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**Exploring Innovative Supply Chain
Practices to Enhance Resilience in Times of
Frequent Disruptions**

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Exploring Innovative Supply Chain Practices to Enhance Resilience in Times of Frequent Disruptions

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1. Introduction

The COVID-19 pandemic has emerged as a formidable driver of unprecedented disruptions across global supply chains. From a socioeconomic perspective, the illness of an individual entailed a narrower engagement in productive activities, thus implying a huge loss when aggregated at a macroeconomic level (Kovács & Falagara Sigala, 2021). This wasn't an isolated case, but simply a gigantic one that couldn't be overlooked. In fact, if we consider the last 3 years, we moved from 3700 disruptions in 2019 to 11642 in 2021 (Placek, 2022), hence we can see how supply chain disruptions have been consistently increasing throughout the years.

The pandemic has exposed the vulnerabilities of previous supply chain models, where the priority was often placed on extreme over-optimization, followed with the intention of making processes more efficient: strategic plans built on single-sourcing suppliers, excessively long supply chains with little geographical diversification and zero inventory have thus shown themselves in all their frailty.

In response to these rapidly-emerged challenges, companies have been redesigning their supply chain strategies, placing greater emphasis on resilience, agility, and risk mitigation, thus fostering a vision of supply chains as value-generating levers.

In an attempt to see the glass half-full, we should quote a great thinker of the past, Josef Schumpeter, and face the recent pandemic not as an unpredictable black swan, but as a “force of creative destruction” that opens up the opportunity to build back something better than before.

Given this fluid context, which can be classified as VUCA (Volatile, Uncertain, Complex, Ambiguous) (Bennis et al., 1986), executives are changing the focus of their investments from maximization of efficiency to risk hedging. Metaphorically, it is pointless to have perfect, beautiful toys that, on the other hand, cannot withstand the first bump or attrition and stop working properly.

Previous studies highlight that geopolitical dynamics (Maihold, 2022; Bednarski et al., 2023), inflation (Mullin, 2023; Vallejo, 2022; Maersk, 2023), and climate changes (Stern Review, 2006; Hitchcock, 2012) can trigger disruptions in supply chains, and these risks are typically analysed from a macroeconomic and policy-making perspective. To mitigate and protect against such risks, innovative practices such as 3D printing (Serohi, 2021; Naghshineh & Carvalho, 2022), Digital Twin (Barykin et al., 2021; Jones et al., 2020), Cross-functional teams (Bode et al., 2011; de Vries et al., 2021) and Artificial Intelligence (Bubeck et al., 2023; Hitch, 2023) are proposed to enhance supply chain resilience. Additionally, the literature emphasizes the growing importance of resilience and sustainability in supply chain management (Ciuriak, 2023; Brakman et al., 2020; Macdonald et al., 2018; Seuring & Müller, 2008).

However, these discussions often lack the perspective of multinational companies, which is of crucial importance since they operate daily within global supply chains. In fact, geopolitical, inflation, and climate risks are rarely framed from the viewpoint of large multinationals, who are often on the front lines of managing the emerging disruptions. Furthermore, the four innovative practices previously mentioned would require practical evaluation by industry professionals to assess their potential and limitations. Lastly, it would also be valuable to understand how resilience and sustainability are truly prioritized in multinationals' supply chain processes and whether they are seen as drivers of new, competitive business models.

Thus, the objective of this thesis is to offer a new, detailed perspective over the resilience of supply chains in times of frequent disruptions.

This will be explored through three research questions.

The first question will be: *What are the risks recognized as the major potential causes of disruption in the supply chain of multinational companies?*

The second question will be: *Are the selected four practices – 3D printing; Digital Twin; Cross-functional teams; AI – already applied by multinational companies to mitigate the risk of disruption in the supply chain? If not, is there a recognized potential application of these practices?*

The third question will be: *To what extent are the concepts of resilience and sustainability prioritized within the supply chain of multinational companies? Furthermore, are they considered drivers for the development of new, competitive business models?*

The thesis is structured as follows: first, a comprehensive theoretical background will be conducted to explore the state-of-the-art of the chosen topics, which will then be systematically coded into a series of research proposals, following the outline provided by the three research questions. After a thorough explanation of the research method employed, which is based on qualitative interviews, the findings emerging from the interviews will be analysed. Finally, space will be given to discussions, where the theoretical premises will be compared with the empirical information gathered through the direct experience of the professionals who participated in the study, thus allowing to reach a more comprehensive understanding of these topics.

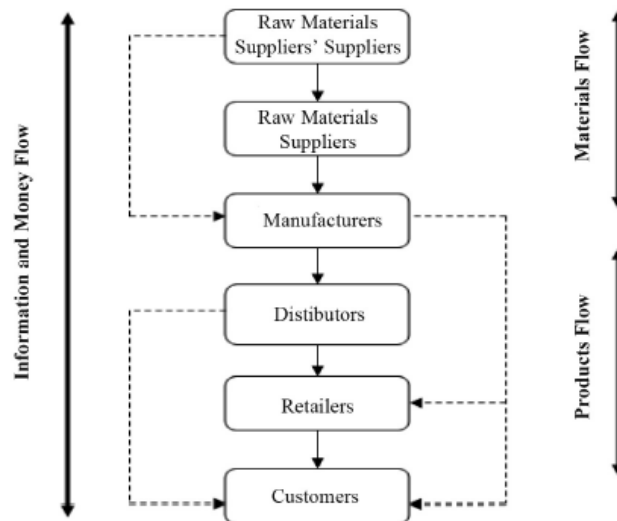
2. Theoretical Background

2.1. Definition of supply chain and resilience

Firstly, it's important to have a general understanding of the current state of the arts. When talking about supply chains, we refer to “a sequenced network of business partners involved in production processes that convert raw materials into finished goods or services in order to satisfy the consumers' demand” (Mensah & Merkurjev, 2014).

An essential supply chain is composed by a number of actors: raw materials suppliers, manufacturers, distributors, retailers, customers. The image below (Mensah & Merkurjev, 2014) depicts clearly how they can be connected with each other.

