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Risks and Global Supply Chains: What We Know and What We Need to Know

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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 had been 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 at 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-resilience 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 light of current policy proposals and advancing technology before pointing to the rich menu of topics for future research on the risk-GSC nexus.

1. INTRODUCTION

In 2020, an 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 2020b, Colantone et al. 2021). These shortages generated headlines that, in turn, thrust supply disruptions to the top of policy makers' 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, p. 1).

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 stressed making GSCs either shorter and more domestic (through reshoring activity) or more diversified (Javorcik 2020, Lin & 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 (Sturgeon & Memedović 2010, Johnson & Noguera 2012a). The importance of GSCs was highlighted in early empirics (Grubel & Lloyd 1975) and theory (Batra & Casas 1973, Woodland 1977). Their importance was underscored every decade since, with important theory contributions starting in the 1980s (Dixit & Grossman 1982, Ethier 1982, Sanyal & Jones 1982, Helpman 1984) and the 1990s (Francois 1990, Jones & Kierzkowski 1990, Deardorff 1998, Hummels et al. 1998, Venables 1999).

GSCs have also long been on the policy agenda. The United States 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 so-called 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 positive. 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 starting around 1990 (Baldwin 2006, Taglioni & 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, for example, than that of the so-called newly industrializing economies of 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—China above all.

The new landscape called for fresh theorizing related to vertical specialization, production fragmentation, multinationals, and other facets of firm behavior, which flourished in the 2000s (Hummels et al. 2001, Yi 2003, Antràs & Helpman 2004, Kohler 2004, Markusen 2005, Antràs et al. 2006, Grossman & Rossi-Hansberg 2008) as well as more recently (Koopman et al. 2010, 2014; Johnson & Noguera 2012b; Antràs & Chor 2013; Baldwin 2013; Baldwin & Venables 2013; Halpern et al. 2015; Antràs et al. 2017; Bernard & Moxnes 2018; Grossman & Helpman 2021). Further, the heightened policy importance of GSCs resulted in massive 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; Timmer et al. 2015, 2016; OECD 2019; for an overview of data sources, see Johnson 2018, Antràs & Chor 2022).

Yet, while the academic debate gravitated toward the productivity and welfare-enhancing benefits of GSCs to international firms (Amiti & Konings 2007, Grossman & Rossi-Hansberg 2008, Topalova & Khandelwal 2011, Halpern et al. 2015) as well as firms along the domestic supply chain (Blalock & Veloso 2007, Merlevede & Theodorakopoulos 2021), the GSC narrative in policy circles tended toward 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 United States caused by trade with low-wage nations—with much of this being within GSCs.[1] These widely publicized findings, together with social dislocation in the United States 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 United States and Europe, with several influential studies documenting that perceivable rises in trade exposure, and the associated distributional consequences, can be tied to a political backlash against globalization (Colantone et al. 2021, Rodrik 2021).[2] More generally, Eichengreen (2018) argues that globalization and declining US manufacturing were important in driving the results of 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 & Ye 2013).

The culmination of shocks made many realize how far interdependence had gone in many industrial goods. Evenett & 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 Minister of Economy, 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" (Yasutoshi Nishimura, cited in Evenett & Fritz 2021, p. 30). The European Union embraced a new policy of "strategic autonomy" with the French Minister of Economy 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 article follows a simple progression. Section 2 covers the connections between risk and GSCs across several dimensions—risks to GSCs, risks from

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

[2] Readers are referred to Autor et al. (2020), Che et al. (2020), and Blanchard et al. (2019) for the United States; Dippel et al. (2021) and Dauth et al. (2014) for Germany; Caselli et al. (2021) for Italy; Colantone & Stanig (2018) for the United Kingdom; and Colantone & Stanig (2019) for Western Europe.

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 resilience, before suggesting that the risk-versus-reward framework from portfolio theory provides a convenient approach to thinking about whether policy is justified. The section next 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 that can affect GSC resilience. 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. GSC RISKS

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

2.1. Risks to GSCs

GSCs are composed of firms that sell to each other and to final customers. These firms face risks. As Miroudot (2020c) points out, some risks are exogenous supply and demand shocks; some come from other firms. Supply shocks include classic disruptions such as natural disasters, cyberattacks, 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 including damage to product and to 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 are. 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 & 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 & Lall 2015) are classic examples. Barrot & Sauvagnat (2016) reinforce this message for a wide range of natural disasters by demonstrating sizable drops in sales growth of affected firms' direct customers.[3] More recently, the pandemic and Brexit have spawned much broader shocks. As Gereffi (2020, p. 288) 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 25% of firms experienced 10 or more disruptions in 2020, whereas that proportion 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).

