans. The Japanese Economy Minister, for instance, said in June 2020: "We have become dependent on China. We need to make supply chains more robust and diverse, broadening our supply sources and increasing domestic production."[3] The European Union embraced a new policy of "strategic autonomy" with the French Economy Minister explaining: "We should develop strategic stockpiling, geographic diversification of supply and, where appropriate, increase European production capacity, to build up our autonomy in these strategic areas" (Le Maire, 2020).

Against this backdrop, the rest of the paper follows a simple progression. Section 2 covers the connections between risk and GSCs across several dimensions—risks to GSCs, from GSCs, and how GSCs recover from shocks. Section 3 turns to the question of whether today's GSCs are too risky. It starts with an overview of the business research on how firms deal with risk and their approaches to resiliency, before suggesting that the risk-versus-reward framework from portfolio theory provides a convenient approach to thinking about whether policy is justified. The section discusses how exposure to foreign shocks is measured before showing evidence that exposure may be higher than direct indicators imply. The final segment of Section 3 reviews policies which can affect GSC resiliency. Section 4 swings the spotlight to the issue of what the future of GSCs might look like given the policies under discussion and the impact of digital technology (digitech). We close with concluding remarks and suggestions for future research.

2 Global supply chain risks

Risk in a stock portfolio is easily defined, measured, and controlled since the shocks (price changes) and impact (wealth changes) are clear. Not so with supply chains. GSCs vary considerably by industry, country, product characteristics, position in the chain, the strategies of the companies, and by distribution channels (Cattaneo et al., 2010). This section considers the nature of risk in GSCs and the literature that has dealt with it.

[2]See Autor et al. (2020); Che et al. (2020), and Blanchard et al. (2019) for the US; Dippel et al. (2021) and Dauth et al. (2014) for Germany; Caselli et al. (2021) for Italy; Colantone and Stanig (2018) for the UK; and Colantone and Stanig (2019) for Western Europe.

[3]Cited in Evenett and Fritz (2021).

2.1 Risks to GSCs

GSCs are composed of firms which sell to each other and final customers. These firms face risks. As Miroudot (2020*c*) points out, some risks are exogenous supply and demand shocks; some come from other firms. Supply shocks include classic disruptions such as natural disasters, cyber-attacks, labor strikes, bankruptcy of suppliers, and industrial accidents; as well as disruptions from broader sources such as trade and industrial policy changes, and political instability. On the demand side, firms face risks stemming from damage to product and company reputation, customer bankruptcy, entry of new competitors, policies restricting market access, macroeconomic crises, and exchange rate volatility. Transportation disruptions can be put in a separate category since they are both very frequent and not associated exclusively with supply or demand. Moreover, transportation is part of the service sector, and thus potentially subject to different shocks than goods. This was the case during the pandemic since services tend to be more labor intensive and often involve unavoidable face-to-face contact. Restrictions on crew changes on container ships in Singapore, for instance, proved massively disruptive to global shipping in 2020 (Heiland and Ulltveit-Moe, 2020).

In normal times, GSC shocks tend to be geographically and/or sectorally concentrated in terms of direct impact. The 2011 Tōhoku earthquake in Japan (Carvalho et al., 2021) and flooding in Thailand (Haraguchi and Lall, 2015) are classic examples. Barrot and Sauvagnat (2016) reinforce this message for a wide range of natural disasters by demonstrating sizable drops in sales growth of affected firms' direct customers.[4] More recently, the pandemic and Brexit have spawned much broader shocks. As Gereffi (2020) put it: "The COVID-19 pandemic has rapidly become one of the most significant disruptive events in modern times." The Business Continuity Institute (BCI) Supply Chain Resilience Report 2021, which surveyed 173 firms in 62 countries, found that over a quarter of firms experienced ten or more disruptions in 2020, while the figure was under 5% in 2019. Firms blamed Covid-19 for most of the rise, although Europe-based firms also pointed to the implementation of Brexit as an important source of shocks (BCI, 2021).

2.2 Risks from GSCs

All production structures entail risk, but sourcing inputs from abroad exposes domestic activity to foreign shocks. What risks emanate from this? The literature has focused on three aspects of this question: the costs and effects of delinking; the propagation of micro into macro shocks; and whether GSCs amplify the trade impact of macro shocks.

Eppinger et al. (2021) use a multi-sector quantitative trade model with domestic and international supply chain linkages in the spirit of Caliendo and Parro (2015) to simulate the impact of full decou-

[4]While less prevalent, literature has also documented the international transmission of natural disaster shocks. For example, Boehm et al. (2019) document how the 2011 Tōhoku earthquake in Japan disrupted production of US-based affiliates of Japanese multinationals.

pling. As in Antràs and Chor (2018), they allow different trade costs for intermediate inputs and final goods, so they can shut down GSCs. They establish a counterfactual without GSCs (no intermediates trade) and find that national GDPs are lower by 3% to 70% compared to the baseline, depending upon the nation in question. They look at shock transmissions with and without GSCs by considering a China-only supply disruption that lowers Chinese GDP by 30%. With GSCs, the shock produces heterogeneous welfare effects ranging from small positive effects in some nations (which benefit from trade diversion) to -1% in Russia. The same shock without GSCs produces smaller effects for most cases but magnified losses for some large nations (France, Germany, and Japan). However, even economies that gain in the no-GSC case are worse off than they would be in the shock with-GSCs case. The welfare loss from shutting down GSCs outweigh the gain from the shock-shielding effect by an order of magnitude.

Relatedly, Bonadio et al. (2020) empirically examine the international transmission of GSC shocks due to the Covid pandemic using a multi-sector model with input-output linkages. Simulating a global lockdown as a contraction in labor supply, the authors estimate that roughly one quarter of GDP declines across 64 countries is attributed to GSC-related shock transmission. Nonetheless, they argue that severing GSCs will not make countries more resilient to such shocks; rather the renationalization of production will concentrate risk to the domestic economy.

Do GSCs magnify micro shocks into macro fluctuations? A recent *Annual Review of Economics* article focuses exactly on this question (Carvalho and Tahbaz-Salehi, 2019), so we can be brief. To set the scene, consider an economy with no intermediate goods like the Krugman (1980) model of trade. Shocks, say productivity shocks, to any one firm have vanishingly small effects on aggregate outcome since firms are small. Adding in input-output linkages provides a channel for shock propagation. If an intermediate supplier suffers a negative productivity shock, the resulting price rise worsens productivity for its customers and thus propagates through the supply chain. In this way, a micro shock can produce macro fluctuations in certain settings (Acemoglu et al., 2012; Carvalho and Gabaix, 2013; Gabaix, 2011). More broadly, networked production in the presence of nominal rigidities can magnify the welfare costs of inflation, alter the slope of the Phillips curve, and change the impact of monetary policy. This literature is mostly set in a closed economy environment, but the extension to GSCs is straightforward.

A separate line of thought follows up the opposite reasoning by looking at how GSCs could be a source of shock diversification rather than magnification. Seminal work by Caselli et al. (2020), for instance, shows that specialization (due, inter alia, to participation in GCSs) tends to increase vulnerability to sector shocks, but cross-border diversification of suppliers and buyers tends to reduce it. They ground this result in theory[5] and, using a quantitative trade model, argue that in recent

[5]In the theoretical model, trade partner diversification tends to decrease volatility, although this depends on the variance-covariance of shocks across partners. Whether specialization increases or decreases volatility depends on the

decades the later has prevailed for most countries since the 1970s.

D'Aguanno et al. (2021) buttresses these conclusions by showing that the relationship between GSCs and volatility is ambiguous in theory and insignificant in the data. Taking a simulation approach, the authors show that policy barriers to foreign intermediates reduce GSC integration and productivity while having an ambiguous effect on income volatility. The conclusion is that a blanket reduction in supply chain integration can be economically costly while not significantly reducing economic volatility. The study goes on to look at the impact of reshoring and finds that it increases aggregate volatility by reducing source diversification. By contrast, policies that encourage diversification of foreign suppliers lowers volatility by reducing the exposure to individual economies.