Figure 1. Simple Supply Chain stages (Mensah & Merkurjev, 2014)



At the beginning, we only talk of a flow in terms of raw materials. After the manufacturing process, we move to a flow of products. Both information and money are present throughout all the steps inside a supply chain, as they fuel the movement of goods and services. Some supply chain can be so optimized that they skip some intermediators, like distributors or retailers. An example of this can be

the ecommerce, where the raw materials are transformed into finished goods and directly sold to the final customers thanks to an online platform. We are not going to describe every potential supply chain configuration; nevertheless, it was important to note how this big definition includes an infinite range of combinations, with each and every of these having unique features tailored to the specific business model. What is important is that all the elements of a chain are capable of adding value in the process, or else they would be inefficient parts that need to be cut.

Naturally, any agent within a supply chain has a team of people dedicated to managing the relationships, upstream or downstream, with the other agents of the supply chain itself. This is a vital and complex task, that implies reasoning in terms of cost, quality, compliance to standards and, more than ever in this period, risk. Since a vast part of the supply chain is out of the direct control of an agent, like a manufacturer or a retailer, it's essential to assess the risks linked to the transactions taking place across the chain. In the paragraph 2.2 we are going to enlist and describe the set of potential risks and their disruptive effects over the correct functioning of a supply chain.

Moving on, we should define what we mean when we refer to resilience. Taking inspiration from the natural sciences, we define resilience as the ability of a substance to get back to its original state or form after deformation (Mensah & Merkuryev, 2014).

Hence, applied to the supply chain domain, we consider it the ability of a supply chain to absorb the shock stemming from a disruption, to then return at its previous state of functioning.

2.2. Supply chain complexity (SCC)

2.2.1. What is SCC?

Since we could consider the outbreak of disruptions as an independent variable, why nowadays the effects tend to reverberate across the whole supply chain?

This phenomenon, called ripple effect, is mainly driven by the exponential increase in supply chain complexity (SCC), which represents “*the extent to which the supply chain of an organization is made up of a large number of varying elements that interact in unpredictable ways*” (Akın Ateş et al., 2021).

Just to give the flavour of how much it can cost, McKinsey estimated that complexity, within the food and beverage industry alone, could be costing a total of 50 billion USD annually in gross profits (Adams et al., 2016). Not exactly crumbles, we might say.

Complexity in supply chain can be listed in three levels:

- Upstream complexity. Characterized by the relationship between the firm and its suppliers. This is amplified by the number of suppliers, their geographical positions, their size, their organizational culture or technological level (Bode & Wagner, 2015).
(Ex. Dealing with 5 suppliers living in the same country is easier than dealing with 30 suppliers scattered around 3 different continents)
- Internal complexity. Characterized by a high variety in parts, processes and products which lead to frequent changes in the manufacturing schedule (Eckstein et al., 2015).
(Ex. A firm producing a single product with a single process is easier to manage than a firm producing 10 different versions of the same products using 3 different processes to do so)
- Downstream complexity. Characterized by the relationship between the firm and its customers. This is amplified by the number of customers and their variety in preferences (Caridi et al., 2010).
(Ex. Addressing one customer segment in a non-competitive market is easier than addressing multiple customer segments in an oversaturated market)

2.2.2. Effects of SCC on performance

Following the work of Akın Ateş et al., (2021) we observe how the previously enlisted levels of complexity can influence three dimensions of firm performance: operational performance, innovation performance and financial performance. Specifically:

- Operational performance. SCC often results in detrimental performance from an operational point of view. Typical negative effects can be an increase in more transaction costs, long and unreliable lead times, imprecise scheduling of activities and unsuitable product quality. This is often a byproduct of upstream complexity: a larger pool of suppliers inevitably leads to a wider information processing need, therefore broadening transaction costs that aren't often scalable (Bode & Wagner, 2015). Furthermore, the diffused unreliability in delivering will naturally fuel inefficiencies, mainly in the form of larger safety stocks (Caridi et al., 2010). Internal complexity can also be an obstacle because product proliferation is easily linked with higher inventory costs. For instance, Hu et al., (2008) took the automotive industry as an emblematic case, where the huge number of customizable combinations in their vehicles significantly affected quality and productivity. Lastly, even downstream complexity plays a negative role in the operational performance: a high variance in demand makes the exploitation of economies of scale harder and carries with it higher setup costs (Bozarth et al., 2009).
- Innovation performance. In this case, the effect is more ambiguous and difficult to evaluate. Although the suppliers' dispersion typical of the upstream complexity can be damaging for the innovative power of a company, a wider pool of suppliers implies having a bigger basket from which ideas and stimulus can be caught (Choi & Krause, 2006). It's logical to think that having access to a more extended network facilitates the

probability of coming across a new technology or an innovative way of doing things. For instance, Krause and Wagner (2008) took the case of a firm leveraging horizontal competition among a group of suppliers, challenging them to develop the best design for a new product in order to be awarded with a partnership. Here, a bigger group of suppliers, acting in a controlled framework of competition, could be managed with the aim of stemming more innovation for the main company. Fortunately, both internal and downstream complexity are univocally positive drivers of innovation: the first, in the form of product and process complexity, can foster synergies among the various elements at play (Chaudhuri and Boer, 2016), while the second opens up to events of co-creation with the involvement of the customers, thus stemming the main firm innovativeness (Chang & Taylor, 2017).