[3] Although not as widely, the 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.

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 shocks 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 & Parro (2015), to simulate the impact of full decoupling. As Antràs & 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 trade in intermediates) 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 in most cases but magnified losses in 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 outweighs 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-19 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 & Tahbaz-Salehi 2019), so we can be brief here. 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 outcomes 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 (Gabaix 2011, Acemoglu et al. 2012, Carvalho & Gabaix 2013). 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 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, whereas cross-border diversification of suppliers and buyers tends to reduce it. They ground this result in theory[4] and, using a quantitative trade model, argue that cross-border diversification has prevailed in most countries since the 1970s.

[4]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 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.

D'Aguanno et al. (2021) buttress 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 reshoring increases aggregate volatility by reducing source diversification. By contrast, policies that encourage diversification of foreign suppliers lower 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 (2020b) 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 showed—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.[5]

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. Here, "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, p. 94). 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 from the 2011 Tōhoku earthquake in Japan, Japanese carmakers diversified their suppliers (Inoue & Todō 2017). Further, Sáenz & 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 implementing thorough resilience monitoring (i.e., 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 is between diversification of risks and the availability of 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

[5] 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.

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 et al. 2014, Simchi-Levi 2015). 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, whereas long-term relationships speed recovery (Alfaro & 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 (2021, p. 4) 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, p. 114) argues that the combination of trade-policy shocks in the 2010s and the Covid-19 pandemic has forced a rethinking of global value chains: "Current events will force businesses to reengineer 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) cautions 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 (2020b) 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 faced by firms in different nations, sectors, and positions in GSCs. Although these 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 & Parast (2016) discuss the vast heterogeneity in approaches, terminologies, and emphases. To organize the contributions, they use the fourfold principles of Christopher & 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 resilience is important. The view of flexibility and redundancy as an alternative pro-resilience 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 is 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 intrafirm and interfirm 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 World Economic Forum and the consulting firm 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" (World Econ. Forum 2021) that 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 latter 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 balancing 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 span 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 whereby companies care about risks as well as the rewards from cost savings, but social evaluation of the trade-off may put greater stress on the risks. Policy intervention may improve market outcomes when there is a Pigouvian wedge between private and social evaluations. The outcome may also be socially inefficient if a collective action problem creates information asymmetries that force companies to act without full information.

Figure 1 (inspired by optimal portfolio analysis) illustrates the trade-off between the risk (vertical axis) and the rewards (horizontal axis) that come with GSCs. 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 the fact that both firms and society 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 governments provided guarantees when the risk went wrong,[6] and in food production, where atomistic producers underinvest in anti-famine actions. Its

[6]We discuss below how the importance placed on risks to banking has now been integrated into regulatory frameworks.

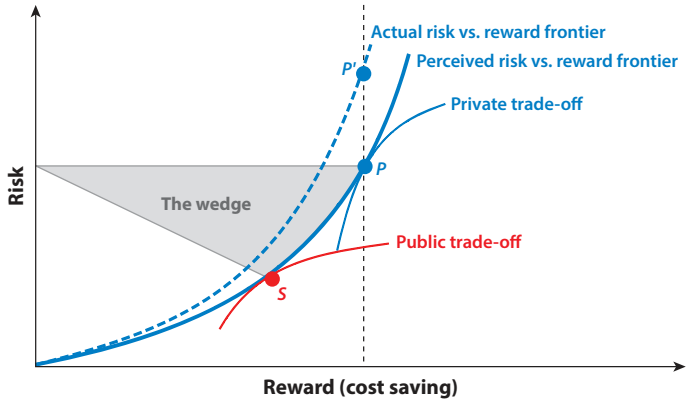

Figure 1

The public-private wedge analysis of global supply chain risks. Points *P* and *P′* refer to desired levels of private risk. Point *S* refers to the desired level of public risk.

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* in **Figure 1**) compared to the private sector (point *P*). This wedge between the public and private evaluation of risk is a clear market failure that could justify policy interventions.

