Swiss Re Institute

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Quantifying business interruption

Risk propagation in complex supply chains

Contents

Executive summary

In recent years, the COVID-19 pandemic and rising global political tensions seriously stretched trading relationships. They prompted trends, such as re-shoring and friend-shoring, that implied a shortening and simplification of the supply chain. However, whilst there have been shifts in the sourcing of goods, supply chains remain highly complex. The Bank of International Settlements suggests that "the average distance between firms has increased without a corresponding increase in network".[1] The trend has mainly been driven by Asian companies outside of China interposing themselves in between US and Chinese trading partners. Such stretching, the BIS concludes, "has an important bearing on the question of global value chain resilience."

There are underlying trends affecting supply chain resilience. Urbanisation concentrates value at risk within supply chains. Around 56% of the global population currently lives in cities, a figure expected to grow to 70% in 2050.[2]

The concentration of value in global supply chains heightens the impacts of risks such as natural catastrophes, including earthquake, flood, storms, drought and heat. The port of Iskenderun, Turkey, was closed for months following a 7.8 magnitude earthquake in 2023.[3] A heatwave in Sicily, Italy, in 2023, caused mass power outages, limiting water and power for consumers and producers alike.[4] As analysed in this paper, shipping in the Panama Canal fell by around half from 2021 to 2024, as the region suffered prolonged drought. Swiss Re offers our clients an extensive data base of natural catastrophes, modelled and mapped in granular detail within our CatNet® product.[5] Beyond catastrophes, natural disturbances to supply chains will grow from biodiversity and ecosystem services stress, such as pollution and water shortages.[6]

Just as potentially disruptive to supply chains are man-made interruptions. The recent drought in Panama coincided with conflict in the Middle East and attacks on Red Sea shipping on route for the Suez Canal from Houthi groups in Yemen in 2023, causing falls in container fleet ships by 67%.[7] Around 12% of global trade in a typical year passes through the Suez Canal, with significant costs for re-routing.[8] Conflict between Russia and Ukraine displaced many trading relationships, most significantly in energy, food and some manufactures, resulting in a global inflationary spike. The Ukrainian conflict also highlighted the use and effects of cyber warfare and criminality, both of which can also threaten supply chains.[9]

Insurance can play an important role in improving the supply chain resilience. Swiss Re has long tracked potential disturbances in the supply chain.[10] In the second part of this publication, we focus on the use of business interruption/contingent business interruption (BI/CBI) risk transfer products. Costing BI/CBI risks can be challenging due to lack of connected, reliable data. We show how, using a methodology defined by Swiss Re Institute and the Consortium for Data Analytics in Risk (CDAR), we can better understand BI/CBI exposures within supply chains. With this knowledge, insurers can work with their insured parties to define and shape appropriate and adequate risk coverage. Swiss Re can offer its clients a range of tailored BI/CBI solutions.[11]

Companies and governments are struggling to implement strategies to increase supply chain resilience, including in-sourcing, nearshoring, increasing stocks and supplier redundancy. Devising effective strategies requires an understanding of supply chain nodes, networks and interdependencies to calculate BI/CBI risks and the potential risk propagation and accumulation.

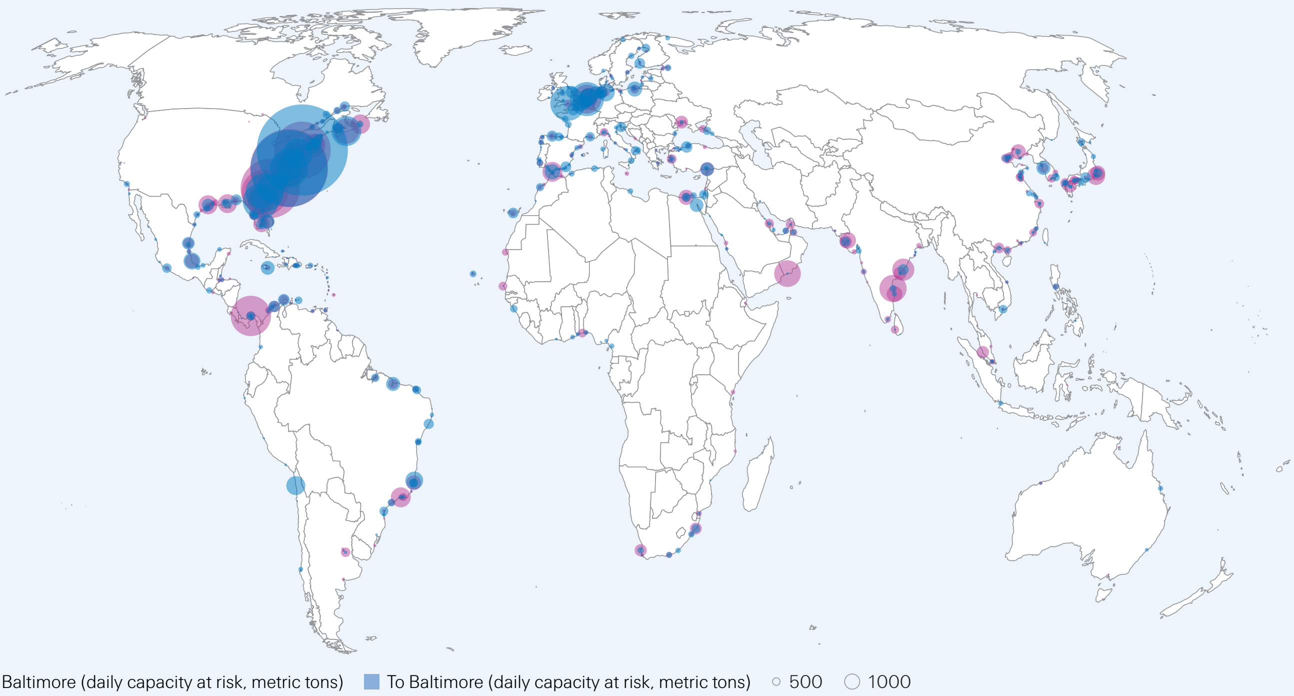
1 Qui, H. et. al., *Mapping the realignment of global value chains*, BIS Bulletin No 78, 2023.
2 *Urban Development*, World Bank, accessed August 2024.
3 *Current Status of Turkey's Mersin and Iskenderun Ports*, Hellenic Shipping News, 24 February 2023.
4 *Sicily heatwave brings power cuts, water shortages*, AFP, 24 July 2023.
5 For further details, please see: *Swiss Re CatNet® Premium (landing page)*
6 Salmi, A., et.al., *Biodiversity management: A supply chain practice view*, Journal of Purchasing and Supply Management, 2023.
7 *Red Sea, Black Sea and Panama Canal: UNCTAD raises alarm on global trade disruptions*, UNCTAD, 26 January 2024.
8 *What is the Red Sea crisis, and what does it mean for global trade?*, The Guardian, 3 January 2024.
9 Greenfield, V.A. et.al., *Cybersecurity and Supply Chain Risk Management Are Not Simply Additive*, Rand, 2023.
10 For further details, please see: *Swiss Re Supply Chain Resilience (landing page).*
11 For further details, please see: *Swiss Re Commercial Property & Business Interruption Insurance (landing page).*

Supply chain risk drivers

Supply chains: Scope and scale

On March 26, 2024, container ship Dali struck the Francis Scott Key bridge at the entrance to Baltimore harbour, causing the bridge to collapse, shutting the ninth largest port in the United States. Baltimore handled USD 80 billion of cargo in 2023.[12] As a result of the collapse, trade was disrupted for 76 days, with significant rerouting costs and increased transit times. A shipping channel was only opened again into the port in June 2024.