The last planetary disruption of GSCs—the so-called Great Trade Collapse (Baldwin, 2009)—was sparked by a macroeconomic shock (the Global Financial Crisis). The trade collapse was the steepest in recorded history and the deepest since the Great Depression. The drop was sudden, severe, and synchronized. Imports and exports of all WTO members plummeted simultaneously and trade growth turned negative in all product categories. Most remarkably, the ratio of trade-to-GDP dropped far more than it had in previous recessions. Contemporary studies hypothesized that GSCs played an important role in this (Bems et al., 2010, 2011), however subsequent empirical work concluded that the main cause was a synchronized collapse in demand for trade-intensive durable goods (Bems et al., 2013).

Further, various studies have highlighted that GSCs helped attenuate the collapse. Antràs (2021) notes that due to the "sticky" nature of supply chain trade, most of the adjustment was short-term and on the intensive margin. This story was echoed by Bricongne et al. (2012) and Behrens et al. (2013) who show using detailed French and Belgian microdata, respectively, that intensive margin effects dominated and that firms' involvement in GSCs played a minor role in the collapse.[6]

2.3 Recovering from shocks: Resilience versus robustness

When it comes to responding to shocks, the business literature distinguishes between supply chain 'resilience' and supply chain 'robustness'. "Resilience is widely defined as the ability of organizations and supply chains to plan for, respond to, and recover from disruptions in a timely and cost-effective manner" (Martins de Sá et al., 2019). In contrast, robustness is the ability to maintain operations during a crisis (Brandon-Jones et al., 2014).

Building robustness typically requires establishing redundancy when it comes to external suppliers or multiple production sites for internally produced inputs. For example, in reaction to the shock

sector in which the country specializes, and how it correlates with sector and country shocks. The overall effect depends on the strengths of these two channels.

[6]Relatedly, Freund et al. (2021) provide evidence that intermediate imports in auto and electronics sectors were significantly less affected by the Tōhoku earthquake in Japan compared to final goods imports, suggesting that GSC-links are difficult to untangle after a crisis.

from the 2011 Tōhoku earthquake in Japan, Japanese carmakers diversified their suppliers (Inoue and Todō, 2017). Further, Sáenz and Revilla (2014) underscore that holding buffer stocks and relying on standardized inputs from multiple suppliers, designing the supply chain with an eye to the riskiness of locations and particular suppliers, and thorough resilience monitoring (assessing the time to recover for each type of supplier) can help ensure a resilient GSC in the face of shocks.

A key trade-off in both resilience and robustness involves diversification of risks versus lower cost and higher quality inputs, which tend to be localized in markets with niche expertise. For some products like surgical masks, there is little extra cost in diversifying suppliers since the technology is simple and not subject to enormous scale economies. Advanced semiconductors, by contrast, are so scale- and technology-intensive that there are only a few suppliers in the world. Moreover, customization unavoidably ties manufacturers to a particular supplier and often to a particular plant. In such cases, robustness is not an option, and the business narrative has focused on concrete strategies to determine a company's "time to recovery" or "time to survive" (Simchi-Levi, 2015; Simchi-Levi et al., 2014). Further, resilience involves working closely with the supplier and creating mutual trust (Bode et al., 2011; Dubey et al., 2017; Martins de Sá et al., 2019). There is evidence, for instance, that supplier diversification slows recovery from supply disruptions while long-term relationships speed recovery (Alfaro and Chen, 2012; Jain et al., 2017).

3 Are GSCs too risky?

Risk is certainly a recurrent theme in contemporary GSC studies. As the World Economic Forum (WEF, 2021) puts it: "the increasing frequency of supply-driven disruptions—ranging from global pandemics and the climate crisis to cyber threats and geopolitical tensions—combined with an ever-intensifying set of demand-driven disruptions—including the rise of new consumer channels, pent-up demand and a fragmented reopening of the global economy—will continue to destabilize global value chains."

Javorcik (2020) argues that the combination of trade-policy shocks in the 2010s and the pandemic has forced a rethinking of GVCs: "current events will force businesses to re-engineer their global value chains ... the pandemic has exposed weaknesses inherent in a system that requires all of its parts to work like clockwork." As mentioned, governments around the world are reevaluating the merits of GSCs in, inter alia, medical supplies and semiconductors.

The implicit assumption is that the current state of foreign input reliance is too risky, but is this just press-release-politics reacting to current events? For instance, a thoughtful report from Bank of England economists, D'Aguanno et al. (2021), caution against interventions that are not clearly targeted to address well-understood market failures and externalities. This begs the question—when it comes to risk, how high is too high from a policy perspective?

Before answering this question from an economist's perspective, we consider how business scholars approach the age-old issue of GSC risk. Having followed the matter for decades, Miroudot (2020*b*) points out that some of today's policies are disconnected from the conclusions of the supply chain literature.

3.1 How firms manage risk

Firms have always sought to manage risks in their supply chains. The scholarly literature on this appears mostly in management, operations research, international business, and logistics journals. These scholars seek to capture the vast heterogeneity of the realities facing firms in different nations, sectors, and positions in GSCs. While the studies can appear (to economists) to oscillate between anecdotes and frustratingly vague conceptualizations, the key insights are nevertheless important and can be used to better inform pro-resilience policy.

In a recent review of the business literature on supply chain resilience, Kamalahmadi and Parast (2016) discuss the vast heterogeneity in approaches, terminology, and emphasis. To organize the contributions, they use the fourfold principle of Christopher and Peck (2004): supply chain reengineering, collaboration, agility, and supply chain risk management (SCRM) culture. Reengineering aims to boost resilience while keeping cost optimization and customer satisfaction in mind by increasing flexibility and/or redundancy in the supply chain. The need to boost knowledge about suppliers and to consider their resiliency is important. The view of flexibility and redundancy as an alternative pro-resiliency option permeates this literature.

The collaboration principle notes that risk management in a highly interconnected GSC cannot even be properly examined without cooperation among firms in the GSC. Collaboration has many facets, but emphasis on trust and information sharing are common. Agility, the third principle, is the ability of a GSC to adapt rapidly to shocks. The most often mentioned pro-agility factors are visibility and velocity. Making rapid decisions about a disrupted supply chain demands extensive knowledge of the whole system and the status of its elements (visibility). Velocity refers to the pace at which the GSC can be reconfigured; this involves intra-firm and inter-firm aspects. The last principle, SCRM, refers to a corporate culture in which it is normal to expect people throughout the organization to develop responses to abnormal situations. The goal is to have all components of the system prepared to contribute to the development of rapid and effective solutions. The literature stresses leadership and innovation as important aspects of this.

In response to Covid-19 disruptions, the WEF and A.T. Kearney interviewed over 400 operations and supply chain executives to develop an updated framework for resilience building. The result is a 'resiliency compass' (WEF, 2021) which organizes eight pro-resilience strategies into demand-facing and supply-facing pillars. The demand-side action works first with the design of individual products and a product portfolio to foster interchangeability of inputs and production arrangements. The

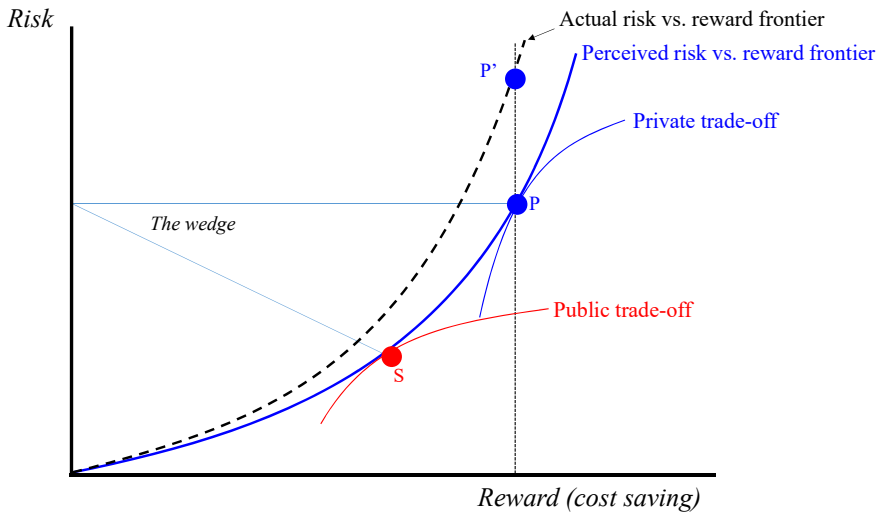
second and third pillars stress increases in engagement with customers in light of possible disruptions as well as boosting inventories and keeping cash buffers. The last is to diversify distribution channels including wholesalers, retailers, distributors, and direct online sales.