Where does the wedge come from? The question deserves extensive theory and empirical investigation in the GSC context. Because, to the best of our knowledge, no studies have explored this (apart from Grossman et al. 2021), analogies with other sectors provide some intuition. In the financial setting, the wedge stems from a divergence between investors' and governments' preferences. Banks do not internalize the macro costs of a banking crisis, whereas governments do. In food production, the wedge arises because individual farmers do not take account of the full social costs of famine, whereas governments do. In the GSC world, divergences in public-private risk preferences can arise from a wide range of mechanisms whereby individual firms do not internalize the full risk of their actions.

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). The authors of the MGI report analyzed data on the number of publicly disclosed suppliers to 668 companies spanning a range of sectors, and they 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. Whereas 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 companies' inputs are actually made can result in private misjudgments as to how risky a GSC is for firms of all sizes. The situation is shown as the actual risk-reward trade-off taking place above the perceived trade-off, which would also result in a wedge. Given the lack of information about where things are made, one classic source of the

wedge would be a coordination failure, whereby each firm engages in what it considers to be a reasonable amount of risk without considering the possibility that a common shock could lead to subsequent shocks with broader macroeconomic consequences. Information problems are a classic source of intervention-justifying externalities. Because 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 and cheap to share, and it provides value to many. With this in mind, D'Aguanno et al. (2021) draw parallels to reforms of the global financial system, which were underpinned by large efforts to enhance policy makers' understanding of stress points, and they advocate for similar reforms to enhance transparency in complex GSCs so that risks can be more easily monitored. Among other elements, this would include efforts to enhance the timeliness and availability of granular data on GSCs. As we shall see, even with the available data at hand, misperception of actual vulnerability is pervasive. Therefore, pinning down just how exposed countries are to disruptions abroad can help with empirical evaluations of whether GSCs are too risky.

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 narrative on risky GSCs 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 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 & 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 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 & Miroudot 2013), whereby 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

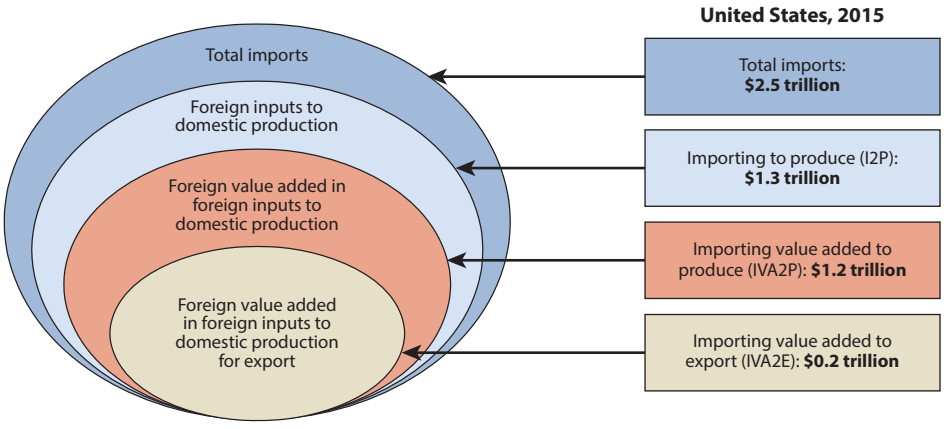

Figure 2

Types of sourcing-side global supply chain (GSC) exposure. Authors' illustration based on data for the United States in 2015 from the OECD TiVA Database 2018 (see **https://stats.oecd.org/Index.aspx?DataSetCode=TIVA_2018_C1**).

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.

To fix these 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 & Noguera 2012a) that is one of the principal indicators of a nation's involvement in GSCs.[7]

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 by Koopman et al. (2010), and widely popularized by the OECD], provide 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. This can be seen as the exposure of a nation's exports to foreign ruptures affecting value added, and it 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 the 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. Because 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 assembly 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 sketch of the issues involved.[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,

[7] Below, we discuss different types of shocks that might affect gross production versus value added and provide a discussion of why various indicators are more or less appropriate depending on the type of disruption.

[8] Readers are referred to Miller & Blair (2009) for an overview of input-output foundations, Johnson (2018) for a review of GSC measures, and Baldwin & Freeman (2022) for details on GT-based indicators.

invested, or exported. With matrix notation, this identity for every sector can be compactly written as $\mathbf{X} = \mathbf{AX} + \mathbf{F}$, where $\mathbf{X}$ is the vector of gross production by each sector (if there are n sectors, $\mathbf{X}$ is an $n \times 1$ vector), $\mathbf{F}$ is the corresponding $n \times 1$ vector of final usage, and $\mathbf{A}$ 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, $\mathbf{AX}$ is the intermediate usage and $\mathbf{F}$ is the final usage. In this literature, $\mathbf{X}$ is usually called gross production to distinguish it from net production, that is, production minus the output used up as intermediate inputs.