Figure 1
Representation of trade dependence on the port of Baltimore



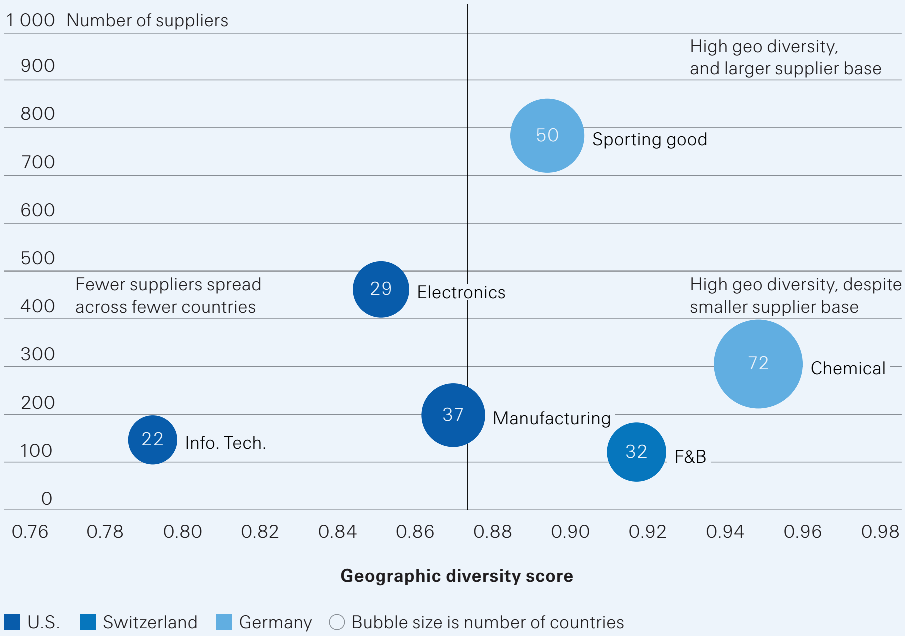
Source: Swiss Re Institute compilation based on IMF PortWatch[13], Verschuur, J., et al, 2022[14], World Bank Official Boundaries[15]
Note: Daily capacity at risk is defined as the loaded capacity (payload multiplied by the carrying capacity of the vessel) of vessels on a given route.

The Baltimore closure underscores the global interconnectedness of supply chains, whether coal to India or car parts to Europe, and how repercussions of one incident can reverberate along the entire chain. Our analysis shows how over 415 ports, around 10% of global commercial ports, trade with Baltimore (see Figure 1). The daily value of risk, pre-bridge collapse, was equal to 151 000 metric tonnes of vessel capacity, equivalent in weight to 20 Eiffel Towers. In the event, supply chains proved largely resilient to the closure, despite increased costs. Effective data sharing mechanisms helped reallocate traffic to other East coast ports together with extra road and rail capacity coming on stream.[16]

[12] *Baltimore collapse: US braces for supply chain disruption*, The Guardian, 27 March 2024.
[13] *IMF PortWatch*, University of Oxford, 2024.
[14] Verschuur, J., et al, *Ports' criticality in international trade and global supply-chains*, Nature Communications, 2022.
[15] *World Bank Official Boundaries*, World Bank, 2024.
[16] *How supply chains used FLOW after the Baltimore bridge collapse*, Supply Chain Dive, 15 May 2024.

Supply chains vary by sector. Of those we surveyed, major apparel manufacturers have the largest supply chains spread over wide geographies. However, automotive, chemicals and aerospace all have complex supply chains with thousands of suppliers, mostly unknown to them (as we discuss in the second section of this document). Having a highly diversified supply chain by company may not increase resilience if those suppliers are geographically concentrated. Our analysis suggests a sporting goods brand may have many more suppliers (up to 800) than, for example, a chemical company; but is still vulnerable to poor geographic diversification.

Figure 2
Representation of geographic and supplier diversity for selected companies and segments

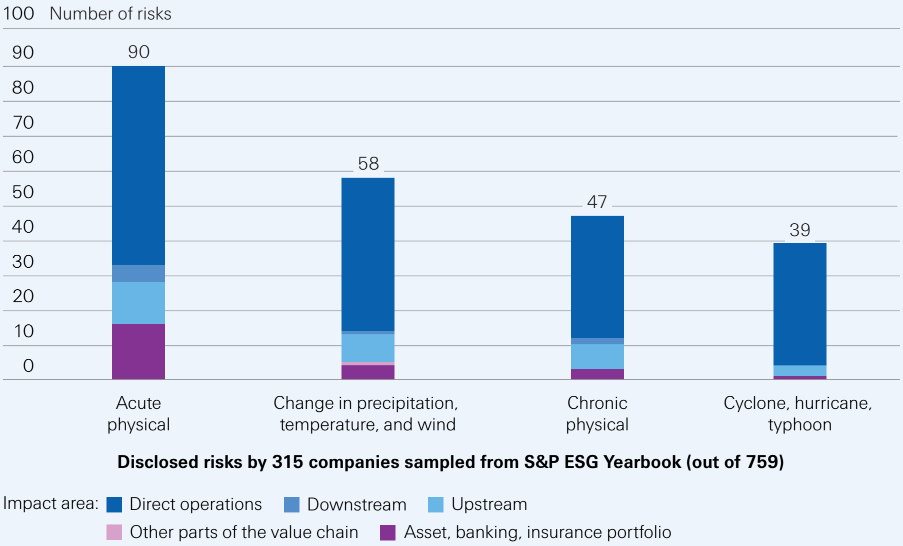


Source: Swiss Re Institute analysis based on public disclosures by companies and Open Supply Hub[17]
Note: Geographic diversity score has been calculated as a complement to the Herfindahl-Hirschman index to represent supplier diversity. A higher geographical diversity score means lower dependence on a particular geography for supplies. The companies are not necessarily representative of their sector.

Supply chains: Assessing physical risks

Supply chains are vulnerable to natural and man-made disasters. The World Economic Forum highlights the growing complexity of supply chains and the need for resilience at scale.[18] Companies acknowledge this vulnerability; but largely in terms of their own operations. Their visibility of supply chain risk, particularly beyond first tier suppliers, is often only partial.[19]

Figure 3:
Distribution of selected risks by supply chain impact area



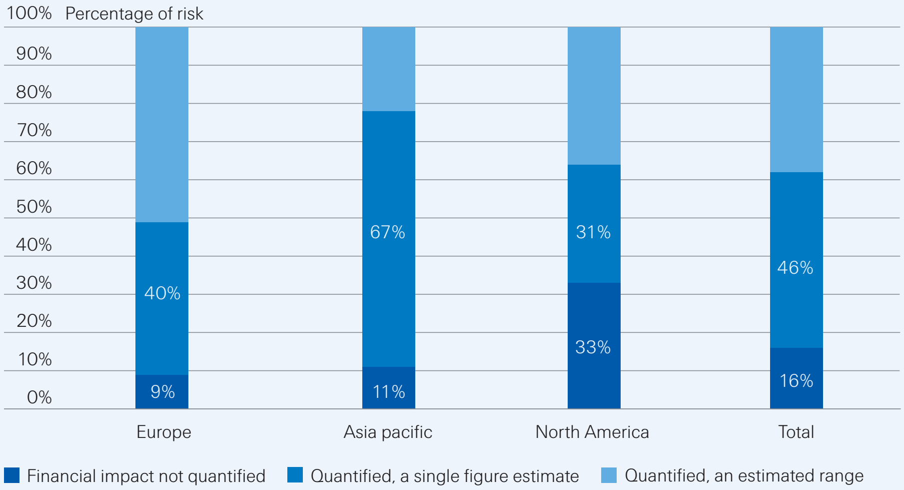
Source: Swiss Re Institute compilation based on CDP disclosure questionnaire; S&P Global
Note: Chose 315 companies from 12 largest economies from the S&P ESG yearbook (total of 759 companies)

Most companies recognise physical risks, such as storm or earthquake, as having a potentially severe impact on their direct operations. Figure 3 suggests that company risk modelling is largely focused on direct operations (dark blue) rather than third party risks in other parts of the supply chain. Companies have much less a view of risk impacts on their suppliers.

There is significant variability in company reporting metrics. Some companies report potential damage cost after an adverse event, whereas others report mitigation/adaptation costs, insurance costs, or damage to assets under management. Complex physical risks driven by multiple variables are less understood.[20] In Figure 4, we see that most risks are quantified through a single data point (light blue). A significant number of risks, particularly in North America, do not have any financial value attributed.

[17] *Explore global supply chain data*, Open Supply Hub, 2024.
[18] *Shared Intelligence for Resilient Supply Systems*, World Economic Forum, 2023.
[19] *sigma* 1/2022, *Natural catastrophes in 2021: the floodgates are open*, Swiss Re Institute.
[20] *Assessing physical risks from climate change: do companies and financial organizations. have sufficient guidance*, World Resources Institute, 2021.

Figure 4:
Quantification of financial impact associated with climate risks



Source: Swiss Re Institute compilation based on CDP disclosure questionnaire; S&P Global
Note: Chose 315 companies from 12 largest economies from the S&P ESG yearbook (total of 759 companies). All disclosed risks including non-physical risks are considered while assessing quantification of financial impact for better representation.