The supply-side actions start with making logistic systems more visible and flexible by boosting control of and information on warehousing, inventory, and transportation. Here, cooperation with suppliers and customers is essential. Boosting the flexibility of manufacturing processes and/or creating redundancies is the second supply-side pillar. The third is creating trusting relationships with suppliers, which involves a balancing of diversifying sources while creating strategic partnerships with a few. Advanced planning is the last pillar. The study points in particular to the use of digitech and planning that spans the company's whole product portfolio, production facilities, logistics, and suppliers.

3.2 Do we need policy? The risk versus reward wedge diagram

This section conceptualizes the policy problem as a standard risk-reward trade-off where companies care about risks as well as the reward from cost savings, but social evaluation of the trade-off may put greater stress on the risk. Policy intervention may improve market outcomes when there is a Pigouvian wedge between private and social evaluations. The outcome may also be inefficient socially if a collective action problem creates information asymmetries that force companies to act without full information.

Figure 1: The public-private wedge analysis of GSC risks.



Source: Authors' illustration.

The trade-off between the risk that comes with GSCs (vertical axis) and the rewards (horizontal axis) is illustrated in Figure 1 (inspired by optimal portfolio analysis). Risk is assumed to increase as manufacturers concentrate production of a particular input in the single cheapest location. Diversification of sources reduces risk but at a diminishing rate. The indifference curve shapes reflect that

firms and society both would prefer less risk for any given level of reward, but the public cares relatively more about risk. This divergence, assumed here for illustration's sake, is clear in sectors such as banking where, in the past, government provided guarantees when the risk went wrong,[7] and in food production where atomistic producers underinvest in anti-famines actions. Its applicability to any particular GSC is an empirical matter, but it is easy to imagine that medical supplies share features of the public-private wedge in food production, as might other 'strategic' inputs such as semiconductors. The situation depicted has the public desiring a lower level of risk, point S, than the private sector, point P. This wedge between the public and private evaluation for risk is a clear market failure that could justify policy interventions.

Figure 1 shows a second possible justification for policy interventions. Real world GSCs are massively complex. Even large, sophisticated companies do not know all their suppliers and the suppliers of their suppliers. To drive this point home, we refer to a study by the McKinsey Global Institute (MGI) (Lund et al., 2020). MGI analyzed data on the number of publicly disclosed suppliers to 668 companies spanning a range of sectors and found that companies' first-tier suppliers make up only a small fraction of the full value chain network. For instance, General Motors was reported to have 856 direct (tier-1) suppliers, but over 18,000 tier-2 and below suppliers. With such a large network, it is easy to see how supply chain visibility can turn to supply chain opaqueness. While the MGI report focused primarily on large firms, the lack of firms' understanding of where they sit in their own supply chains can become exasperated for small and medium enterprises. Specifically, smaller companies might not have the financial or operational resources to examine their own supply chains. Even worse, purely domestic firms might not appreciate being part of a global network at all.

This lack of information about where their inputs are actually made can result in private misjudgments as to how risky a GSC actually is for firms of all sizes. The situation is shown as the actual risk-reward trade-off taking place above the perceived trade-off. Information problems are a classic source of intervention-justifying externalities. Since GSCs are interwoven and generally not fully contained within the boundaries of a single firm, information about them has public good features. It is costly to collect, cheap to share, and provides value to many. As we shall see, misperception of actual vulnerability is pervasive.

3.3 Measuring exposure

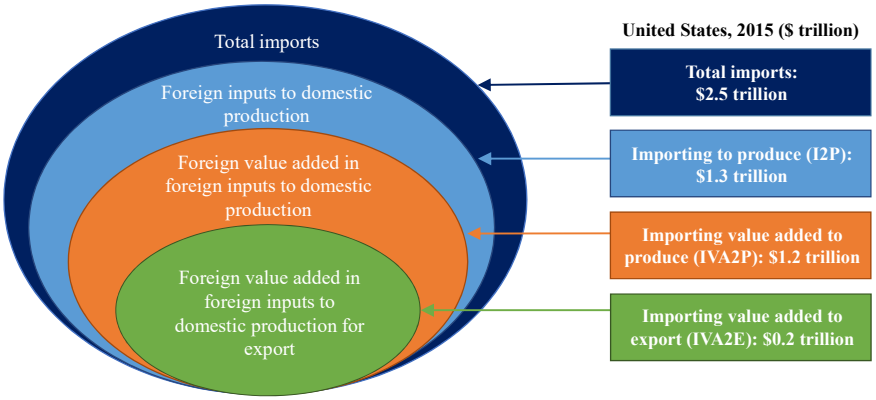
How exposed are domestic firms to GSC shocks? This simple question has many answers since there are numerous ways of gauging foreign exposure (Figure 2). Much of the 'risky GSCs' narrative focuses on foreign supply ruptures. The broadest direct indicator of such supply-side exposure is a nation's imports (typically represented as a share of GDP). A more pointed direct indicator focuses on imported

[7] We later discuss that the importance placed on risks to banking have now been integrated into regulatory frameworks.

intermediate inputs—in keeping with concerns about reliance on foreign suppliers of inputs to domestic production. This is the 'Importing to Produce' measure (or, I2P, Baldwin and Lopez-Gonzalez, 2015). This is typically scaled as a share of all purchased inputs, or as a share of gross production.

The next indicator draws upon the core logic of GSCs which tells us that the location of production and the location of the work can be very different. Using observed trade flows (called 'gross trade (GT)' in the GSC literature) may misrepresent the true location and overstate the magnitude of foreign exposure. A telling example is the famous iPhone case (De Backer and Miroudot, 2013) where assembly mostly happens in China—so import measures point to a massive dependence on China—but most of the value in an iPhone is added elsewhere. To capture this important production-versus-work distinction, many indicators eschew GT to focus on 'value-added trade (VT)', namely, the foreign value added embodied in GT flows. The resulting indicators look at the foreign value added in imported intermediates. These are usually scaled by domestic value added, or domestic production.

Figure 2: Types of sourcing-side GSC exposure



Source: Authors' illustration based on Baldwin and Lopez-Gonzalez (2015). Figures for United States in 2015 from OECD TiVA Database 2018.

To fix ideas, observe that the difference between VT and GT is called 'double counting'. For instance, a component in a US-made auto may cross the US-Canada and US-Mexico borders several times as it moves its way down the internationalized production line. The value of the component is thus added several times to the GT flows while it is added only once to the VT flows. The ratio of VT to GT is the famous value added to gross exports, or VAX, ratio (Johnson and Noguera, 2012*a*) that is one of the principal indicators of a nation's involvement in GSCs.

Finally, some of the most widely used indicators, such as the 'Backward Participation' measure (introduced by Hummels et al., 2001, computed with international input-output tables in Koopman et al. 2010, and widely popularized by the OECD) provides yet a narrower definition. Focusing on VT that crosses a border at least twice, this indicator looks at the fraction of a country's imported foreign value added that is re-exported. In other words, this measure looks at 'importing to export'.

It can be seen as the exposure of a nation's exports to foreign ruptures affecting value added. This is shown as the smallest area in Figure 2. On the right-hand side of Figure 2 we list associated values for the US economy in 2015. As is evident, the numbers decrease drastically—by $2.3 trillion—as we move from the outermost to the innermost layer.