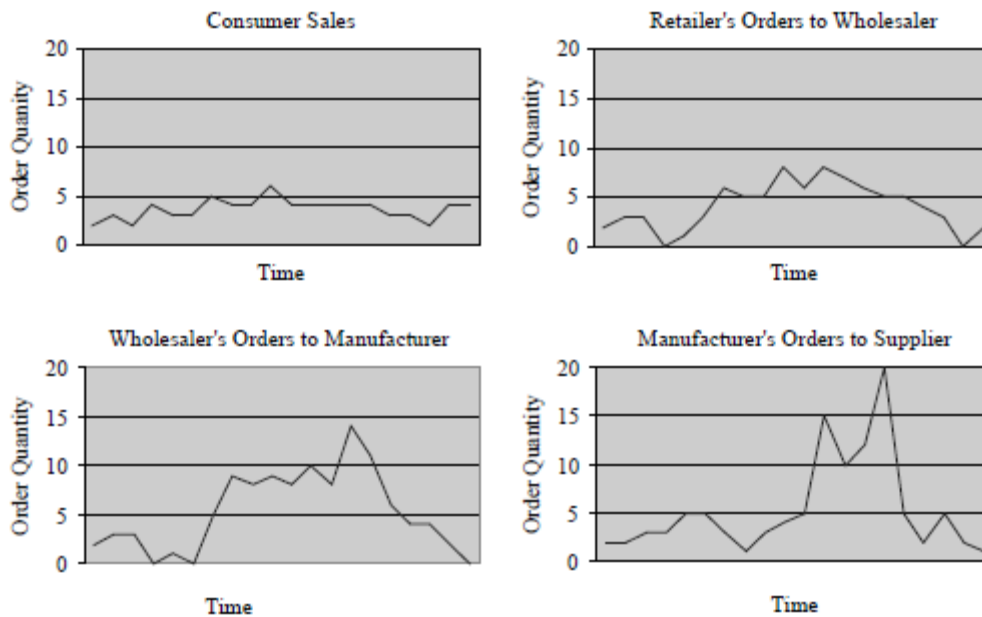
- Financial performance. This last dimension is quite difficult to analyze as it undergoes a series of indirect effects that are only partially influenced by SCC and by the other two dimensions previously described. Logically, upstream complexity makes decision-making more difficult for the managers of a company, and this might lead to supplier opportunism. Hence, shrinking the cost-saving potential of supply chain management. Internal complexity usually drive ambiguous effects: differentiation of products is a vital determinant of increased competitiveness and revenues, but beyond a certain threshold, this breadth of offerings may become heavy due to increased changeover costs, inventory levels and lead times, therefore weighting on operational costs and, consequently, narrowing profits (Wiengarten et al., 2017). Lastly, when thinking of downstream complexity, difficulties in predicting the demand nourish uncertainty, therefore making it harder to schedule convenient volumes of production and, almost certainly, leading to a declining customer satisfaction (Chen et al., 2018)

Overall, as highlighted by Akin Ateş et al., (2021), we see that the final balance is a net negative effect on operational performance, a net positive effect on innovation performance and a more ambiguous effect on financial performance, which slightly tends to be positive. Hence, acknowledged that we live in a world of intrinsically complex supply chains, we can now look at them with a certain hindsight and establish whether or not the trade-offs related to such complexity is justified or not. Companies that are targeting cost-saving and optimization, may cut off some branches from both suppliers, product offerings and customer segments in order to attain this goal, while companies that see development in innovation and diversification of products should concentrate on those practices that can help in managing correctly the inherent complexity of their supply chains (Leuschner et al., 2013).

2.2.3. The Bullwhip effect

We have already said how much supply chain management emphasizes close coordination among the various companies involved in the chain. It requires supply chain members to recognize that they are part of a complex, highly interdependent network. All the companies involved in the network are important in establishing a desired level of customer service in the supply chain and satisfying their customers' requirements. In this sense, an emblematic example is the Bullwhip Effect, named for the first time by a Procter & Gamble logistics executive around the 1990. This is a situation where small order variability at the customer level amplifies along the supply chain's intermediaries, from the direct retailer up to the manufacturer. In his 1997 paper, Lee et al. provides a set of graphs to clearly depict the phenomenon.

Figure 2. The Bullwhip Effect (Lee et al., 1997)



It starts by acknowledging the relatively stable demand in consumer sales, the primordial cause of the whole supply chain movement. The retailer demand graph begins to slightly misalign from the actual consumer demand, but then this become even more exacerbated in the wholesaler demand first and the manufacturer demand after, where we see a radical distancing from the original curve. This progressive, increasing misalignment after each stage of the supply chain is the so-called Bullwhip Effect. The usual consequence is the set of reactions put in place by the various players, who prefer to have extra stocks to maintain established service levels, thus manifesting important rising in inventory holding costs due to overstocking.

When trying to understand the causes of the Bullwhip Effect, there are various positions. Forrester (1958), who was the first noticing how the amplifying trend always moves upstream from retailer to manufacturer, attributes the phenomenon origin to the irrational behaviour of the participants. On the same trajectory, Sterman (1989) demonstrated through a popular social experiment, the “Beer Game”, how often the players of a supply chain underestimate the order delays and the slight change in demand at the beginning of the chain because they lack the visibility over the entire supply chain. Therefore, the key source of this is

stemming from the struggles in evaluating complex feedback loops along the chain. However, another thread presupposes that the behaviour of the consumers is rational, but rather is the supply chain structure and processes which force them to adopt certain behaviours. Specifically, 4 key causes are identified: demand forecast updating, order batching, price fluctuation and rationing during shortages (Lee et al., 1997). Demand forecast updating refers to the marginal increase of safety stock after each step of the chain. Order batching relates to the common mechanism of ordering per batches, therefore implying periods with abrupt spikes in demand followed by periods with little to no orders at all. Prices fluctuation stems from marketing and sales strategies, which develop discounts and promotions that are going to suddenly distort the purchasing patterns. Lastly, probably the most intricate, is rationing during shortages of supplies: when companies rations the offering of goods due to shortages at their upstream supply chain level, customers adequate by placing larger and more frequent orders, thus breaking the previously established demand dynamics. The key variable, as recognized by Paik & Bagchi (2006), is the high number of intermediaries along the chain, who add steps that weigh on the variability of demand. However, all the researchers cited previously on this regard confirmed that smoother information flows and enhanced visibility could majorly address this issue, reducing dramatically the downsides.