Because the world is a closed economy, the concepts apply equally to a world with one nation and to a world with many nations. If there are n sectors in each of m countries, the vectors are $nm \times 1$, and $\mathbf{A}$ 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 our level of discussion here.

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

To fix ideas as to what $\mathbf{L}$ tells us, suppose we want to identify all the production necessary to produce one dollar of final output in the first of the $n \times m$ sectors (i.e., sector 1 in nation 1). To this end, we set the first element of $\mathbf{F}$ to 1 and zero out all the others. Using $\mathbf{X} = \mathbf{LF}$, we see that this means that the first column of $\mathbf{L}$ 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 $\mathbf{L}$ 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 foreign input reliance index.

Most of the discussion on risky GSCs revolves around manufactured goods, so we focus here 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 four biggest manufacturing producers (China, United States, Japan, and Germany) from 2004 to 2018. China's rise jumps out as the dominant feature; its share tripled in 15 years and is now more than 10 percentage points above the second biggest world manufacturer (the United States). 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 **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 10 years.[9] The total foreign input reliance (FIR) line takes account of all Chinese inputs that are

[9] 2005 and 2015 are the earliest and latest years currently available in the 2018 version of the OECD Inter-Country Input-Output (ICIO) Tables, upon which we base this analysis (see **https://www.oecd.org/sti/ind/input-outputtables.htm**).

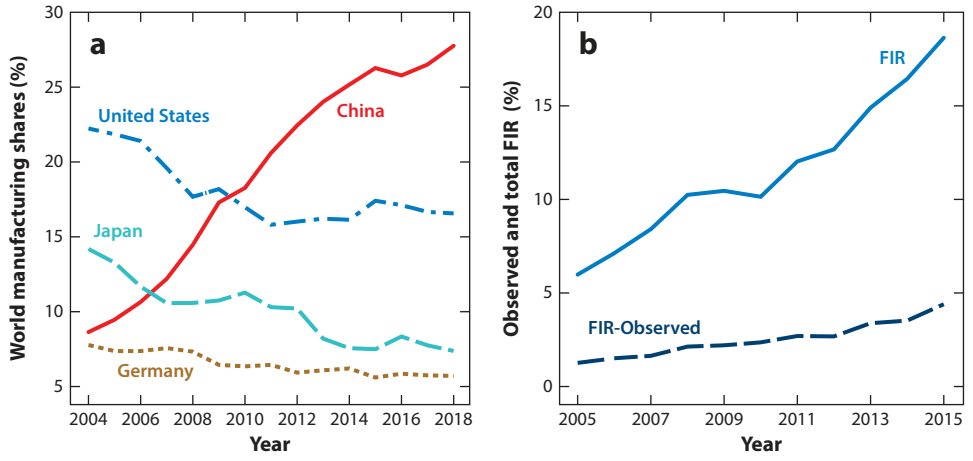

Figure 3

Global manufacturing shares and the difference between observed (FIR-Observed) and total (FIR) foreign input reliance. (*a*) World manufacturing shares of the top four nations, 2004–2018. (*b*) Observed and total FIR of the US motor vehicle sector on Chinese inputs. Panel *a* based on data from the World Bank World Development Indicators (see **https://databank.worldbank.org/source/world-development-indicators**). Panel *b* based on data from the OECD Inter-Country Input-Output (ICIO) Tables 2018 (see **https://www.oecd.org/sti/ind/input-outputtables.htm**).

bought directly by the US auto makers as well as indirectly—i.e., that are embedded in the inputs they buy from other US and foreign suppliers (which come from the relevant elements of **L**).[10] For example, General Motors buys ultrashort-range radar technology from the Canadian company Alps Electric, so although General Motors 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 14 percentage points.[11] Looking across all US manufacturing sectors' reliance on China, the average difference between FIR-Observed and FIR in 2015 was 7.6 percentage points.[12]

Note that, in line with the schema in **Figure 2**, 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 would affect the whole value of the shipment, that is, 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 & Freeman 2022).

[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 that could be problematic for some applications, but not for measuring total exposure to foreign production shocks.