Two additional points are worth noting before turning to an overview of how the indicators are calculated from data, and a summary of what they tell us about GSC risks. First, we note that using VT data as opposed to GT data redresses two misrepresentations: the true magnitude of the exposure (VT instead of GT) and the true geographic location of the exposure. Since the relevant measure of foreign exposure is not independent of the type of foreign shock to which a nation is exposed, the indicators we focus on below deal with these separately.

Second, GSC shocks can originate from the demand as well as the supply side, so there are sales-side versions of all the aforementioned indicators. These are based on exports rather than imports, and they seek to capture the exposure of domestic production, or domestic work, to foreign market sales.

When measuring exposure to foreign supply shocks, the core question is: *Where are things made?* The answer comes at three levels. When a Ford rolls off the assembling line in Dearborn Michigan, we can say it was made in Dearborn. This is the first-level truth, but it is not the whole truth. The second level recognizes that the Dearborn plant buys inputs from other sectors located at home and abroad. Tracing the first-level production location of inputs gives us the second-level answer; this provides a directly observable dependence on foreign inputs, or I2P in Figure 2. The I2P measure is directly observable from standard trade databases, and this has many merits, but I2P is not the whole truth either because purchased foreign inputs also use inputs. The third-level answer, the whole truth of foreign input reliance, takes account of the infinite sequence of all the inputs into all the inputs. This can be found with the help of a global input-output matrix and a single line of matrix algebra. The calculation details have been discussed at length many times, so we provide only a line sketch of the issues.[8]

The logical departure point is the well-known usage-identity for production. This states that production is used as intermediate inputs into production, or as final goods that are consumed, invested, or exported. With matrix notation, this identity for every sector can be compactly written as: $\boldsymbol{X} = \boldsymbol{AX} + \boldsymbol{F}$, where $\boldsymbol{X}$ is the vector of gross production by each sector (if there are n sectors, $\boldsymbol{X}$ is an $n \times 1$ vector), $\boldsymbol{F}$ is the corresponding $n \times 1$ vector of final usage, and $\boldsymbol{A}$ is a standard matrix of input-output coefficients that shows the inputs from each sector needed to produce a unit of output in each sector (thus it is an $n \times n$ square matrix). In other words, $\boldsymbol{AX}$ is the intermediate usage and $\boldsymbol{F}$ is the final usage. In this literature, $\boldsymbol{X}$ is usually called 'gross production' to distinguish it from

[8]See Miller and Blair (2009) for an overview of input-output foundations, Johnson (2018) for a review of GSC measures and Baldwin and Freeman (2021) for details on GT-based indicators.

'net production', i.e., production minus the output used up as intermediate inputs.

Since the world is a closed economy, the concepts apply equally to a world with one nation and a world with many nations. If there are n sectors in each of m countries, the vectors are $nm \times 1$, and $\boldsymbol{A}$ is $nm \times nm$. Traditionally, subscripts are used to track the origin sector and nation, and the destination sector and nation, but these are unnecessary for the level of discussion here.

Note that $\boldsymbol{X}$ gives the first-level answer, i.e., where things are made, and $\boldsymbol{AX}$ gives the second-level answer, i.e., the source of directly purchased inputs. To get the third-level answer, i.e., the total foreign input reliance, we must take account of the inputs' inputs with a line of linear algebra. Solving the identity for $\boldsymbol{X}$ yields $\boldsymbol{X} = \boldsymbol{LF}$, where $\boldsymbol{L}$ is the Leontief inverse, namely, $\boldsymbol{L} = (\boldsymbol{I} - \boldsymbol{A})^{-1}$. Importantly, this expression allows us to solve for the infinite sequence of inputs' inputs.

To fix ideas as to what $\boldsymbol{L}$ tells us, suppose we wanted to identify all the production necessary to produce one dollar of final output in the first of the $n \times m$ sectors (sector 1 in nation 1). To this end, we set the first element of $\boldsymbol{F}$ to 1 and zero out all the others. Using $\boldsymbol{X} = \boldsymbol{LF}$, we see that this means that the first column of $\boldsymbol{L}$ gives us a list of how much production is needed from each sector in each nation to produce the single unit for the sector under study. A moment's reflection reveals that this provides the third-level answer to all where-is-the-production-done questions; it tells us how exposed sector 1 in nation 1 is to the production of all the sectors in the world. More generally, each column of $\boldsymbol{L}$ lists the production necessary to produce a unit of final output of the corresponding sectors.

3.3.1 GSC sourcing-side exposure: Levels and trends in the FIR index

Most of the risky-GSC discussion revolves around manufactured goods, so here we focus on exposure in the manufacturing sector. It is important to start with a bird's eye view—namely, the first-level answer to the where-are-things-manufactured question.

Figure 3*a* shows the world shares of the biggest four manufacturing producers (China, US, Japan, and Germany) from 2004-2018. China's rise jumps out as the dominant feature; its share tripled in 15 years and is now more than 10ppt above the number two world manufacturer (the US). Share gains must be matched with share losses and the steady decline of the other manufacturing giants' dominance in world manufacturing is the second most salient feature.

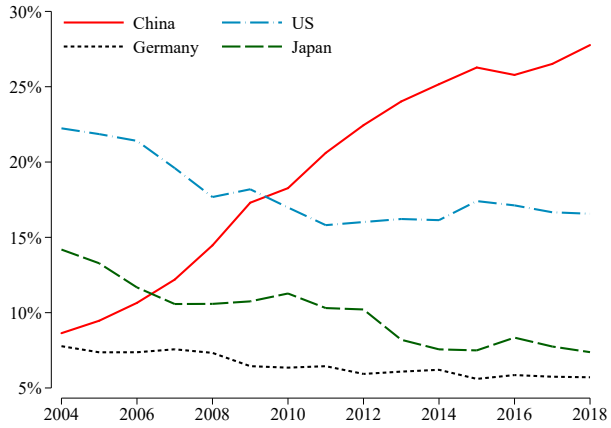
Figure 3*b* illustrates differences between the second- and third-level answers in the context of the US auto sector's reliance on Chinese inputs. Specifically, the observed foreign input reliance (FIR - Observed) line shows the US auto sector's intermediate imports from China as measured by standard trade data (which come from the relevant elements of $\boldsymbol{AX}$); the flows are shown as a share of its gross production. This indicator shows that the US auto sector gradually increased the share of its intermediate inputs purchased from China by a couple percentage points over ten years.[9] The total

[9] 2005 and 2015 are the earliest and latest years currently available in the latest (2018) version of the OECD ICIO tables, upon which we base this analysis.

foreign input reliance (FIR) line takes account of all Chinese inputs that are bought directly by the US auto makers, and indirectly—i.e., embedded in the inputs they buy from other US and foreign suppliers (which come from the relevant elements of $\boldsymbol{L}$).[10] For example, GM buys ultra-short-range radar technology from the Canadian company Alps Electric, so while GM has no direct reliance on China for this input it does have an indirect one, since Alps sources some of its inputs from China. Looking at Figure 3*b*, in 2015 the difference between the US auto sector's FIR-Observed and FIR with China amounted to roughly 14ppt.[11] Looking across all US manufacturing sectors' reliance on China, the average difference between FIR-Observed and FIR in 2015 was 7.6 ppt.

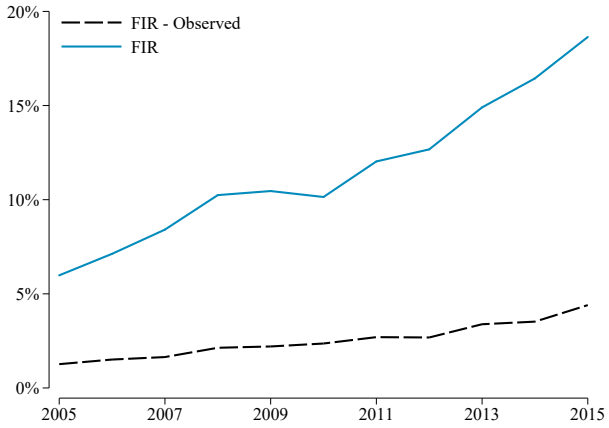
Figure 3: Global manufacturing shares and the difference between observed (FIR - Observed) and total Foreign Input Reliance (FIR)

(a) World manufacturing shares, top 4 nations, 2004-18



Source: Authors' computations based on data from the WB WDI database.