2.3. From Just In Time to Just In Case

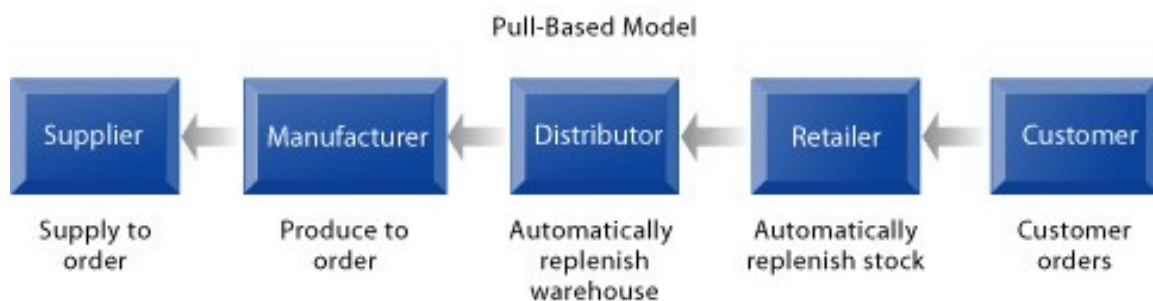
Before Covid-19, the systems of supply globally were rooted, on a higher or lower degree, to a single paradigm: Just-In-Time.

2.3.1. Just In Time (JIT)

For decades, this has been the hallmark of modern day globalization. This was developed and adopted by Toyota between 1960-1970. Not simply a management system, this philosophy revolves around optimization of the stocks in order to gain

in terms of efficiency. In a nutshell, JIT aims to align raw-material and component orders from suppliers directly with the production schedules. The success of JIT manufacturing relies on steady production, high-quality workmanship (which also minimize wastes in the process) and reliable suppliers with high degree of involvement in the chain (Investopedia, 2023). A key ingredient for the smooth functioning of JIT is Kanban, an inventory control system which automatically highlights through visual cues whenever orders of new materials and parts are needed. Therefore, JIT is a pull system where the customer purchase at a store starts the entire chain: the retailer automatically reorders the purchased item; the distributor do the same when he receives the order by the retailer; the manufacturer use the raw materials/components he has to manufacture the required products, while automatically reordering these from his suppliers. The whole chain of orders started with a single purchase made by the end-customer.

Figure 3. Pull-based supply chain model



If the “first unbundling of international economy” was the separation of consumption and production, started in the 19th century, while the “second unbundling of international economy” is steered by JIT (Baldwin, 2016). Both depends on revolution in the transportation: in the first case, products could be produced in one country and consumed in another; in the second case, thanks to multi-mode transportation and containerization, the supply chain could fragment its processes where resources and knowledge could maximize the vertical specialization in a specific section of the chain. In fact, a similar possibility

transforms into reality the mechanism of comparative advantage theorized by Ricardo due to the fine-grained delocalization of tasks, where each country takes care of the ones in which it can be relatively more productive than the others (Baldwin, 2019). For example, in the textile industry I would prefer to delocalize the production in Vietnam and have both marketing and design functions in Italy; although Italy may theoretically produce more textile than Vietnam, focusing the resources into an activity that creates more value is certainly wiser. Naturally, the consequences can be harsh if underestimated: the rapid deindustrialization of advanced economies, with the rising of social turmoil, is a byproduct of this system. In fact, as described by Autor & Dorn (2013), the abrupt downsizing and closing of manufacturing plants in the first-world economies led to a dramatic decline in medium-skilled jobs, while preserving low-skilled and high-skilled ones. This critical process, called labor market polarization, remains one of the hardest challenges to be faced nowadays (Goos et al., 2009).

2.3.2. Inventory management

When talking about JIT, we see how much stress is put over inventory optimization. In order to extend our comprehension of this philosophy, we should ask what the consequences are of having high or low inventory levels. Let's start with the pros:

- Customer service
Extra slacks surely allow to easily meet customer demand promptly, since products are already available for purchase. This is especially valuable in market where the demand is unpredictable.
- Bulk supplies
Supplying goods in huge volumes less frequently within a time period allows to leverage on economies of scale, since the fixed cost of purchase and transport will be diluted over a larger number of products.
- Risk hedging

Inventory plays as a cushion to absorb shocks and maintain the business ongoing during time of crisis. Excess in inventory are the best possible allies when facing supply chain disruptions or production delays.

Instead, going to the cons:

- Carrying costs

This definition includes a range of costs dictated by the simple fact of holding inventory. We count the cost of the warehouse and the human resources working in it, the insurance, cost to maintain or expand the occupied space etc...

- Risk of obsolescence/deterioration

Goods that are kept in inventory incur in a risk of becoming obsolete, especially in rapidly changing industries, or to deteriorate, especially for goods that have very limited life cycle (Ex. Fresh food of pharmaceutical). Similar losses would be a full burden for the company's finances.

- Capital tie-up

Indirectly, keeping stocks implies having slices of liquidity "immobilized" in form of products not yet sold. If we see it through the lens of cost-opportunity, this liquidity could be used for other, more fruitful purposes.

Overall, the entire challenge deals with the trade-off between carrying costs and stockout costs, with the first being the one related to keeping in stock the unsold goods and the second referring to direct/indirect expenses arising from not having a product when needed. This crucial trade-off finds different balancing points, depending on the industry and the specific company features; therefore, it's only possible to assess the respective advantages and disadvantages, not to find a "one size fits all" rule.

2.3.3. The crisis of JIT

Now that this system has been put to the test, we see that CEOs all around the globe are thinking whether it's necessary to adapt it somehow to the mutating macroenvironment or whether it's time to adopt a brand-new paradigm of supply and production.