Analysis of the loss estimates indicates that complex physical risks are being underestimated.[21,22] Loss estimates could be improved by:

- Utilising fully probabilistic catastrophe modelling, linking physical hazards with loss outcomes and encompassing the entire range of statistically possible events and asset-specific vulnerabilities.[23]
- Greater geographic granularity, given that natural catastrophe hazards are extremely location specific. Several service providers are scaling up their resolution at up to 1 metre scale.[24]

Natural catastrophes: Understanding flood risks

In 2011, Bangkok experienced record flood losses totalling USD 46 billion, of which insurance losses were USD 15 billion.[25] Most of the insured losses originated from factories in the Chao Phraya River basin, including some of Asia's largest automobile and electronics manufacturers. Insurers included flood risk cover without additional premium charges in industrial all-risk (IAR) insurance policies, so that large commercial properties were covered at a premium level that did not reflect the actual risk. The total premium volume on IAR policies in Thailand was only USD 370 million in 2011, which led to a loss ratio of over 3 200%. Losses far surpassed the capacity of Thailand's insurers; and global reinsurers paid about 90% of the total claims. The 2011 floods highlighted the challenges of flood modelling in urban areas, particularly those undergoing rapid expansion. Swiss Re's Quantum Cities™ programme seeks to quantify entangled risks in densely populated cities, applying new data and modelling approaches to help insurers better understand, price and ultimately help protect communities against urban risks such as floods, including in high growth cities in developing countries where past data is often not available.[26]

Flood is a complex risk, dependent on a confluence of variables, including precipitation, tides, run off and highly localised topography. The effects of floods on supply chains can

[21] *Let's get physical: Comparing metrics of physical climate risk*, Finance Research Letters, 2022.
[22] S. Mathews et al, *The risk of corporate lock-in to future physical climate risks: the case of flood risk in England and Wales*, Centre for Climate Change Economics and Policy, 2021.
[23] *sigma* 1/2022, *Natural catastrophes in 2021: the floodgates are open*, Swiss Re Institute.
[24] *The climate risk landscape*, UNEP 2021.
[25] *The world's costliest flood: the 2011 Thailand flood*, 10 years on, Swiss Re, 2021.
[26] Montoya, A., *Managing risks in the world's megacities is increasingly complex*, Swiss Re, 2021.

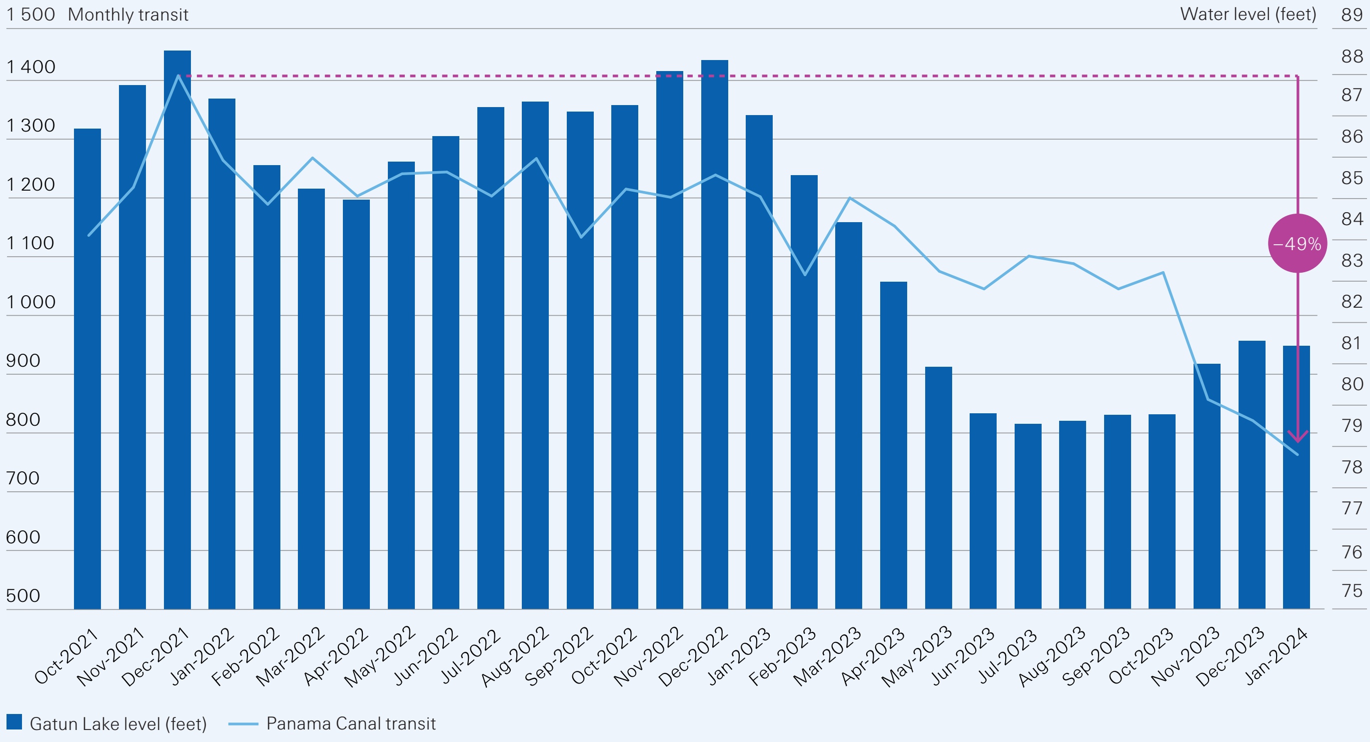
be profound, given the fact that many supply chains end in coastal or river-based cities. The impacts of river and coastal floods last for an average of 11 days, compared with 4.25 days for hurricanes.[27] Floods are compounded by wind speed and storm surge. An increment of 1m storm surge or 10m/s wind speed is associated with two days increase in port disruption duration; while a 35m/s wind speed or 2.5m storm surge typically results in ten-day port disruption in the US.[28]

Flood impacts and water level rises will both grow as threats to ports and so to supply chains. Investment costs for port adaptation and relocation in response to sea level rises are between USD 223–768 billion to 2050.[29] Ports are further at risk to storms and cyclones. Major ports, such as Shanghai or Ningbo, are currently closed around 5–6 days a year because of very strong winds. Extreme events can be even costlier; Hurricane Katrina, in 2005, shut the port of New Orleans for almost four months.[30]

Drought: A transport disrupter

The Panama Canal is crucial for global trade and supply chains. Around 12% of total U.S. trade volume traversed the Panama Canal in 2021, suggesting a one-week disruption of the canal would cost USD 1.5 billion.[31]

Figure 5:
Number of monthly transits in the Panama Canal, October 2021 – January 2024



Source: Swiss Re Institute based on UNCTAD calculations[32], Panama Canal Authority[33]

[27] *Extreme Weather Events*, UNCTAD, 2023.
[28] Verschuur, J., et al, *Port disruptions due to natural disasters: Insights into port and logistics resilience*, Transportation research part D: transport and environment, 2020.
[29] Hanson, S. et al, *Demand for ports to 2050: Climate policy, growing trade and the impacts of sea level rise*, Earth's Future, 2020.
[30] Verschuur, J., et al, *Systemic risks from climate-related disruptions at ports*, Nature Climate Chane, 2023.
[31] Woodwell Climate Research Center, *Drought in Panama is disrupting global shipping*, 2024.
[32] UNCTAD, *Navigating troubled waters: Impact to global trade of disruption of shipping routes in the Red Sea, Black Sea and Panama Canal*, 2024.
[33] Panama Canal Authority, *Gatun Water Level Indicators*, 2024.