(b) Observed and total FIR of US motor vehicle sector on Chinese inputs



Source: Authors' computations based on data from the OECD ICIO database 2018.

Note that, in line with the Figure 2 schema, one could also map the full reliance measure on a VT, instead of a GT basis. This can be useful when considering exposures to shocks that affect value added rather than production. For instance, if the shock is due to a labor strike that affects only the value that is added in China, then a VT-based FIR indicator may be more appropriate. By contrast, if the shipping of key components from China were disrupted by, say, a natural disaster, the vulnerability is to the whole value of the shipment, i.e. the FIR that is based on GT. The general point is that there is no perfect indicator of GSC risk; the indicator used should be matched with the risk being evaluated (Baldwin and Freeman, 2021).

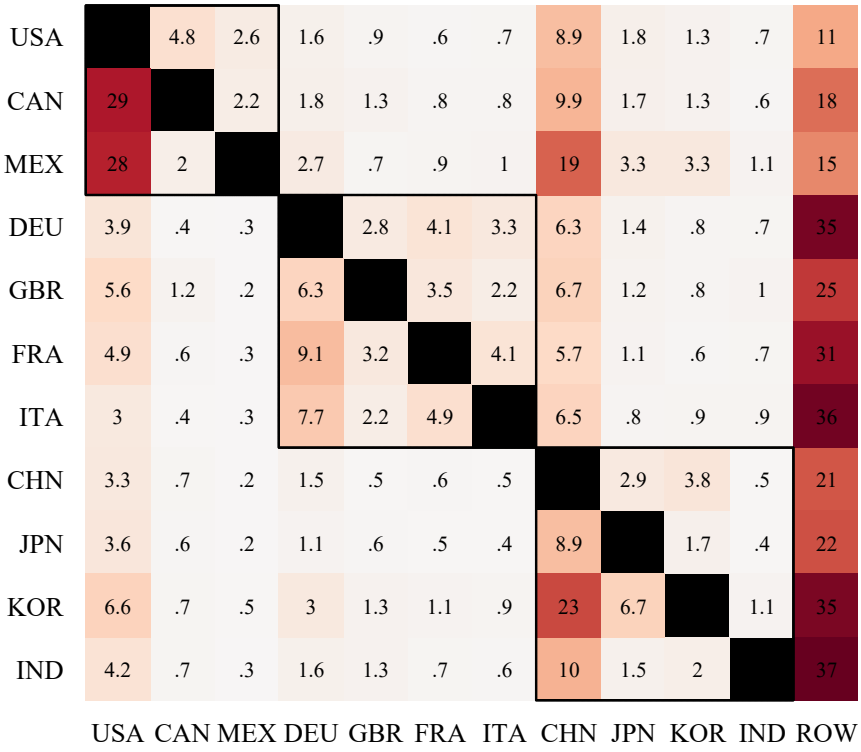
Returning to the GT-based FIR measures, it turns out that the increasing reliance on China's industrial inputs shown in Figure 3*b* is true more generally. Figure 4 shows an aggregate bilateral

[10] Similarly, Timmer et al. (2021) apply GT concepts in their computation of a supply chain fragmentation ratio.

[11] Note that, as many components cross borders multiple times, the measures involve some double counting which could be problematic for some applications, but not for measuring total exposure to foreign production shocks.

FIR measure for all G7 countries and other major manufacturing economies in 2015, and a 'Rest of World (ROW)' aggregate. The importing nations are listed down the rows and supplying nations across the columns. The numbers show the share of the row-nation's total manufacturing production that is made up of inputs from the column nation. For example, the 29 in the row for Canada (CAN) and column for the USA indicates that 29% of Canadian manufacturing production was made using inputs sourced directly and indirectly from the US.

Figure 4: Foreign input reliance (FIR, %): Row nations' reliance on inputs from column nation for manufacturing production, 2015



Notes: Colors indexed to share sizes; darker reds indicate higher FIR. Countries denoted by ISO-3 codes. ROW stands for rest of world. *Source:* Authors' computations based on OECD ICIO database 2018.

Importantly, these are not value-added numbers, but rather gross production numbers. As mentioned, this shows a given sourcing country's exposure to ruptures in origin nation production, say a medical lockdown of all Canadian manufacturing plants or surges in demand (e.g., increased orders of PPE). The colors are indexed to the share sizes, with darker reds indicating more exposure, or reliance. Since the indicator is based on production and GT, there is double counting, so the row sums need not equal 100.[12]

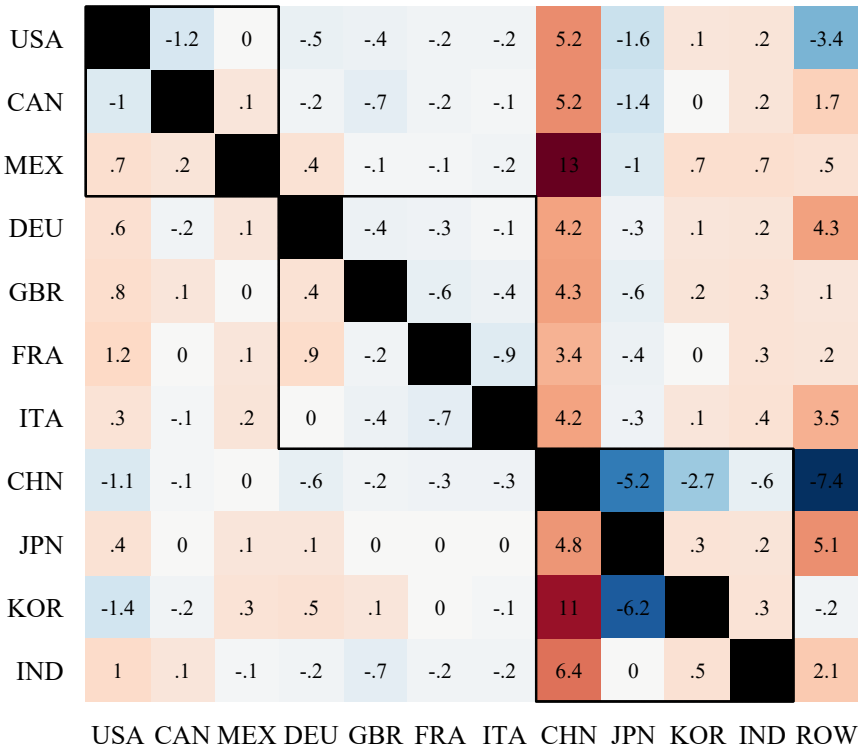
The regionalization of GSCs is plain. For example, what Baldwin (2008) called 'Factory Asia' is highlighted with the southeast box where the colors tend to be darker than in the off-block cells

[12]The matrix diagonal has been excluded, as we are interested here in foreign inputs. The diagonal term would show a nation's input reliance on itself—both in terms of direct domestic sourcing and indirect sourcing through the re-import of previously exported inputs.

of the matrix. Factory Europe is the middle box and Factory North America is the northwest box. The global importance of the US and China, but especially China, is shown by the fact that their columns are highlighted primarily in red. Otherwise put, the fact that the USA and CHN columns are relatively dark indicates that they are important suppliers of inputs to the manufacturing sectors of all nations. While America dominates Factory North America far more than China does in Factory Asia, it is remarkable that more than 5% of all countries' gross production relies on inputs from China. Further, note the asymmetry between the US manufacturing production's reliance on Chinese inputs, 8.9%, and China's manufacturing production's reliance on US inputs, 3.3%.

After seeing Figure 3*b*, it should come as no surprise that most of the numbers in the 2015 bilateral FIR matrix with respect to China are much larger in 2015 than they were in 2005. This point is shown in Figure 5, which displays the percentage point difference between FIR in 2015 and 2005 for each pair of nations. Red-shaded cells indicate FIR increases, while blue-shaded cells highlight FIR decreases.