[12]Of course, this discussion relates to the evolution of FIR but does not address the evolution of risk. When using the FIR measure to consider overall risk, the probability of disruption in any given location should also be considered.

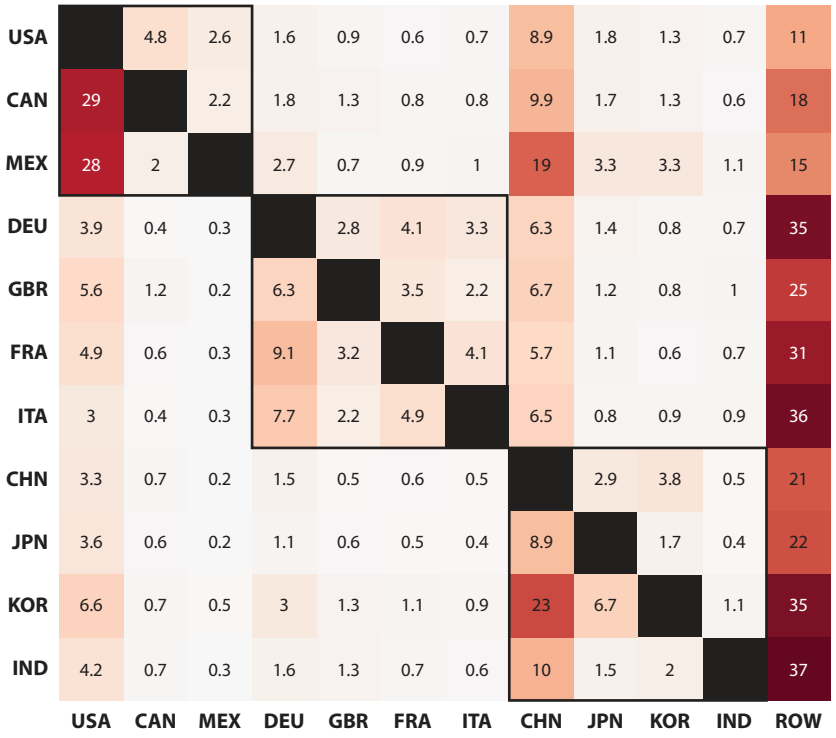

Figure 4

Foreign input reliance (FIR). Values shown are percentages. They indicate row nations' reliance on inputs from column nations for manufacturing production in 2015. Colors are indexed to share sizes, with darker reds indicating higher FIR. Countries are denoted by ISO-3 codes; ROW stands for rest of the world. Authors' computations based on OECD Inter-Country Input-Output (ICIO) Tables 2018 (see **https://www.oecd.org/sti/ind/input-outputtables.htm**).

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 FIR measure for all G7 countries and other major manufacturing economies in 2015, as well as a rest of the 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 Canada (CAN) row and the USA column indicates that 29% of Canadian manufacturing production was made using inputs sourced directly and indirectly from the United States.

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. Because the indicator is based on production and GT, there is double counting, so the row sums need not equal 100.[13]

[13]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—in terms of both direct domestic sourcing and indirect sourcing through the re-import of previously exported inputs.