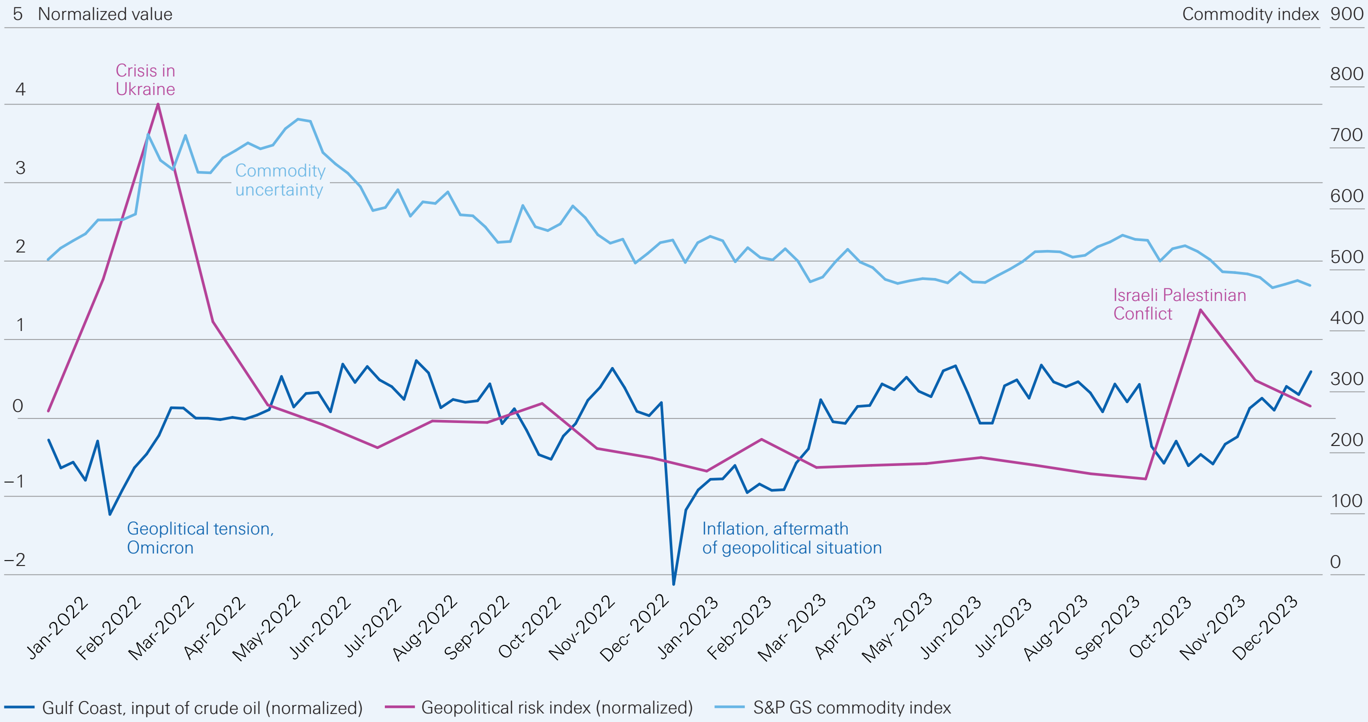
The effect of a strong El Niño and rising average global temperatures exacerbated severe drought in Panama in 2023, a phenomenon with an estimated 40-year return period.[34] SRI analysis found that the fall in water levels in Lake Gatun (see Figure 6) contributed to lower monthly transits from December 2021 to January 2024 by 49%. Moreover, ships needed to increase buoyancy in lower waters by reducing transit loads.

Supply chains are equally dependent on riverine trade. The Rhine suffered droughts in both 2018 and 2022. In 2018, total inland water transport in Germany fell by 11% over 2017. The resulting fall in industrial production in 2018 may have been as high as 1.5% across the whole of Germany; equivalent to a fall in GDP of 0.4%.[35]

Societal risks: Geopolitics and expecting the unexpected

The disruptions to the Panama Canal came at the same time as major disruptions on the Suez Canal. In November 2023, in a display of solidarity with Palestinians following the Israeli-Gaza conflict, Houthi factions in Yemen began attacking shipping in the Red Sea on route to the Suez Canal. The effect was dramatic. The United Nations Conference on Trade and Development estimated that freight passing through Suez was down around 45% in January 2024 from the commencement of the Houthi attacks.[36]

Figure 6:
Relation between geopolitical risk, commodity prices, and crude oil import (U.S. Gulf Coast)



Source: Swiss Re Institute based on U.S. Energy Information Administration (2024)[37]; S&P GSCI(2024)[38]; Caldara, Dario, and Matteo Iacoviello (2022)[39]

[34] Barnes. C. et.al.,*Low water levels in Panama Canal due to increasing demand exacerbated by El Niño event*, Imperial College London, 2023.
[35] Schattenberg, M., *Current water level of the Rhine brings back memories of the year 2022*, Deutsche Bank, 2023.
[36] *Freight through Suez Canal down 45% since Houthi attacks*, Reuters, January 26, 2024.
[37] *Weekly petroleum status report*, U.S. Energy Information Administration, 2024.
[38] *S&P GSCI*, S&P 2024.
[39] Caldara, D., Iacoviello, M., *Measuring geopolitical risk*, American Economic Review, 2022.

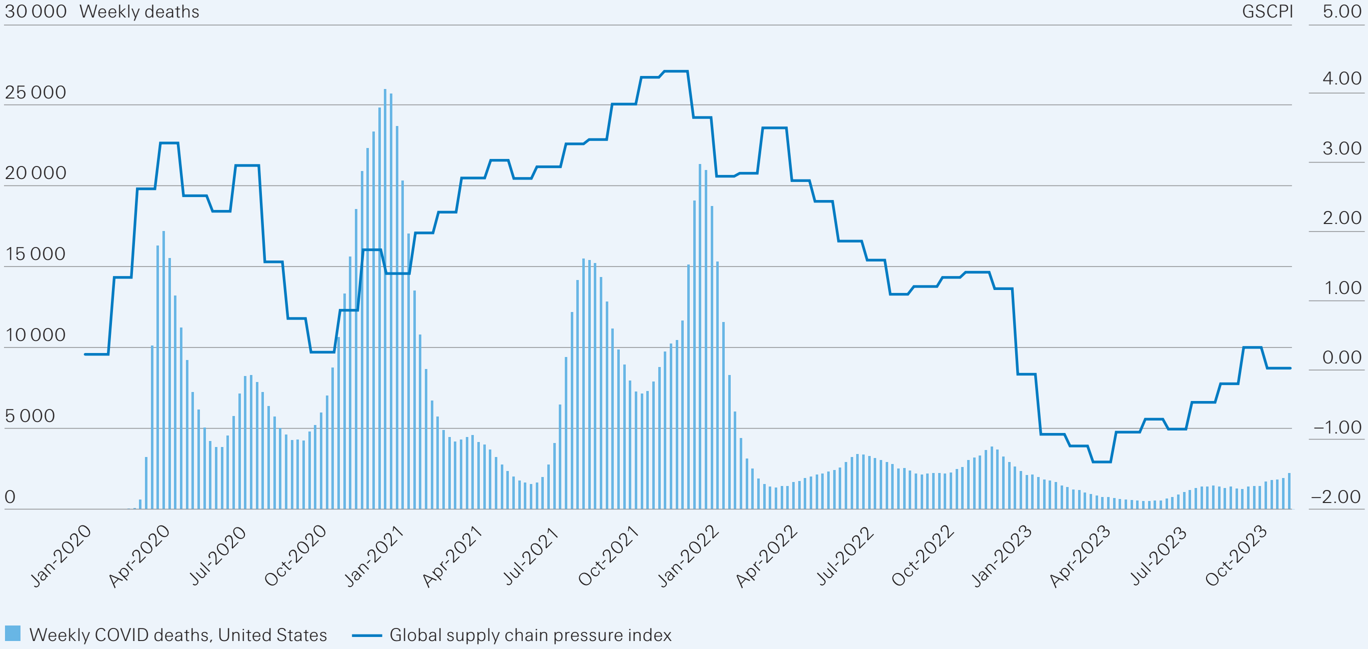
The current Suez crisis came at a point when supply chains had already been stretched by the Russian-Ukrainian conflict in 2022. In Figure 6, there is a correlation between the rise in commodity indexes and the Ukrainian conflict. Moreover, periods of political crisis have a drag on economic activity, partially seen by the lower crude oil supplied to refiners on the US Gulf Coast. SRI analysis indicates that between January and June 2022, the commodity index rose by over 40 percent because of geopolitical crises and the COVID-19 Omicron wave.

The Russian-Ukrainian conflict had an immediate impact on car manufacturers, particularly in Europe. Ukrainian component manufacturing, most specifically wire harness systems, was severely disrupted. Moreover, Russia, facing European sanctions, remains a key global supplier of nickel, palladium and neon gas, all necessary components of catalytic converters.[40] High levels of geographic concentration increase the risks that could arise from physical disruption, trade restrictions or other developments in major producer countries.

Societal risks: Pandemics going viral

Whilst pandemics have long been modelled within insurers' Life and Health business, the spill over into supply chains had not been fully realised until the waves of lockdowns accompanying COVID-19.