What is sure, is that multinationals will start by enlarging their stocks, since it is the most immediate and effective way to tackle the issue in the short term. Corporations have discovered on their skin how unpleasant can be an excessive dependency over suppliers that are out of our area of control. We all saw how global value chain fostered FDIs (Foreign Direct Investments), vertical specialization/economies of scale and the abrupt emersion of economies like China. However, it is now possible to taste the vulnerabilities of such a system, which have remained hidden until today and have finally erupted all at once. Since it is not possible to forecast all the possible scenarios and outcomes, it's consequently impossible to attain a risk zero strategy. As the whole trade-off between cost-efficiency and risk management unveils, decision-makers should be capable of making wiser risk assessments, thus taking into account the fragility connected with global supply chains. In fact, already in 2019, Brakman and van Marrewijk (2019) highlighted in a paper how a strong involvement in global supply chains heightened the shock sustained by a national economy during a recession. Continuing to associate performance of countries, firms and workers to mono-dimensional indicators like GDP, revenues and productivity will never allow to build resilience among systems, since this property requires investments that, in the short term, will be contrasting with the previously cited indicators. However, despite being less immediate, the benefits are more stable in the long term. In other words, instead of maximizing a trajectory of growth, without building back-up plans in case of shocks, it would be better to establish a trajectory of growth that, although less impressive, is going to steer as closely as possible to the predefined path, avoiding collapsing at the first setback.

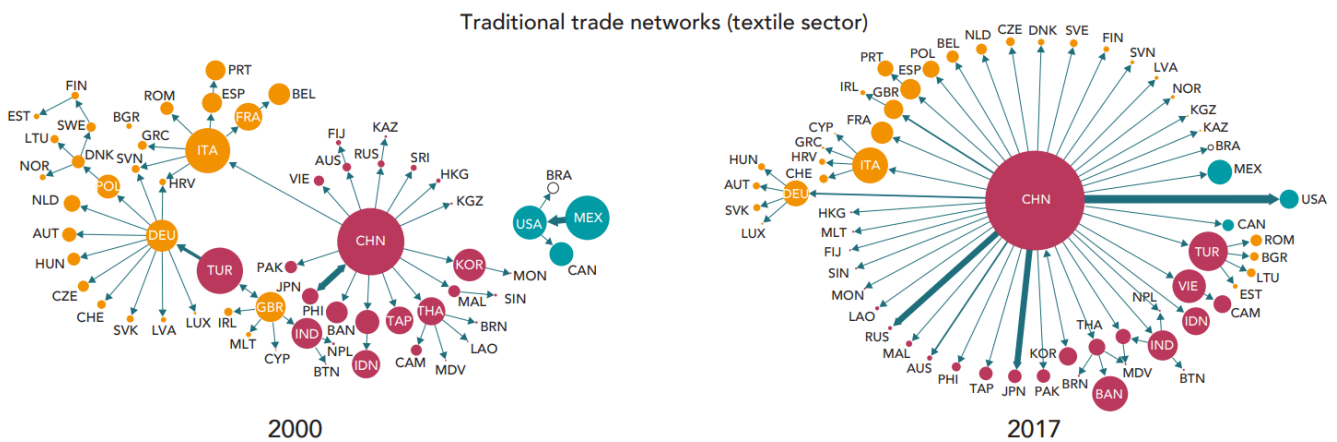
To sum up this new tendency in a catchy phrase: “Goodbye Just-In-Time, welcome Just-In-Case” (Financial Times, 2020)

2.3.4. Just In Case (JIC)

What do we mean with this new buzzword? Simply, it’s a reconsideration of the lean notion of efficiency. This new concept doesn’t see anymore “inventory” and “local production” as frightening words, but instead recognize that there’s value also in this not efficiency-centered practices. Stocks becomes the main barrier in time of volatility and uncertainty, while proximity is re-evaluated as a tool to untangle the complexity within supply chains. This doesn’t mean returning to an autarkic economy or a decrease in international trade, but rather involves recognizing the increase penalty of geographical distance. Especially when considering those components and materials that are critical, these two practices play a key role in ensuring the ongoing business, as highlighted in chapter 2.3.1.

For instance, taking the worldwide textile industry dependency on China from 2000 to 2017, we can instantly visualize why this nation has earned the title of “factory of the world” (WTO, 2019).

Figure 4. Evolution of the textile trade network (WTO, 2019)



In a world without frictions along the supply chains, a country like China can effortlessly leverage on low cost and large scale, thus gaining centrality and classifying as a hub where all the players within a network must pass by (WTO, 2019). However, this was a highly efficient predisposition and the norm for countless industries, not only the textile one. Nowadays, after the scar of the recent disruption, we rapidly spot the weaknesses of such an overoptimized model. Luckily, the switch is currently ongoing, and companies are diversifying their sources geographically, sometimes even shortening their supply chains up to the point of making them national.

Furthermore, in times where borders are becoming again common words in international trades, governments influence heavily the management of supply chains in private companies. Governments, as embodiment of public authority, have a different risk tolerance from private companies. They have a broader spectrum of interests, contrary to the private companies: a supply chain disruption isn't only a problem of operability and profit, but also cascade into widespread unemployment, shortages-driven inflation and maintenance of critical infrastructure. As defined by the IMF (2021), governments end up being residual claimants in this panoramic.

Moreover, since governments are steered by the people guiding the nation in a specific historical period, disruptions can stem problems of political accountability: in time of crisis, if the government is held liable of certain drawbacks, it might experience consistent erosion of the trust in the political party at power. Hence, the preservation of self-interests partially favors a more preventive approach. On this side, we have two brilliant examples:

- China, being one of the main producers of medical equipment and APIs (Active Pharmaceutical Ingredients), plays a pivotal role in the global healthcare supply chains, covering around 40% of the worldwide demand (Mantell Associates, 2021). Hence, when it stopped exporting as much as it was doing before Covid-19, with the aim of redirecting it for domestic

usage, the shortages immediately drove price risings worldwide. The country benefitted from its huge national manufacturing capabilities, which could match the impressive demand (PIIE, 2020)

- Japan, seeing the increasing geopolitical tensions around China and, probably, being particularly sensitive to rare scenarios with apical consequences after the Fukushima disaster, set up a fund to subsidize the companies that diversified their activities out of China, thus favoring the decoupling process from the continental player (Bloomberg News, 2020). Moreover, the general push towards the creation of resilient supply chains manifested also in the inventory management of private companies. In the graph, taken from the study of Zhang & Doan (2023) based on a large-scale quarterly government survey of Japanese manufacturing firms, we see how not only the pool of companies manifested overall increased inventories, but how this is mainly concentrated on raw materials and components that might generate bottlenecks.