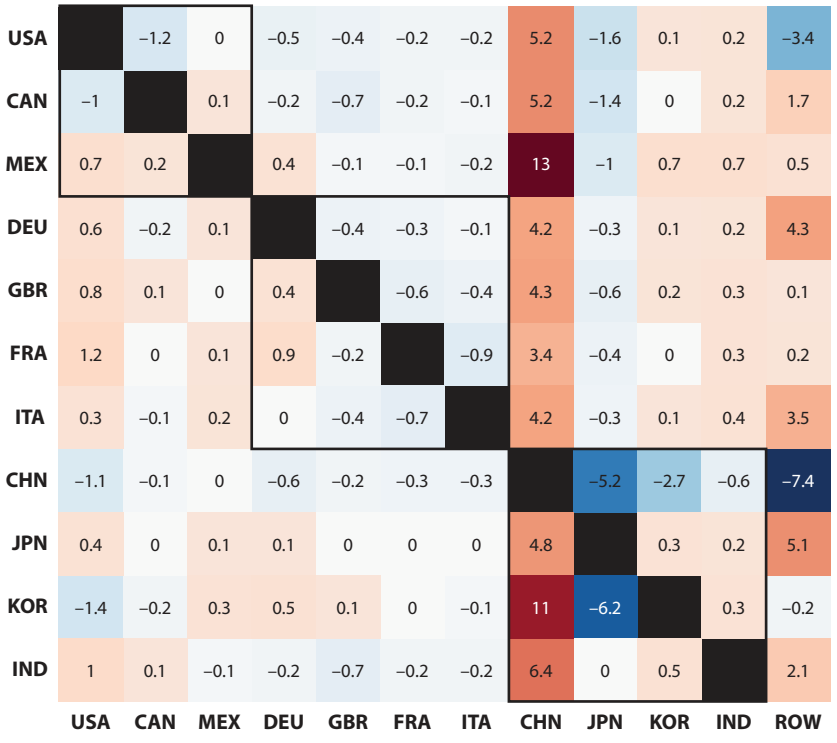

Figure 5

Change in foreign input reliance (FIR). Values shown are percentage points. They indicate row nations' reliance on inputs from column nations for manufacturing production in 2015 compared to 2005. Red-shaded cells indicate FIR increases; blue-shaded cells indicate FIR decreases. Countries are denoted by ISO-3 codes; ROW stands for rest of the world. Authors' computations based on OECD Inter-Country Input-Output (ICIO) Tables 2018 (see **https://www.oecd.org/sti/ind/input-outputtables.htm**).

The regionalization of GSCs is plain. For example, what Baldwin (2008) called Factory Asia is highlighted in the box at the bottom right, where the colors tend to be darker than in the other cells of the matrix. Factory Europe is represented by the central box, and Factory North America is shown in the upper-left box. The global importance of the United States and China, but especially China, is shown by the fact that their columns are highlighted primarily in red. In other words, the fact that the USA and China (CHN) columns are relatively dark indicates that they are important suppliers of inputs to the manufacturing sectors of all nations. Although the United States dominates in 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 United States' 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 not come as a surprise that most of the numbers in the 2015 bilateral FIR matrix with respect to China were 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, whereas blue-shaded cells highlight FIR decreases.

The figures in the China column are all positive, with some of them in the double digits. The figures in the United States column are small, mostly under 1 percentage point, 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 must 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 the China row is negative. This indicates 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 deregionalization of GSCs in North America and Europe due to the shift toward China as a source of industrial inputs.

3.3.2. GSC selling-side exposure: levels and trends in the foreign market reliance 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. Because the indicator is based on sales measured by GT (instead of VT) concepts, there is also double counting involved. The double counting overstates reliance when considering a whole-world shock, but it is useful in capturing the full exposure when thinking about single-country and bilateral shocks.

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 $\mathbf{X} = \mathbf{B}'\mathbf{X} + \mathbf{V}$, where $\mathbf{V}$ is an $n \times 1$ vector of value added. The $\mathbf{B}$ matrix (commonly known as the allocation coefficients matrix) is analogous to the $\mathbf{A}$ 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, $\mathbf{B}'\mathbf{X}$ represents the destination of directly sold inputs. Solving for the gross output row vector, $\mathbf{X}'$, we get $\mathbf{X}' = \mathbf{V}' (\mathbf{I} - \mathbf{B})^{-1}$, where $\mathbf{G} = (\mathbf{I} - \mathbf{B})^{-1}$ 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 United States. However, the US-China asymmetry is less marked and is reversed, given that China's sales-side reliance on the United States is 6.7%, while that of the United States on China's market is only 5%. The evolution of FMR is again similar to that of FIR, but the deregionalization is less marked (**Figure 7**).

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 the exact figures for brevity, but a visual examination when summing across the rows of **Figures 5** and **7** reveals a net aggregate decrease in China's TFR of roughly 29 percentage points, in contrast with a net aggregate increase for virtually all other countries.[14]