Figure 7:
Impact of COVID-19 on Global Supply Chain Pressure Index (GSCPI)



Source: Swiss Re Institute compilation based on Federal Reserve of New York (2024)[41], CDC COVID data tracker (2024)[42]

The Global Supply Chain Pressure Index (GSCPI) of the Federal Reserve of New York shot up (see Figure 7), with the first wave of the pandemic (represented by weekly US COVID deaths), falling briefly, before staying high over subsequent waves.[43]

[40] Silberg, G., *The impact of the Russia-Ukraine war on the auto industry*, KPMG, 2022.
[41] *Global Supply Chain Pressure Index*, Federal Reserve of New York, 2024.
[42] *COVID data tracker,* Centers for Disease Control and Prevention, 2024.
[43] *A New Barometer of Global Supply Chain Pressures,* New York Fed, 2024.

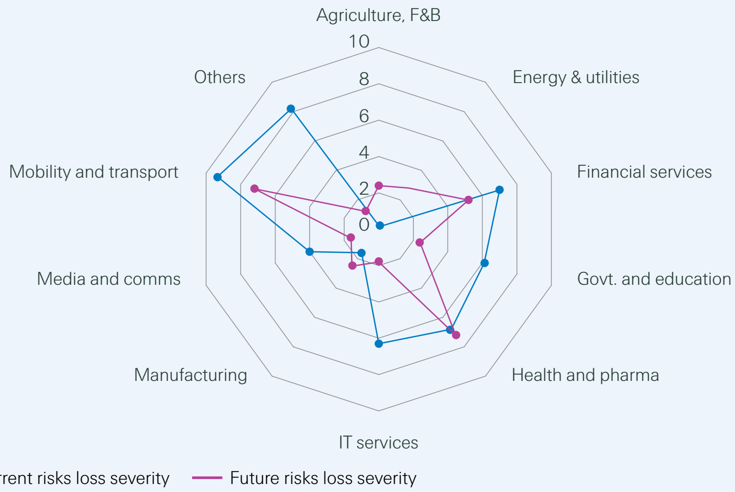
One study suggests a disease outbreak as major as COVID occurs once every 209 years, based on patterns from previous epidemics going back several centuries.[44] However, there are many modern threats – viral or bacterial lab leak, biological attack, globalisation of human and livestock traffic, and climate change – which could all exacerbate pandemic risk.

Societal risks: Cyber exposure of digital supply chains

Digital supply chains can build resilience – as they did with the Baltimore port blockage – but open a new vulnerability.

ENISA, the European Union Agency for Cybersecurity, believes that supply chains will be the single largest cyber security threat by 2030. At the Swiss Re Institute, we estimated that healthcare & pharmaceutical, transport/warehousing, and technology companies are likely to face higher AI risk at a sectoral level. The relatively high exposure of the mobility and transport sector, both to current and future AI risk, is striking.

Figure 8:
Current and future AI-related cyber risk severity across industries



Source: Swiss Re Institute[45]

Companies may have a restricted and imperfect understanding of their supply chain risks. This impacts how they can understand complex and interconnected risk, including the effects of climate change, natural catastrophes, geopolitical exposure and cyber risk.

[44] *Extreme epidemics are more likely than expected*, Nature Italy, 2021.
[45] *Tech-tonic Shifts*, Swiss Re Institute, May 2024.

Quantifying and modelling supply chain business interruption risks

Supply chain interconnectivity: The challenges of calculating BI/CBI risk

In the first half of this publication, we discussed the increasing challenges and pressures facing supply chains. In this second part, we consider how insurers manage supply chain interruption, most notably in the form of Business Interruption (BI) and Contingent Business Interruption (CBI) policies; how insurers can better understand and model their own BI/CBI exposures; and how we can help insurers and insureds improve and refine their supply chain risk management.

Defining characteristics: Business Interruption (BI) and Contingent Business Interruption (CBI)
Several insurance products can be impacted by supply chain interruptions; but there are two major insurance lines that specifically address business interruption risk: 1) Business Interruption (BI) insurance, which "replaces income lost in the event that business is halted due to direct physical loss of, or damage to, insured physical assets" and 2) Contingent Business Interruption (CBI) insurance, which "protects BI losses of an insured caused by a disruption in the operations of a supplier or other business partner that is the direct result of a physical loss of, or damage to, physical assets of the supplier or other business partner.[46] BI insurance covers losses related to the insured party's own assets; CBI covers losses incurred due to supply chain interruptions caused by third parties. BI and CBI are usually sold as riders or included into Property Damage policies rather than as stand-alone products. Typical terms of coverage can differ by country and CBI is usually provided with a sub-limit only.[47]

BI/CBI exposures are a big deal for insurers. Back in 2004, Swiss Re estimated that BI accounted for around half of the premiums and losses in the property insurance line. Twenty years later, for large claims of more than USD 5 million, the average property insurance claim which includes a BI component is more than double that of the average property damage claim without BI.[48]

However, understanding the data dynamics behind BI/CBI, and therefore underwriting the risk, has challenges:

- **Aggregated products and risk accumulation:** As BI/CBI coverage is typically bundled with property insurance, it can be difficult to disaggregate the underlying data and understand loss drivers. This can lead to significant risk accumulation that can be difficult to quantify and therefore manage, especially for reinsurers.
  The accumulation risk is particularly marked for CBI due to lack of precise supplier information and interdependent data across more than one insured party.

- **Lack of granular data:** Lack of standalone data makes underwriting based on past losses challenging.

- **Categorisation:** Names matter. Losses within group companies are frequently booked under subsidiaries and not consolidated under shared ontologies.

[46] Adapted from Kagan,J., *Business Interruption Insurance: What It Covers, What It Does Not*, Investopedia, 2023.
[47] *Business Interruption Insurance: every choice has a consequence*, Swiss Re Corporate Solutions, 2018.
[48] *Business Interruption loss trends*, Allianz, February 2022.

- **Size:** The larger a company, the more complex and networked its processes, the disproportionately larger supply chain losses can become. This is especially so for companies in sectors which typically have complex supply chains such as automotive, chemicals, electronics and aerospace.

- **Protection gaps:** Insured parties may not be aware of their potential exposures and subsequently may have insufficient coverage in place.

In cases where historic loss data is lacking, risk management procedures gain in importance. Insured parties are typically required to have business continuity management (BCM) plans if an event or supplier failure prevents production. BCMs should include measures to minimise downtime, including some visibility of the supply chain.

In order to offer BI and/or CBI covers, insurers need to assess the loss potential and then price the products. BI and CBI pricing is typically tied to a single property, for example, the cost of a factory unable to function. The risk must be identifiable and quantifiable; and broken down into two key metrics. The first one is the estimated maximum loss (EML), which represents the maximum anticipated loss a business could experience due to a covered event. It is used to determine the appropriate coverage limit for the policy. The second one is the maximum possible loss (MPL), which refers to the worst-case scenario loss, and it is used to ensure that the policy can adequately protect against catastrophic events.

Since BI insurance covers loss of net profit and continuing expenses after a major insured event, insurers usually require the insured to provide worksheets containing BI values assigned to each location (such as a factory), which should represent the company's (or plant's) future expected profit. There are no standard methods for the allocation, but it is considered good practice to assign gross profit value determined for insurance purposes. The assigned BI can be used to calculate the exposed BI, which, when combined with the duration of the interruption, gives the MPL.

However, this focus on risk tied to single plants or facilities only takes partial account of supply chain interdependencies. As we have seen in the first part of this analysis, supply chains are becoming more complex and interlinked. To appropriately quantify BI and CBI risks, taking into account the risk propagation that can occur across entities and even across industries, Swiss Re worked with the Consortium for Data Analytics in Risk (CDAR) at the University of California Berkeley, to develop a pioneering supply chain risk propagation model.[49]

BI/CBI: Accounting for risk propagation in complex supply chains

In order to quantify companies' supply chain risks, we need to calculate the probability and intensity of BI/CBI and its potential propagation across trade networks, which can be complex in the case of products with a large number of parts produced at different locations. Moreover, we need to be able to quantify the financial materiality of BI/CBI risk so as to develop effective risk mitigation approaches (avoiding risks where possible); and for unavoidable risks, risk management solutions (aiming to reduce losses where possible).

[49] For details see: Gurdogan, H. et. al., *A propagation model to quantify business interruption losses in supply chain Networks*, Consortium for Data Analytics and Risk (CDAR), 2022.