Figure 5: Change in FIR (ppt): Row nations' reliance on inputs from column nation for manufacturing production, 2015 vs. 2005



Notes: Red-shaded cells indicate FIR increases; blue-shaded cells indicate FIR decreases. Countries denoted by ISO-3 codes. ROW stands for rest of world. *Source:* Authors' computations based on OECD ICIO database 2018.

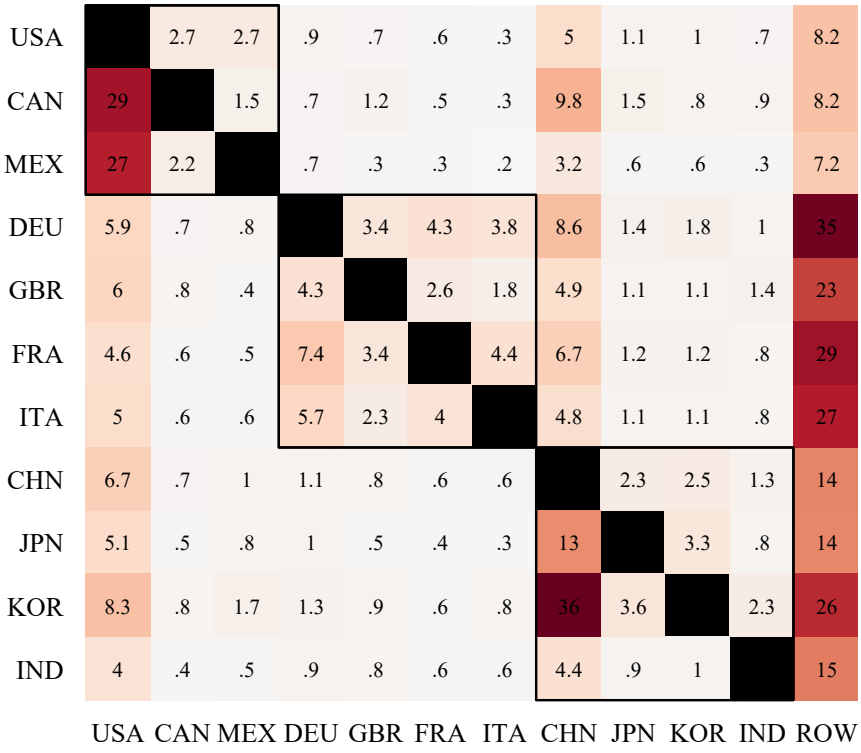
The figures in the China column are all positive with some of them in the double digits. The figures in the USA column are small, mostly, under 1ppt, and some are even negative. Most other entries are negative, although Germany's importance as a supplier has fallen less than Japan's. Given the broad trend documented in Figure 3*b*, which holds across manufacturing sectors, we conjecture

that the reliance of nations on Chinese inputs will have increased substantially between 2015 and today. More generally, the charts bring out the unique role of China in the evolution of GSCs; every major manufacturing nation's output is more reliant on Chinese inputs. Note also that every element in China's row is negative. This says that China reduced its reliance on imported inputs from every nation (as its rise as a manufacturing powerhouse allowed it to source more inputs from itself). We also see evidence of a de-regionalization of GSCs in North America and Europe due to the shift towards China as a source of industrial inputs.

3.3.2 GSC selling-side exposure: Levels and trends in the FMR index

Firms involved in GSCs face sales-side shocks as well as sourcing-side shocks. Just as the FIR index measures countries' total reliance on foreign production on the sourcing side, the Foreign Market Reliance (FMR) index measures countries' reliance on foreign markets on the sales side. That is, FMR is the bilateral dependence of a row nation on sales to a particular column nation. Since the indicator is based on sales measured by GT (instead of VT) concepts, there is also double counting involved. The double counting overstates reliance if considering a whole world shock, but it is useful in capturing the full exposure when thinking about single country and bilateral shocks.

Figure 6: Foreign Market Reliance (FMR, %): Row nations' total input sales to column nations' manufacturing sector, 2015

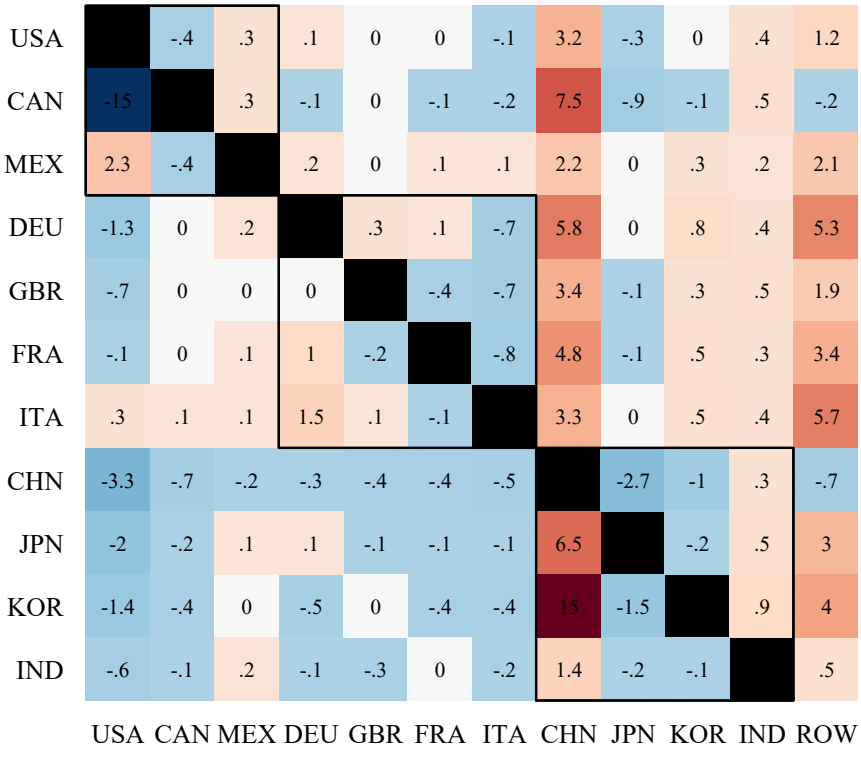


Notes: Colors indexed to share sizes; darker reds indicate higher FMR. Countries denoted by ISO-3 codes. ROW stands for rest of world. *Source:* Authors' computations based on OECD ICIO database 2018.

The FMR measure differs from FIR in that it relies upon the cost-accounting identity for production, instead of the use-accounting identity. This states that the value of gross production (i.e. sales) is equal to the cost of productive factors employed, plus the cost of intermediate goods used. With matrix notation, the cost-accounting identity for every sector is $\boldsymbol{X} = \boldsymbol{B'X} + \boldsymbol{V}$, where $\boldsymbol{V}$ is a $n \times 1$ vector of value added. The $\boldsymbol{B}$ matrix (commonly known as the 'allocation coefficients' matrix) is analogous to the $\boldsymbol{A}$ matrix, except that it represents the inputs from each sector scaled by the gross output of the *selling* (rather than the buying) sector. As such, $\boldsymbol{B'X}$ represents the destination of directly sold inputs. Solving for the gross output row vector, $\boldsymbol{X'}$, we get $\boldsymbol{X'} = \boldsymbol{V'}(\boldsymbol{I} - \boldsymbol{B})^{-1}$ where $\boldsymbol{G} = (\boldsymbol{I} - \boldsymbol{B})^{-1}$ is the less well-known but equally important Ghosh inverse matrix, which allows us to solve for the infinite sequence of input sales.

Figure 6 shows the numbers for the main manufacturing nations. Since trade among the main manufacturers is dominated by intra-industry trade, it is not surprising that Figure 6, which examines countries' bilateral FMR, resembles Figure 4. We see the regionalization of GSCs, and the dominance of China and the US. However, the US-China asymmetry is less marked and reversed since China's sales-side reliance on the US is 6.7% while that of the US on China's market is only 5%. The evolution of the FMR is again similar to that of FIR but the de-regionalization is less marked (Figure 7).