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

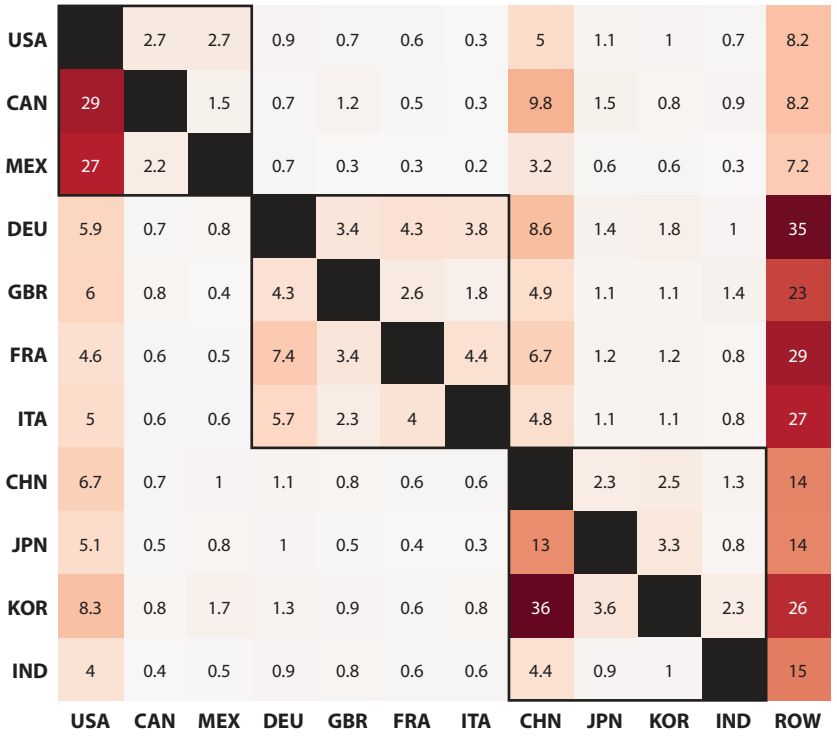

Figure 6

Foreign market reliance (FMR). Values shown are percentages. They indicate row nations' total input sales to column nations' manufacturing sector in 2015. Colors are indexed to share sizes, with darker reds indicating higher FMR. Countries are denoted by ISO-3 codes; ROW stands for rest of the world. Authors' computations based on OECD Inter-Country Input-Output (ICIO) Tables 2018 (see **https://www.oecd.org/sti/ind/input-outputtables.htm**).

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, a dual rhetoric has emerged. One general conclusion is that risk would be reduced by making GSCs shorter and more domestic; a contrasting assertion is that safe openness can be best achieved by making GSCs more diversified as a means to reduce concentration risk (see Javorcik 2020, Lin & 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 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 (2020b) argues that this discussion needs to be thought through more carefully and to be grounded more directly in business reality and in lessons from the rich corpus of research on GSC risk management—even if today's problem is somewhat different. The literature focuses on how resilience 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 be roughly categorized as supply ruptures, demand ruptures/surges, and transportation ruptures. The pro-resilience policies

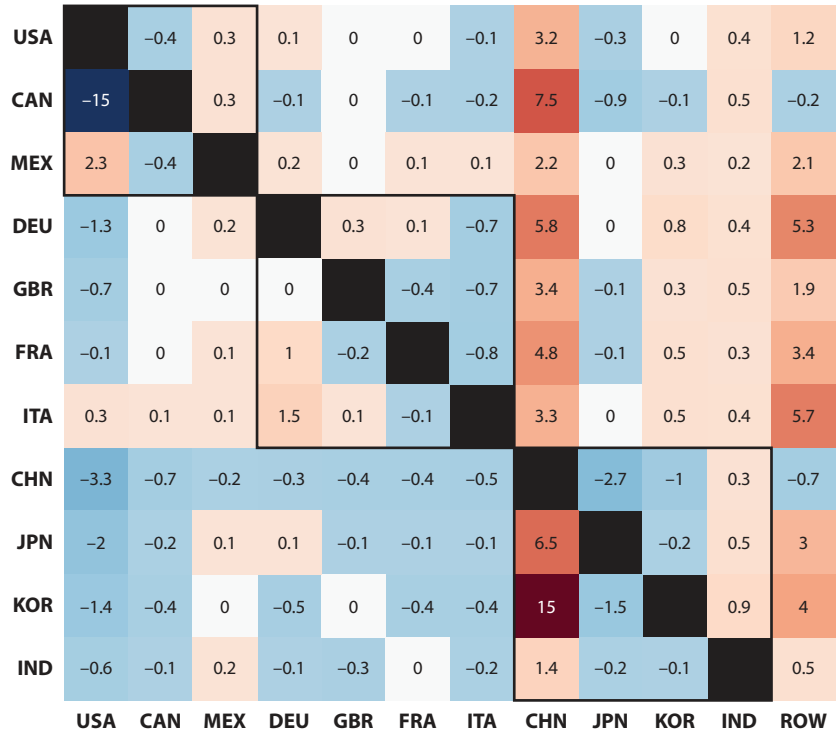

Figure 7

Change in foreign market reliance (FMR). Values shown are percentage points. They indicate row nations' total input sales to column nations' manufacturing sector in 2015 compared to 2005. Red-shaded cells indicate FMR increases; blue-shaded cells indicate FMR decreases. Countries are denoted by ISO-3 codes; ROW stands for rest of the world. Authors' computations based on OECD Inter-Country Input-Output (ICIO) Tables 2018 (see **https://www.oecd.org/sti/ind/input-outputtables.htm**).