This methodology can be consolidated into three steps:

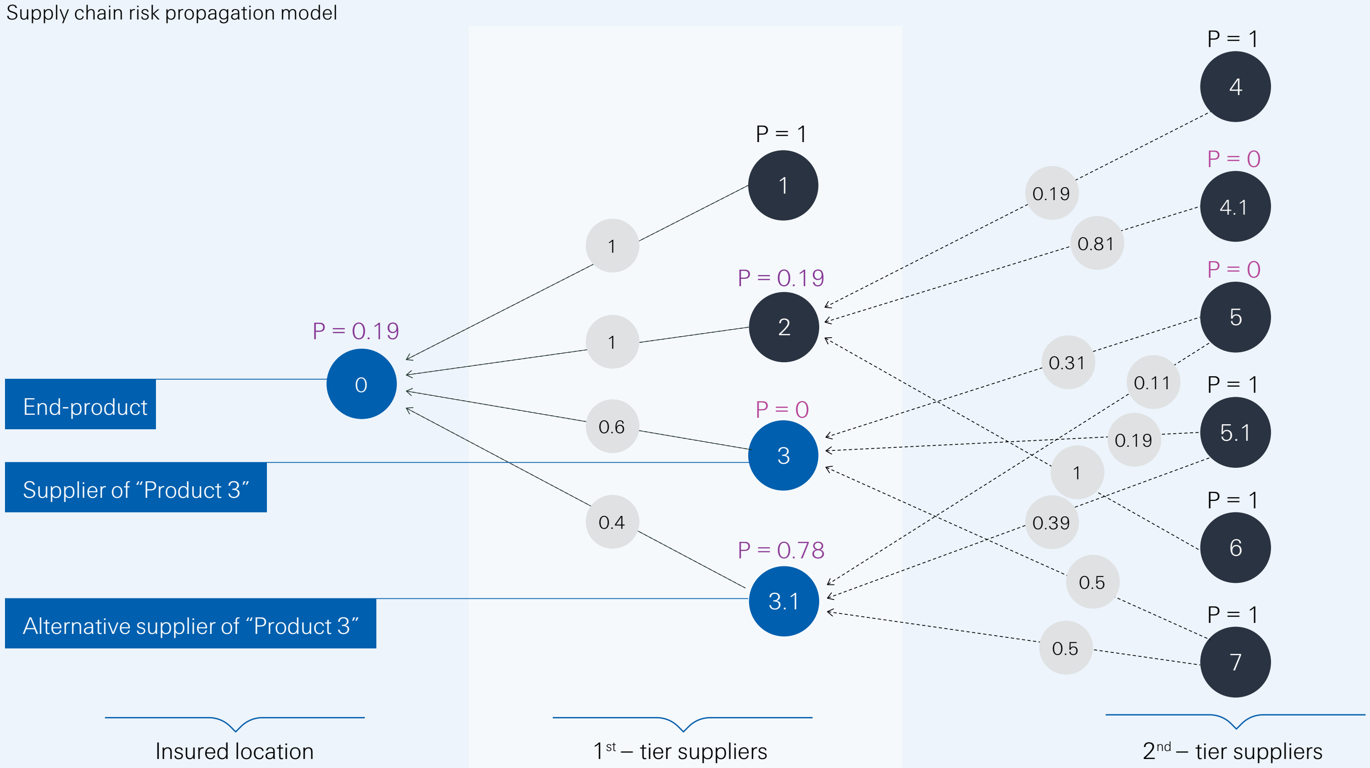
1. Identify required data points, including location interdependency; product / supplier scarcity; dependency on lifelines (including power networks, transportation); and expected production losses within a reference time window, given downtime periods at each node (see Appendix 1).

2. Remove entity ambiguity and map a company's supply chain, from tier-1 to tier-n. Machine learning algorithms can reconcile subsidiary company names using complex matching heuristics, allowing a realistic representation of the supply chain network, including hidden interdependencies among plants and suppliers.

3. With an accurate construction of the supply chain network nodes (including their interconnectedness and dependencies) and using real time and historic global trade data, we can then calculate the financial relevance of dependencies. This allows better quantification of impacted company sales/gross profit. If the dependence of sales on specific supply chain nodes can be calculated, the company's annual exposure can be quantified. This enables us to see how risk propagates through the supply chain by assigning appropriate BI values and quantifying the impact on sales at downstream plants and suppliers. With the mapped network and risk propagation model, we can then calculate the exposed BI from the assigned BI and estimate losses. This can be graphically rendered, as in Figure 9 below.

A full methodological presentation can be found in the joint publication between CDAR and Swiss Re Institute, *A propagation model to quantify business interruption losses in supply chain.*[50] For a given supply chain network, we consider the impact of a hazardous event to each production plant (nodes, starting from the right) using variables to determine the likelihood of a debilitating event and the production plant downtime caused by the disruption. Each impacted location will disrupt dependent locations and the impact will propagate downstream across the supply chain down to the end product (far left).

Figure 9:
Supply chain risk propagation model



Source: Swiss Re Institute

We have applied this model to fictional coffee capsule producer, Buon caffè. First, we developed a supply map; we then determined how we can use this information to identify and quantify BI and CBI losses along the Buon caffè supply chain. For a full explanation, together with examples of the model, please see Appendix 2.

BI/CBI: Risk propagation on automotive supply chains

Substantial automotive CBI losses were incurred as a result of the 2011 Tohoku earthquake and tsunami on the northeast coast of Japan, the event being a classic example of a ripple effect.

Post-disaster, production interruptions at primary and secondary suppliers saw shortages of microchips, electronics and other critical parts, slowing or halting car manufacturing. Most of Toyota's Japanese plants were closed for nearly two months, in which 45% of the company's vehicles were produced. In addition, Toyota's North American production fell to 30% of capacity for the subsequent 6 months due to a shortage of 150 different parts which should have been produced by Toyota's Japanese plants.[51] Toyota's profits fell 77% in the second quarter of 2011, equivalent to USD 1,36 billion.[52]

Japan automotive: Risk propagation across entities and supply chains

Using data from the 2018 earthquake in Osaka, we demonstrated the effectiveness of the Swiss Re Institute/CDAR model in accounting for previously overlooked supply chain interconnectivity and risk propagation effects. First, we identified a sample of impacted automotive manufacturing locations. We then estimated the total BI loss without considering location interdependencies. We then calculated the difference between directly impacted locations and indirectly impacted locations due to dependencies. The earthquake caused a chain reaction with business interruption radiating beyond Japan, affecting other locations within the automotive industry. This ripple effect resulted in an estimated additional 11% CBI losses.

Impacts of power outages on car producers

Power outages following an event can impact a large number of policyholders and therefore represent a potentially catastrophic accumulation risk for re/insurers. Category four Hurricane Ian cut the power for millions of business and residential electricity users in Florida in 2022. Applying One Concern's power outage business interruption model approach[53], we combined US power grid network data with a sample of auto-manufacturers' locations. We then applied a service interruption propagation model, which allowed us to identify dependencies, quantify risk, and estimate downtime probabilities for each location. The estimated losses resulting from a power outage at locations impacted by Hurricane Ian resulted in 2.3 times more losses than BI losses estimated via a standard natural catastrophe model.

[51] Canis, B., *Motor vehicle supply chain: effects of the Japanese earthquake and tsunami*, Congressional Research Service, 2011.
[52] MacKenzie C.A., et.al., *Measuring changes in international production from a disruption: Case study of the Japanese earthquake and tsunami*, International Journal of Production Economics, 2012.
[53] *One Concern Announces Strategic Partnership with Swiss Re to Reveal Nat Cat Business Interruption Risk*, One Concern, August 30, 2023.

Conclusion

Globalised supply chains boost efficiency and reduce costs. However, they are increasingly vulnerable to natural disasters and crises, including floods, droughts, cyber-attacks and geopolitical conflicts. In complex industries, such as automotive, pharmaceutical and aeronautics, where products rely on numerous interconnected suppliers across multiple tiers, disruptions can spread quickly, leading to significant BI/CBI losses.

Higher BI/CBI risk requires companies and re/insurers to better understand and cost the risks of supply chain interconnectivity. Improved understanding can better guide resilient supply chain risk management as well as appropriately priced re/insurance covers.

In order to provide cedents with appropriate coverage, re/insurers must undertake three steps: (1) work together with insured parties to map their entire supply chains across multiple tiers, integrating and reconciling datasets; (2) identify critical risk exposure locations and dependent nodes; and (3) accurately quantify impacted production volumes together with duration. Better quantifying supply chain risks and their propagation allows re/insurers to enhance risk costing and selection, steer portfolios, manage company-level accumulation, and allocate underwriting capacity effectively.