Figure 7: Change in FMR (ppt): Row nations' total input sales to column nations' manufacturing sector, 2015 vs. 2005



Notes: Red-shaded cells indicate FMR increases; blue-shaded cells indicate FMR decreases. Countries denoted by ISO-3 codes. ROW stands for rest of world. *Source:* Authors' computations based on OECD ICIO database 2018.

Having considered sourcing-side and selling-side exposure, it is natural to combine the FIR and FMR measures since both are scaled by manufacturing gross output. We call this sum the 'Total Foreign Reliance' (TFR) indicator. We exclude figures for brevity, but a visual examination when summing across the rows of Figure 5 and Figure 7 reveals a net aggregate decrease in China's TFR of roughly 29ppt, versus a net aggregate increase for virtually all other countries.[13]

3.4 What policies would enhance the resilience of GSCs?

Judging from much of the public discussion and the policies that governments have already announced, it seems that some governments and scholars are confident that they know how to make GSCs less risky. In particular, there is a dual rhetoric which has emerged. One general conclusion is that risk would be reduced by making GSCs shorter and more domestic. On the other hand, a contrasting assertion is that 'safe openness' can best be achieved through making GSCs more diversified as a means to reduce concentration risk (Javorcik, 2020; Lin and Lanng, 2020; O'Neil, 2020; Shih, 2020; White House, 2021, among others).

Writing in mid-2021, we have no formal evaluations of policy impact, nor a clear idea of whether the policy announcements will actually be carried through for long enough to reshape GSCs, but it is worth using what we know from the literature to evaluate the claims.

Miroudot (2020*b*) argues that this discussion needs to be thought through more carefully and grounded more directly in business reality, and lessons from the rich corpus of research on GSC risk management—even if today's problem is somewhat different. The literature focuses on how resiliency can be improved at the firm level—not how it can be improved at the country or global level. Nevertheless, Miroudot notes that four general points are worth stressing.

First, problems and policies should be matched. GSC shocks can roughly be categorized as supply ruptures, demand ruptures/surges, and transportation ruptures. While the SCRM literature cites many pro-resilience policies, some of the most frequent that come up are: diversification of suppliers, customers, and delivery channels; establishing redundant production capabilities; boosting flexibility; stockpiling/inventory/buffer stocks; and better steps to gather precise, extensive, and timely information (Kamalahmadi and Parast, 2016; Martins de Sá et al., 2019).

The shortages of PPE that erupted into the headlines in 2020 stemmed primarily from an unexpected and explosive demand. As such, the problem is not the shape of the GSC, so diversifying sources would not be a solution. The obvious answer is stockpiling. Redundant production could also logically work but it seems unlikely to be the most cost-effective means. On the other side, the shortage of vaccines was a supply problem—it took time to ramp up production. Here, stockpiling would be impossible and reshoring production could well be counterproductive given the important scale

[13] In line with previous explanations, note that the TFR indicator includes both double counting as well as imported inputs (from FIR) and sold inputs (from FMR) which are not re-exported.

economies involved. The policy applied in the US and Europe was for the government to promise to underwrite the costs of vaccine development regardless of the outcome. Trying to reshape the vaccine supply chain would probably have slowed things.

Second, improved information and greater supply chain transparency is probably a no-regrets policy. It seems clear that extreme weather events and geopolitical tensions will more frequently create demand, supply, and transportation shocks (BCI, 2021). Having an overview of the whole supply chain can allow faster and more efficient adjustments. Additionally, climate and social policies are likely to require such information. For example, calculating carbon border tax measures requires good information on the ultimate sources of inputs. Relatedly, efforts to help in timely data production for the types of indicators presented in Section 3.3—and data sharing/harmonization across government bodies—could help expose supply chain vulnerabilities, especially in critical sectors.

Third, policies can be usefully classified into tax/subsidy measures, regulatory measures, and direct governmental control. A glance at how risk is dealt with in three industries is insightful. Food production is almost universally considered as too critical to national wellbeing to be left to the market. Most nations have policies that promote domestic production, create buffer stocks to smooth out demand and supply mismatches, or both. These typically involve large fiscal outlays such the US Farm Bill and the EU's Common Agricultural Policy. It is also worth noting that while such expenditures are justified on wellbeing grounds, they are typically driven by special interest politics. Ensuring a certain degree of food self-sufficiency might be possible through regulation, but it is not the most common path.

The financial sector controls risk mostly via regulation. Given the complexity of the sector, regulations must be continually adapted to avoid changes in investment strategies and technological advances. Moreover, a substantial staff is required for surveillance, enforcement and adjudication activities. De-risking the financial sector with taxes and subsidies, or nationalization, might be possible, but they are not the typical solutions.

The defense sector provides a very different model. Defense is habitually marked by a mismatch of 'supply' of defense services and the 'demand' for defense services. The solution commonly adopted is to build in massively redundant 'production' capacity. That is, armies are kept at the ready for years, even decades, without ever being called into combat. Trying to accomplish this resilience via taxes and subsidies, or regulation, seems implausible given the vast cost involved. Direct public ownership of the production facilities (the military) is the standard solution.

Fourth, as we saw in 2020, macro level policies can act as circuit breakers that prevent supply, demand, and transport shocks from snowballing. Resiliency at the macro level can also be important for resilience at the micro level. For instance, the massive fiscal interventions in 2020 prevented a cascade of bankruptcies that would have made the disruption of GSCs far worse. Likewise, income

support measures allowed demand to carry on even as incomes fell. The result was that the demand shocks did not trigger the Keynesian aggregate demand multiplier.

4 Future shape of GSCs: Trends and conjectures

The future is only knowable once it lies in the past, so forecasting is a tricky business. One way around this is to leverage the point that novelist William Gibson made: "The future is already here—it's just not very evenly distributed."[14] In this spirit, we concentrate on forces that are already in evidence and are thus likely to shape the future of GSCs. The forces depend on policy and technology.

4.1 Will policy matter?

Governments have announced plans to promote domestic manufacturing (Evenett and Fritz, 2021), but will governments follow through with the resources necessary to reshape GSCs? Today's production structures are the equilibrium outcomes that balance agglomeration and dispersion forces, and buyer-supplier networks are notoriously sticky due to the way in which niche expertise for very specific value chains is located around the globe.

Antràs (2021) stresses sunk-cost hysteresis arguments (Baldwin, 1988) in raising doubts about the likelihood that Covid-19-linked policy announcements will actually reshape GSCs. Locational equilibriums are unlikely to shift unless firms perceive a permanent shock[15] and governments commit to substantial, long-term production subsidies (as with agriculture), massive regulation (as in banking), or massive state-lead interventions (as in defense).

Policies on essential medical supplies and semiconductors may well prove to be more durable and effective given their critical nature. Arguments that these sectors are part of today's national defense, broadly defined, are more credible, and thus more likely to endure long enough to reshape production structures.

4.2 Automation tends to localize manufacturing

Digitech is one aspect of the future that is already here but not yet evenly spread. One of the few near-certain forecasts one can make in economics is that digitech will have important economic effects. What are the likely effects on the future of GSCs? The mainstream model of offshoring (Grossman and Rossi-Hansberg, 2008, see Antràs and Chor, 2021 for a review) asserts that manufacturing stages are offshored when the cost-saving from relocation outweighs the extra coordination, communication, and trade costs that separation entails. Digitech will alter this trade-off (Antràs, 2020).

[14]Said in NPR interview on *The Talk of the Nation.* 'The Science in Science Fiction' (30 November 1999; Timecode 11:20; http://www.npr.org/templates/story/story.php?storyId=1067220).

[15]Martin et al. (2020) find that the probability of a trade relationship ceasing is significantly reduced in "sticky" product markets during uncertain times, speaking to firms' wait-and-see behaviors during uncertainty episodes.

To see this, take the per-unit production cost in a typical sector i as $c_{ic} = w_c a_{ic} + r$, where w_c and a_{ic} are the wage and unit-labor input coefficient in country c, and r is all non-labor costs. Simplifying to clarify, suppose that labor is perfectly non-traded but non-labor inputs are perfectly traded (and thus cost the same in all countries). The proportional production cost difference between country c and c' is:

$$\frac{c_{ict} - c_{ic}}{c_{ict}} = \theta_L \left(1 - \frac{\mathrm{w}_c a_{ic}}{\mathrm{w}'_c a_{ict}}\right)$$

where θ_L is the labor-cost share in the prime nation. To be concrete, assume that the cost is lower in country c.