Figure 5. Japanese importers inventory increase after the pandemic (Zhang & Doan, 2023)

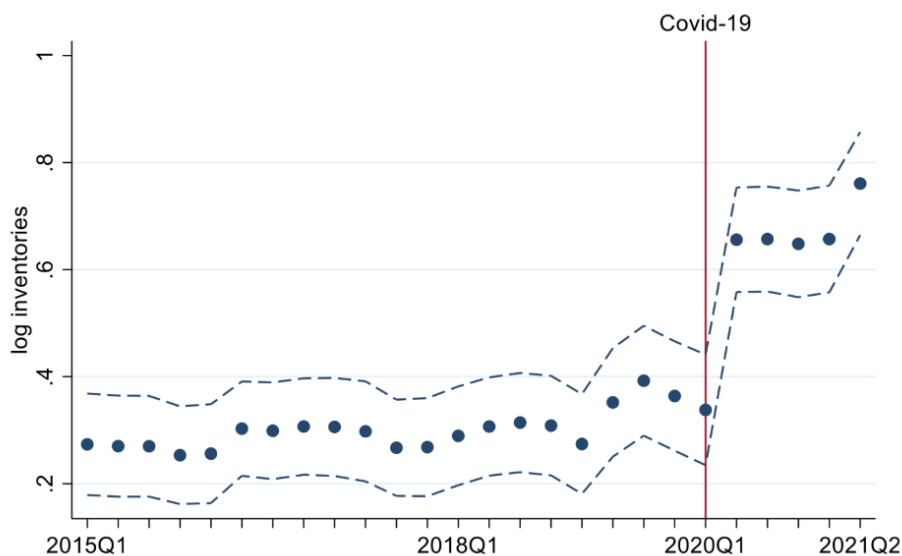
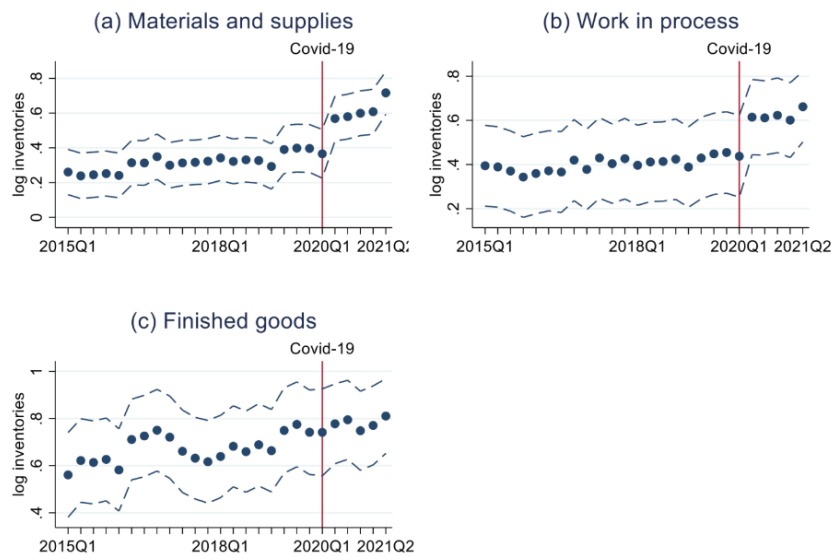


Figure 6. Japanese importers inventory increase (divided per categories) after the pandemic (Zhang & Doan, 2023)



Ironically, the country that firstly developed and made mainstream the adoption of JIT is also one of the first to adapt its historical manufacturing system to the current age, including some degrees of inventory and multisourcing.

2.3.5. Kraljic matrix

The Kraljic matrix is a tool used to segment the suppliers' portfolio. Developed for the first time by Peter Kraljic (1983) as a way to tackle the increasing complexity and globalization of supply chains, it widened up for the first time the role of purchasing, which switched from a merely transactional to a strategic function of every corporation. The simple idea is to continue maximizing the company's profit, while acknowledging and identifying the supply-side risks.

The key features of the matrix are its two dimensions, profit impact and supply risk, and the four quadrants that derive from the formers. As the name suggests, "profit impact" refers to the degree of influence that a supplied item has over the company's financial performance, while "supply risk" includes the dangers related to the supply of the specific item (Competitiveness, volatility of the price, scarcity etc...). Obviously, when considering these two dimensions, we never classify them

in absolute terms, but always relatively to the considered product (Ex. The aluminum can of a Coca-Cola isn't a costly item, but maybe it covers an important impact when considered relatively to the final product).

Figure 7. Kraljic Matrix (ProcureAbility, 2020)



As we can see, we obtain those four quadrants:

- Non-critical category.
 These components have a low financial impact over the company and aren't exposed to risk of supply, as they are probably standardized and findable in abundant supplies. Here, the purchasing function will surely focus on cost minimization, for instance through aggressive negotiation and competition enhancement between a large pool of similar suppliers, and logistics simplification.
- Bottleneck category.
 These components have a low financial impact over the company; however, the supply isn't granted, probably due to oligopolistic/monopolistic suppliers or unreliable delivery. Here, the purchasing strategy goes in two

directions: firstly, ensuring the continuity of supply through long-term contract and safety stocks; secondly, lowering the dependency from these suppliers through product adaptation and research of alternative suppliers.

- Leverage category.

These components heavily influence the financial performance of the company; however, they are easy to supply as they tend to be standardized and abundant in the market. Here, the purchasing strategy focuses on improvement on the financial side: this is done through enhancement of competition and frequent negotiation in order to reduce the cost of these crucial commodities.

- Strategic category.

These components both have a heavy influence over the financial performance of the company and they tend to be scarce or unique, hence coming from a monopolistic supplier. Here, the purchasing strategy tend to go in one way or another: the company can either develop a strategic partnership with this crucial supplier, thus paving the way for co-creation, or setting up the resources and knowledge to produce such component in-house, thus following a radical vertical integration.