Supply chain analytics can enhance resilience by considering factors such as alternative suppliers, product uniqueness and storage options. For unavoidable risks, supply chain insurance is an important support tool in helping companies recover swiftly. Indemnity products, such as BI and CBI, are effective in covering basic risk losses, while new parametric covers protect against triggers such as extreme weather days or river water levels.[54]

Quantifying supply chain risks allows for the development of new risk transfer products and analytical services that can assist companies in enhancing their resilience.

360°capabilities	Potential products and analytics features
Visibility	**Digital twin:** Visualise end-to-end supply chain mapping down to tier-n across all industries globally.
	Risk insights: Explore supplier and product dependencies and overlay historical and live eg weather risk data.
	Alternative suppliers: Find alternative suppliers (and customers) by country and products.
	Supplier risk hotspots: Identify suppliers risk hotspots and concentration.
	BI allocation of revenue at risk: Quantify the portion of revenue at risk at each site considering supply interdependencies.
Mitigation	**Resilience analytics (including revenue impacted):** Advanced supply network analytics and what-if scenarios eg simulate disruptive events and quantify loss of revenue across supply chain.
	Risk mitigation insights: Effective risk mitigation investments on resilience measures by simulating impact of mitigations eg buffer of key material stocks for strategic products, investment on site protections.
Protection	**Insurance covers:** Including new products eg parametric BI covers based on river levels

Source: Swiss Re Institute

[54] See Swiss Re, *Parametric Insurance Solutions*, accessed 2024.

Appendix 1: Key supply chain questions powering our model

01 **Which locations in a portfolio are dependent on others?** Portfolios can contain sites of a company without their suppliers (BI) or include suppliers (CBI). The data source for location information is exposure (submission data) and for suppliers' locations and relationships can come from supply chain relationship or shipment datasets.

02 **Which products (raw material/parts) are supplied to the dependent locations? Which companies supply those products?** eg product description (eg HS code). Our main data source is the shipment dataset.

03 **What is the relative scarcity or risk of those products/suppliers?** Scarcity can be defined based on availability of materials in one or several regions/ countries, number of suppliers, already established relationships with suppliers and tier-n single sources of raw materials (eg silicon).

04 **How can business interruption propagate? What is the probability and intensity of the propagation?** Given an interruption at a location (either at an insured corporate company or their suppliers) how can it propagate to other connected locations? What are the metrics to use? If the products are not single source, how much time would it take to find alternative suppliers?

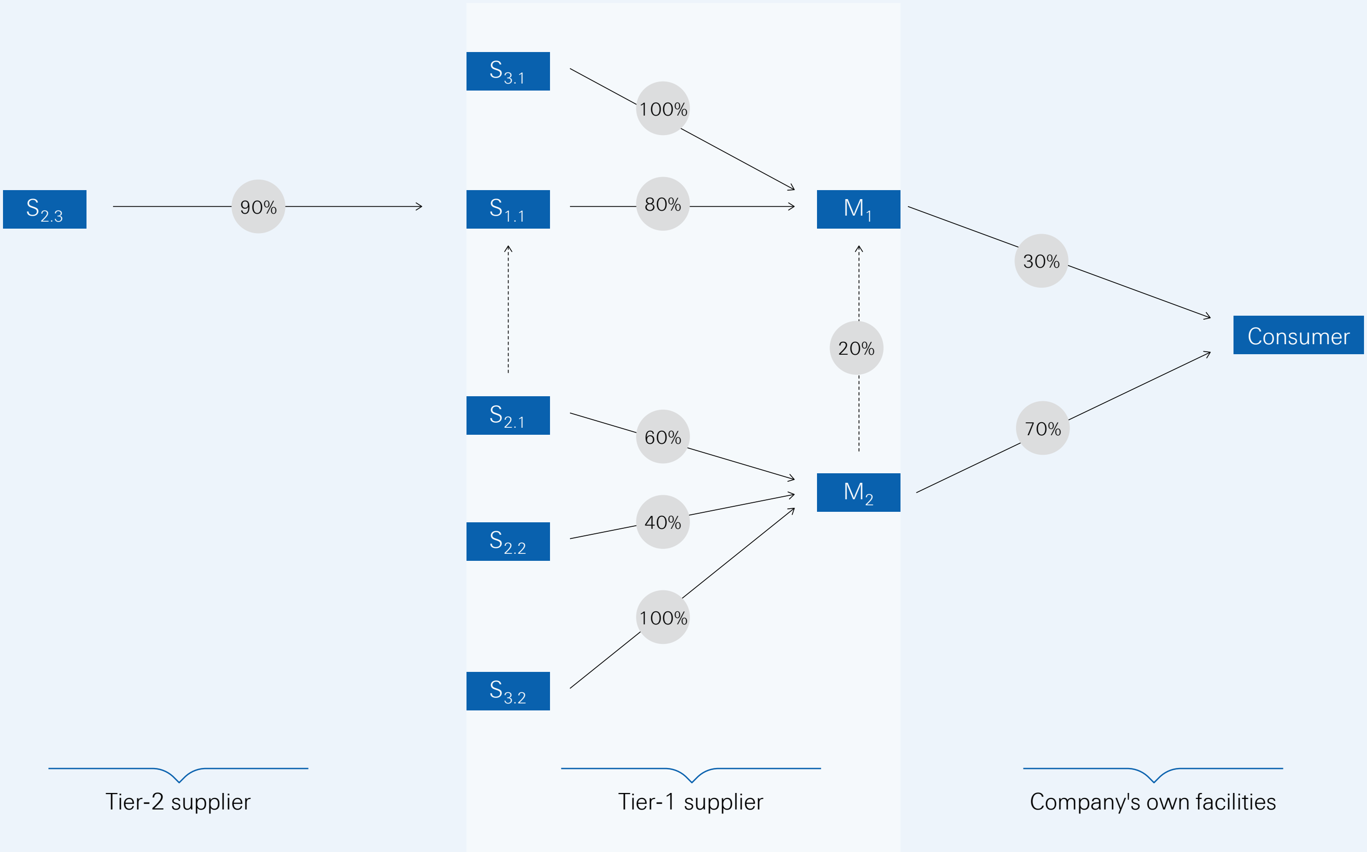
05 **How can we estimate financial losses at a dependent location?** How much is the interdependent CBI/BI exposure at each location? The total assigned exposure can be more than the initially estimated exposure due to the propagation effect.

To quantify supply chain BI and CBI risks and estimate financial losses, insurers must address factors such as production locations and supplier dependencies, and model risk spread to create resilience strategies and products.

Appendix 2: Buon caffè: Working BI Example

Supply chain mapping

Figure 10:
Mapping Buon caffè's supply chain

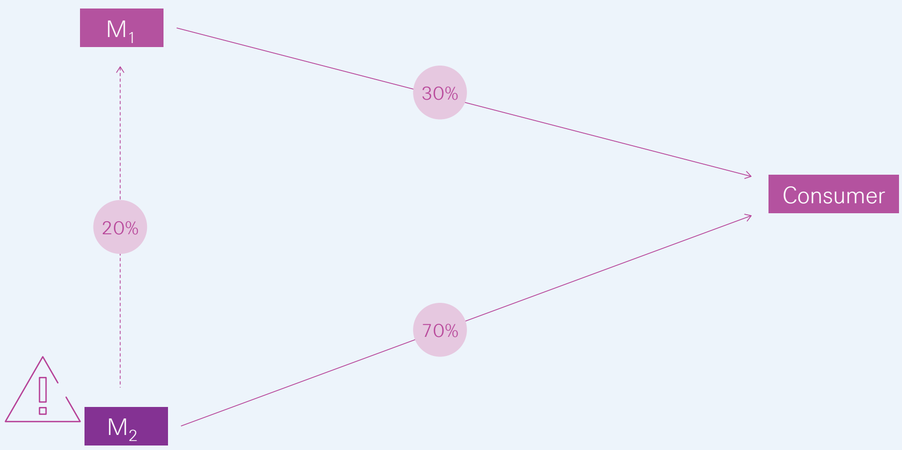


Source: Swiss Re Institute

Buon caffè produces coffee capsules, generating a gross profit of USD 100 million a year. At the core of its supply chain network are two manufacturing facilities, M1 and M2, located in different countries. M1 generates 30% of the company's gross profit; M2 the remaining 70%. Both plants produce coffee capsules processing coffee beans (supplied by other companies) to be sold in aluminium pods, which are made from aluminium sheets (supplied by other companies). S2.1, S2.2 (tier-1 suppliers), S2.3 (tier-2 supplier) supply aluminium sheets, S3.1 and S3.2 (tier-1 suppliers) supply coffee beans while S1.1 supplies aluminium pods derived from aluminium sheets. M2 also processes aluminium sheets and ships aluminium pods to M1. M2 receives 60% of the aluminium sheets needed from S2.1 and the remaining 40% from S2.2. and the only coffee beans supplier is S3.2. M1 receives coffee beans from S3.1 and aluminium pods from S1.1 (80%) and M2 (20%). S1.1 receives aluminium sheets from both S2.3 (90%) and S2.1 (10%). The weights on the incoming arrows for the same product supplied to each node needs to add up to 100% to be able to produce the planned capsule quantities. Dashed arrows represent interdependencies that could be potentially hidden or unknown not only to the insurers but also to Buon caffè, especially when considering interdependencies among suppliers.