cited by the SCRM literature are varied, but some of the most frequent are: diversifying suppliers, customers, and delivery channels; establishing redundant production capabilities; boosting flexibility; stockpiling/inventory/buffer stocks; and taking better steps to gather precise, extensive, and timely information (Kamalahmadi & Parast 2016, Martins de Sá et al. 2019).

The shortages of PPE that made headlines in 2020 stemmed primarily from unexpected and explosive demand. As such, the problem is not the shape of the GSC, and therefore diversifying the 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. Meanwhile, 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 economies involved. The policy applied in the United States 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 down.

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 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 too critical to national well-being 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 as the US Farm Bill and the European Union's Common Agricultural Policy. It is also worth noting that although such expenditures are justified on well-being 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 this is not the typical solution.

The defense sector provides a very different model. Defense is habitually marked by a mismatch between the supply of defense services and the demand for them. 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 (i.e., 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. Resilience 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."[15] 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 & 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,

[15]The citation is taken from an interview on *The Talk of The Nation*, aired on NPR on November 30, 1999; this segment is at minute 11:20 (**http://www.npr.org/templates/story/story.php?storyId=1067220**).

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 (2020b) 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[16] and governments commit to substantial, long-term production subsidies (as with agriculture), massive regulation (as with banking), or massive state-lead interventions (as with 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 its likely effects on the future of GSCs? The mainstream model of offshoring (Grossman & Rossi-Hansberg 2008; see Antràs & Chor 2022 for a review) asserts that manufacturing stages are offshored when the cost savings from relocation outweigh the extra coordination, communication, and trade costs that separation entails. Digitech will alter this trade-off (Antràs 2020a).

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, respectively, and r is all non-labor costs. To simplify, 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

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

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

What happens to offshoring as digitech and artificial intelligence 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 of the fact that most non-labor costs are trade costs. 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 & 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

[16]Martin et al. (2020) find that the probability that a trade relationship will cease is significantly reduced in sticky product markets during uncertain times, which is an illustration of firms' wait-and-see behaviors during uncertainty episodes.

trade, but it is lowering the labor-cost share much less quickly because robotic automation hereto has mostly focused on manufacturing. This difference suggests that the future of services trade looks very different from the 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 2019a).

Digitech has interacted with the Covid-19 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. More recently, however, digital technologies such as collaborative software, online databases, and excellent Internet connectivity have resulted in the fractionalization and separation of some of the stages of SVC production.

Once separation of stages became 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 & Miroudot 2013).

Another feature suggesting that GSCs will shift toward services is the lack of protection in intermediate services 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 2019b). Second, most domestic regulation-based protection of services implicitly assumes that SVCs are spatially bundled, and that regulating the final service product is sufficient to protect all 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 have committed themselves to imposing no barriers to trade in many sectors when it comes to cross-border services trade (i.e., Mode 1 services trade). This made good political sense in the mid-1990s, as 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 the 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 following 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 lies increasingly in services and decreasingly in goods. A twist on this is servicification, the rising value-added share of services in manufactured goods, for which there is evidence both in the aggregate (Miroudot & 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, health care workers recycling PPE, and patients dying for a lack of respirators. Were

GSCs to blame? Judging from the 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, pp. 424–25) 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 concluded that "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 from disturbances of the past, but what changed? Was it the nature of GSCs or the nature of the shocks they faced? There is scant evidence of a radical shift in GSCs in recent years (Antràs 2020b). Common sense, by contrast, suggests that it is the type of shock that 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–like tariff retaliations 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.

The changing challenges faced by 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 private actors face are sufficiently misaligned with the public weal so as to justify expensive or extensive interventions. Expensive and persistent de-risking policies are applied today only to very few sectors, like farming and defense. Medical supplies and a small number of other critical goods sectors may well join the list. Beyond these, we conjecture that sustained policy interventions will be 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 their 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 (2020a,b), and Simchi-Levi & 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 was really behind the 2020 disruptions and how best to 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 unmodeled, 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 is 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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