If we take an electric car as an example, we can try to divide some of its components within a Kraljic matrix. Surely, nuts, bolts and tires would fall into the non-critical item quadrant, while navigation screens would probably appear in the leverage item quadrant (They are an easy-to-supply commodity but their cost is important). Then, some interior parts with the car's brand may fall into the bottleneck item quadrant (They have low economic importance but they are expressively tailored and their absence can even stop the production line), while, finally, lithium batteries would surely be into the strategic item quadrant (These

are very scarce and controlled by very few suppliers, often colluding. As a consequence, these tend also to be expensive due to the gap between supply and demand).

The main outcome of the Kraljic matrix is that it allows to view purchasing as a multilayered function, where at least each quadrant should have its own strategy, people and resources deployed in order to fully attain its potential. Being it also an empirically checked tool, as confirmed by the thorough research of Caniels & Gelderman (2005), it is important to start from Kraljic whenever we want to investigate the complexity embedded within a supply chain. As highlighted by Pwc, to face complexity it is pointless to reason in either-or terms. Instead, a bidirectional application of JIT for those quadrants of the matrix that are less exposed to risk and JIC for those quadrants that are more strategical can be a nice take over the topic.

Now that we have delved into the different nuances of these components, we consider a graph from the WTO Global Value Chain Development report (2023).

Figure 8. Top exporters of potential Bottleneck products 2000-2021 (WTO, 2023)

Table 1.2: Top Exporters of Potential Bottleneck Products, 2000–2021 (%)									
2000		2005		2010		2015		2021	
Economy	Share	Economy	Share	Economy	Share	Economy	Share	Economy	Share
PRC	19.1	PRC	32.2	PRC	35.7	PRC	39.5	PRC	36.3
US	18.4	US	10.0	US	8.5	US	8.3	US	6.4
Japan	9.4	Japan	7.2	Germany	4.4	Germany	4.3	Rep. of Korea	5.0
France	6.2	Germany	5.2	Japan	4.3	Rep. of Korea	4.0	Australia	4.2
Canada	5.2	France	4.9	France	3.6	France	3.2	Viet Nam	4.2
Germany	5.1	Netherlands	3.0	Brazil	3.6	Australia	3.2	Germany	3.4
Italy	3.4	Malaysia	2.8	Australia	3.0	Japan	3.0	Brazil	3.3
UK	3.3	Italy	2.6	Rep. of Korea	2.7	Viet Nam	2.8	Japan	2.7
Netherlands	2.2	Ireland	2.4	Netherlands	2.2	Brazil	2.2	Indonesia	2.4
Malaysia	1.6	UK	2.3	Malaysia	1.9	Netherlands	2.0	France	2.2
Total	74.0		72.5		69.8		72.5		70.2

PRC = People's Republic of China, Rep. = Republic, UK = United Kingdom, US = United States.
Sources: United Nations Comtrade data, 2000–2021; and World Trade Organization estimates.

The first thing that catches the attention is the predominant role of China, which additionally presents a huge gap with the second on the podium, the USA. Seen

with the hindsight of the Kraljic matrix, it becomes crystal-clear how the actual trend is not convenient and stems dangers. This graph alone can explain the shortages emerged during the Covid pandemic. What the matrix tells us is that, in this specific case, reasoning in term of economic and operational efficiency hides subterranean hazards that will probably emerge all at once. A simple yet complete framework instantly highlights the risks within a supply chain. Therefore, before starting to discuss about the range of practices that can be adopted in order to build up resilient supply chains, it's necessary to start with a general evaluation on the financial influence and degree of dependency that suppliers have over a company. And, to do so, the Kraljic matrix remains a perfect baseline.

2.4. The new shapes of offshoring: reshoring, nearshoring and friendshoring

Offshoring is the practice of moving a part of our business out of the home country, either by building owned subsidiaries abroad (captive offshoring) or by relying on a foreign player (Offshored outsourcing). This allows to leverage on a wider range of resources and human capital scattered around the globe (Lewin, 2005). Offshoring touches both the high value-added activities, like engineering, design and R&D, or the low value-added activities like manufacturing (Liebermann, 2004). This business practice stemmed spontaneously as a result of an increasingly integrated international market, resulting from universal reduction of tariffs driven by WTO, implementation of robust dispute settlement arrangements, enthusiastic participation of the emerging countries into the undergoing global value chains and the levelling of geopolitical risk with the inclusion of Russia and China to the global market within the WTO system.

Offshoring has become a very mainstream model in international business, applied by nearly every industry in one way or another. However, this historically established practice is now weakening as the founding pillars over which it was

built are starting to tremble. We are referring to a wave of economic nationalisms and rapid changes in the geopolitical playing field. Other than the inherent fragility present in value chain that are only efficiency-driven, the social effects of offshoring also have a share: the offshoring of manufacturing is often accused, rightly or wrongly, of the impoverishment across the middle-income class and the rise in inequalities. The public opinion in many Western countries accuse their governments and corporations of “having sold out their excellence”, hence losing national industrial capacities. Furthermore, corporations started dribbling the regulatory burdens with the threat of offshoring as a pre-emptive action, externalizing the risk of their decision-making on the least represented stakeholder: local communities. Thus, the classical doctrine of offshoring, as suggested by Dan Ciuriak (2023), is undergoing a transformation in order to survive the macro-mutations in the surrounding environment. In particular, three new similar but different offsprings are becoming new hot words in business journals and policy-making circles:

- Nearshoring.

This represents the practice of relocating manufacturing facilities closer to home with the aim of narrowing volatility in variables like shipping distance, time of delivery and logistics complexity. Multinationals then need to assess their requirements around the proximity-efficiency trade-off, which is inevitable in most cases. A strengthening factor for nearshoring is that even emerging countries where manufacturing had been offshored are catching up, some faster than others, to developed countries wage levels. Hence, the narrowing of advantageous gain in offshoring manufacturing may be an indirect force fuelling nearshoring.