Interdependent BI

Figure 11:
Buon caffè's manufacturing facilities



Source: Swiss Re Institute

We consider the same supply chain network as in Figure 1 but only take into account Buon caffè's plants (BI element) and their interdependencies (CBI element). The objective is to estimate the maximum potential loss business interruption (MPL-BI) for M2. We will perform the calculation with and without considering interdependencies to show how the loss estimation changes. We assign BI values based on gross profit, as shown in the tables below.

1. If the production interdependency between plants M2 and M1 remains hidden: If M2 shuts down the loss estimates will only be related to the disruption of M2. Assuming an impact of 100% in the worst-case scenario, the exposed BI is then USD 70 million, that is 100% of the assigned BI of M2. Assuming that the restoration period is 15 months, the MPL-BI will be 70 × 15 : 12 = USD 87.5 million.

Location	Assigned BI value (USD m)	Expected BI impact (USD m)	Expected impact %
M1	30		0%
M2	70	70	100%
Total	**100**	**70**	

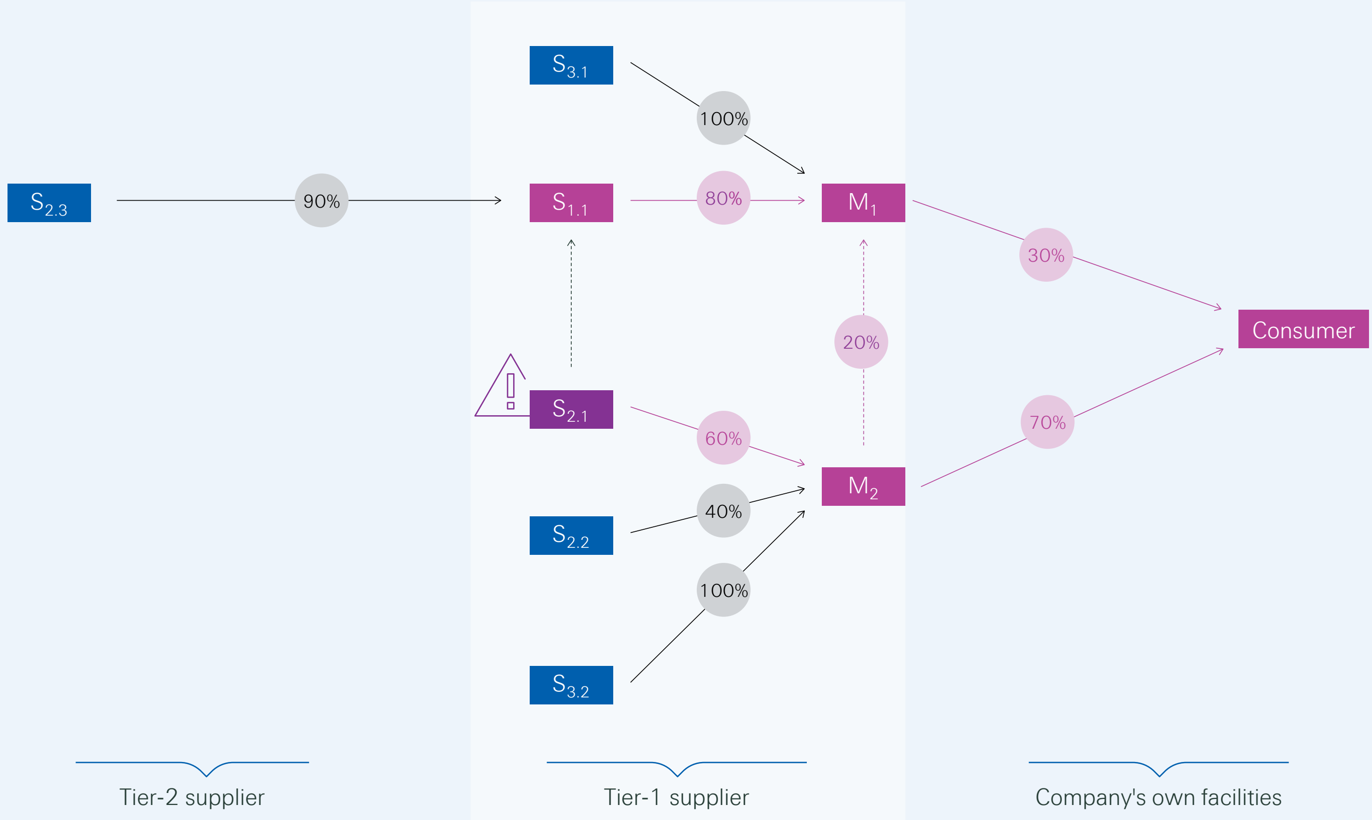
2. After more detailed analysis, the interdependency between M2 and M1 is discovered: The financial strength of the dependency is derived from the data. For example, using machine learning techniques, if M2 shuts down, we know M1 will be impacted in the worst-case scenario (20% impact). In this case, the exposed BI is actually USD 76 million. The MPL-BI is USD 95 million, around 9% more than the previous estimation.

Location	Assigned BI value (USD m)	Expected BI impact (USD m)	Expected impact %
M1	30	6	20%
M2	70	70	100%
Total	**100**	**76**	

This example highlights that even if the BI values to each plant have been assigned properly, without considering interdependencies, BI estimates will be inaccurate as insurers cannot propagate the risk across the network. This means that in the case of an actual loss Buon caffè will be underinsured / unknowingly exposed.

Interdependent BI and CBI

Figure 12:
A disturbance at Buon caffè's Tier 1 supplier



Source: Swiss Re Institute

In this example, Buon caffè would like to purchase a CBI cover for key tier-1 suppliers, that is S2.1. In order to calculate the risk, one must estimate the maximum potential loss business interruption (MPL-BI) for S2.1 that is also related to the MPL-CBI of Buon caffè. We perform the calculation with and without considering interdependencies to show how the loss estimation changes. BI values for M1 and M2 have been assigned based on gross profit while, even if the BI values for the suppliers (eg. S2.1) are not known, the business interruption propagation can still be quantified.

1. If all interdependencies remain hidden: If S2.1 shuts down, the loss estimates will only reflect the business interruption of M2. Assuming an impact of 100% for S2.1 in the worst-case scenario, the exposed CBI for Buon caffè is then USD 42 million, that is 60% of the assigned BI of M2 and 42% of the total assigned BI. Assuming that the restoration period is 15 months, the MPL-CBI will be 42 × 15 : 12 = USD 52.5 million.

Location	Assigned BI value (USD m)	Expected CBI impact (USD m)	Dependency on S2.1
S1.1			10%
S2.1			100%
S2.2			0%
M1	30		0%
M2	70	42	60%
Total	**100**	**42**	

Source: Swiss Re Institute

2. After more detailed analysis, the interdependencies are discovered: The financial relevance of the dependencies is derived from the data. For example, using machine learning techniques, we know that if S2.1 shuts down, then M1 will also be impacted in the worst-case scenario (10% × 80% + 60% × 20% = 20% impact). In this case, the exposed CBI is actually USD 48 million. The MPL-CBI is USD 60 million, that is around 14% more than the previous estimation.

Location	Assigned BI value (USD m)	Expected CBI impact (USD m)	Dependency on S2.1
S1.1			10%
S2.1			100%
S2.2			0%
M1	30	6	20%
M2	70	42	60%
Total	**100**	**48**	

Source: Swiss Re Institute

If the interdependency between M2 and M1 remains hidden, if M2 shuts down the loss estimates will only be related to the disruption of M2. If the interdependencies remain hidden, if S2.1 shuts down the loss estimates will only be related to the disruption of M2. Assuming an impact of 100% in the worst-case scenario, the exposed BI is then USD 70 million, that is 100% of the assigned BI of M2. Assuming that the restoration period is 15 months, the MPL-BI will be 70 × 15 : 12 = USD 87.5 million.

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