What happens to offshoring as digitech and artificial intelligence (AI) continue to automate manufacturing? While there can be countervailing effects, it is likely that θ_L will fall (Manyika et al., 2019). If this happens, and separation costs do not fall as much, firms will tend to shut down GSC trade and produce all stages locally. The outcome might look like decoupling, or deglobalization, but it would have nothing to do with mitigating the risk of GSCs. It would be the result of long-term trends in industrial automation and the fact that most non-labor costs are trade. Taking the logic one step further suggests that the same trend could make all manufactured goods non-traded. This stark result is not a prediction but rather an illustration of digitech's possible impact on the future of GSCs (see Baldwin and Forslid, 2020 for a more extensive discussion of this possibility).

4.3 Digitech will make services more tradeable

Advancing digitech is also lowering the trade- and labor-cost shares in services (Lund et al., 2019), but not at the same pace as in industry. For services, digitech is rapidly lowering the costs of trade, but lowering the labor-cost share much less quickly since robotic automation hereto has mostly focused on manufacturing. This difference suggests that the future of services trade will look very different than then future of goods trade. In fact, aggregate stylized facts are in line with this projection as trade in services has grown faster than trade in goods for many years (WTO, 2019*a*).

Digitech has interacted with the pandemic to facilitate services trade in another way. One of the most obvious outcomes of the pandemic is a heightened ability of services firms to spatially unbundle their value chains. Services, like goods, are typically produced by value chains—especially complex service products in professional sectors like human resources, law, finance, accounting, architecture, and media. Think of the process of providing investment advice to clients, the process of developing, pricing, and marketing life insurance, or the process of selecting, hiring, and on-boarding new workers.

In the old days, these service value chains (SVCs)—just like manufacturing value chains—tended to be bundled in a single building. But, digitech such as collaborative software, online data bases, and excellent internet connectivity have resulted in the fractionalization and separation of some of these stages of SVC production.

Once separation of stages was technically feasible, vast international wage differences made offshoring of some stages profitable. This has already happened extensively for some services tasks—think of call centers and web development. The advance of digitech—accelerated by Covid-19—is expanding the range of service tasks that can be offshored (De Backer and Miroudot, 2013).

Another feature suggesting that GSCs will shift towards services is the lack of protection in intermediate service tasks that make up many of the intermediate stages of SVCs. This results from several policies. First, since the Declaration on Global Electronic Commerce, WTO members have refrained from imposing customs duties on electronic transmissions; this 'moratorium' was renewed in December 2019 (WTO, 2019*b*). Second, most domestic regulation-based protection of services implicitly assumed that SVCs were spatially bundled, so regulating the final service product was sufficient to protect all of the jobs along the chain. For example, countries limit who can provide legal, medical, and engineering services via qualifications, but the workers undertaking the intermediate tasks in the SVCs are often much less regulated. Third, as part of the Uruguay Round, most developed nations committed themselves to imposing no barriers to trade in many sectors when it comes cross-border service trade (Mode 1). This made good political sense in the mid-1990s since most services were non-traded and those that were traded were dominated by exports from high-wage nations.

The upshot of this is that the main barrier to globalization of SVCs is now technological. Given short doubling times for digitech related to the processing, transmission, storage, and gathering of information, these technology barriers are falling far faster than the costs of shipping did since the unbundling of production and consumption of goods since 1820, and the unbundling of manufacturing stages since the 1990s. These trends suggest that the future of international supply chain trade will be increasingly in services and decreasingly in goods. A twist on this is servicification, namely the rising value-added share of services in manufactured goods, for which there is evidence both in the aggregate (Miroudot and Cadestin, 2017) and at the firm level (Ariu et al., 2019).

5 Concluding remarks and suggestions for future research

When the Covid-19 pandemic struck, online media were replete with images of empty store shelves, healthcare workers recycling PPE, and patients dying for a lack of respirators. Were GSCs to blame? Judging from public statements and policy responses to date, the predominant policy rhetoric has been that the shortages would have been less severe in the past and would be less severe in the future if GSCs were either shorter and more domestic, or more diversified. But are these assertions right, or simply a 'rush to judgment'?

Given the speed at which the shortages were attenuated and the historically unprecedented pace at which vaccines were developed, tested, and mass produced, it is plausible that GSCs will go down in history as the heroes of the pandemic. Surveying very early data, Evenett (2020) noted that "countries

witnessed surges in infection at different times [which] implies that smoothly functioning supply chains could ramp up production and ship medical supplies and medicines to destinations where demand was surging." He concludes: "it should be evident that, by any reasonable standard of logic and evidence, the case made against cross-border supply chains is unconvincing."

The shortages of 2020 and 2021 certainly seem to be very different than disturbances in the past, but what changed? Was it the nature of GSCs, or the nature of the shocks facing them? There is scant evidence of a radical shift in GSCs in recent years (Antràs, 2021). Common sense, by contrast, suggests that the type of shock has changed radically. Instead of localized shocks hitting a handful of firms at a time, many recent shocks have been global and cross-sector. US protectionism in the 2010s, triggered a cycle of "trade war" tariff retaliation that shocked GSCs in many countries and industries at the same time. In 2020, various combinations of sudden and synchronized surges in demand, ruptures of production, and disrupted transportation networks created worldwide shortages of essential goods. With climate change, extreme weather events—including those on an international scale—seem destined to increase in frequency and severity.

Changing challenges facing GSCs call for changes in GSCs, but should governments be instrumental in directing the changes? As suggested in Section 3, the answer should involve a careful consideration of whether the incentives facing private actors are sufficiently misaligned with the public weal so as to justify expensive or extensive interventions. Expensive and persistent de-risking policies are today applied to only a very few sectors, like farming and defense. Medical supplies and a narrow list of other critical goods sectors may well join the list. Beyond these, we conjecture that sustained policy interventions seem unlikely unless vested interests take the reins. BCI (2021) documents that businesses are already adjusting rapidly to the new nature of shocks. The report shows how firms have revamped supply chains to ensure continuity of supply, reviewed manufacturing models, and returned to stockpiling including, in some cases, shifting away from just-in-time manufacturing.

A logically separate, but temporally correlated, concern is the reliance on industrial inputs from China. In strategic sectors such as semiconductors, the political forces that underpin expensive policies in defense procurement may well reshape the relevant GSCs. This seems more likely to the extent that geostrategic tensions persist and intensify.

In terms of policy, one 'no regrets' option would seem to be stress testing. This is standard operating procedure in the financial sector. Why not extend it to critical goods sectors? D'Aguanno et al. (2021), Miroudot (2020*a*,*b*), and Simchi-Levi and Simchi-Levi (2020) provide an interesting set of ideas on this. International cooperation would naturally be part of this as the information externalities are global. An analogy with the global network of weather stations suggests that information sharing could be win-win (Hoekman, 2014).

Only time and research will tell what really was behind the 2020 disruptions and how best we

should deal with the changed situation. So what might future research focus on?

On the theory side, the discussion in Section 3 suggests that the risk-GSC nexus serves up a rich menu of un-modeled, yet important phenomena. Risk considerations are not entirely new to GSC studies (Costinot et al., 2013), but the theory has largely assumed away risk for convenience, and this has been echoed in the empirics. From the business literature, it seems that risk affects the shape of GSCs to a far greater extent, and via a set of mechanisms that is far richer than seen in today's GSC models. On the empirical side, the possibilities are even greater. Nothing helps econometricians more than truly exogenous shocks, and 2020 and 2021 were bursting with them. This, coupled with the availability of massive, high-frequency, online data and headline-grabbing importance, suggests that there is a great deal of impactful empirical research to be done on GSCs and risk. Overall, we see exciting times ahead for GSC researchers. Things have, as they say, changed so much that not even the future is what it used to be. It is riskier than we thought.

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