- Reshoring.

This represents the practice of bringing off-shored economic activities back at the home country. Although this can be labelled as a peculiar case of

nearshoring, this practice differentiates itself for the root cause. In fact, it usually is the visible expression of a fervent economic nationalism within the country. Indeed, there are many positive externalities stemming out of this, as suggested by classic industrial policy: the most relevant one would probably be the spillover of know-how, which would then drive further innovation and dynamism in the local economy. Uncoincidentally, reshoring is often encouraged and subsidised by national policy-makers and governments as it mostly generates positive responses in the public opinion and consensus, renewing the economic outputs of entire territories.

- Friendshoring.

This is actually another shade of nearshoring, but rather than influenced by internal politics it is directed by the external one. This is strictly linked with current affairs, where choosing suppliers or new offshoring bases heavily involves political and diplomatic alliances in the decision-making.

Two additional concepts, quite similar between each other, play a role in this discussion: these are decoupling and derisking. Decoupling implies drastic reduction or abrupt cut off in the economic interdependence over strategic goods/services between two regions manifesting diplomatic tensions. By limiting the flow of technology, data and investments it can create a trajectory with two emerging technological ecosystems, built on paradigmatic technologies like AI or genetic engineering that, although employed in very similar manners, are rendered artificially incompatible with each other (Ciuriak, 2023). On the other hand, derisking is a softer version of the previous concept. It sits more in a grey area, accepting that globalization is an irreversible phenomenon while trying to mitigate apical risks in some very critical areas, thus accepting the extra costs related to a similar practice.

Now, it would be interesting to see how in the three key regions of the world, regarding international trade, supply chain management and governments

intersects each other, generating these new practices. China is proceeding with, what has been denominated in the industrial policy framework “Made in China 2025” of May 2020, the Dual Circulation approach. Contemporarily, the country is trying to insulate its domestic market from external shocks and competitors and leverage on it for the growth of the national industrial apparatus, while enlarging its international reach through the Belt and Road Initiative, a portfolio of major infrastructural investments aimed at decreasing the distance between China and new potential accessible markets. Meanwhile, the USA are initiating a decoupling from China, following the so-called “Sullivan Doctrine”, taking the name from the White House Security Advisor Jake Sullivan, who said that “*it’s necessary to maintain the largest possible lead advantage over key technologies like AI, microelectronics, quantum information systems, biotechnologies and clean energy technologies*”. Concretely, this translates into a reshoring of high value-added activities, coupled with a renewed push to capture the top STEM talents around the globe, and enforcing hard export controls towards China to restricts the access to the previously mentioned technologies. Lastly, we have the EU with a more pragmatic approach based on derisking, as mentioned by the EU Commission President Von der Leyen in 2023: “*It is neither viable, nor in Europe’s interest, to decouple from China. Our relations are not black or white, therefore our response cannot be either*”. Thus, EU is focusing on building solid capabilities in green and digital technologies, trying to establish itself as leader in these innovative industries and capture around 40% of the global share in these innovations. Then, improving the control and screening of foreign direct investments and imports.

Although the 3 most important regions of the world are positioning themselves in a manner that suggest a growing suspicion of international free markets, this processes often remain groundbreaking declarations of intent and preliminary trials. According to many scholars, the current division of labour, resources and concentration of production capacity across the world is extremely path-dependent (Butollo et al., 2022). Hence, it would be difficult to steer such a paradigmatic

change from one day to another without truly putting unprecedented political willingness and investments.

2.5. Sustainable Business Models

2.5.1. The entrance of sustainability in the corporate world

Traditionally, supply chain management had always been focusing on effectiveness, efficiency and economic performance. However, the growth in complexity and the increasing pressure from governments and stakeholders is redirecting company's business models towards a wider integration of sustainable parameters (Sehnem et al., 2019). Sustainability is thus seen as a concept to be embraced in order to better understand the world and, as a consequence, the needs of a business. Through a set of frameworks, it permits to envision in broader terms the role a company is playing in the overall chessboard, including its impact on environment and society. Starting from a key definition from the World Commission on Environment and Development (1987), Sustainable development is identified as "a development that meets the needs of the present without compromising the ability of future generations to meet their own needs". This beautiful, thought-provoking quote can be resized also to a company activity. In an ideal sustainable business model, a company shouldn't weaken its future capabilities and assets to reap extra gains in the short-term. Although the company policies and laws surely presents some flaws in fighting short-termism tendencies, there are some very intuitive frameworks which allow to view every business decision with something more than the traditional economic-driven lens. The Triple Bottom Line approach is characterized by three dimensions – the economic, environmental and societal ones – as parameters to be compulsorily assessed in any decision-making process (Elkington, 2002). From the moment in which the management has to evaluate each decision through these 3 viewpoints, the understanding of the trade-offs that may stem in a longer period of time becomes

unavoidable. Then, of course, the acknowledgment doesn't automatically have to result in a complete embracement of the sustainability cause from one day to another, but for sure brings to the table a different, holistic manner to approach the impact of a business activity. After this first step, where companies had begun broadening their stakeholder audience, the cascading of sustainability across strategical and day-to-day operations has followed (and is still following). What before was done only for a sense of ethical responsibility by very few, virtuous players is now increasingly seen as a competitive advantage to be nurtured. Welcoming sustainability brought important cost-saving in form of the 5 Rs of sustainability – reduce, recycle, reuse, remanufacture, redesign (Scur and Barbosa, 2017). More and more operational excellence practices have been studied and implemented in light of this new viewpoint – Circular economy, Internet of things, life-cycle assessment, carbon footprint assessment, co-creation, alliance management etc...

What were the drivers steering such a paradigmatic, ongoing change in modern business models? While a handful of companies had always taken into account sustainability as a cornerstone of their strategy, due to its intrinsic embeddedness in the enterprise vision, most of the companies were simply considering it out of their responsibility. Since businesses, in the very end, exist to satisfy a demand, the characteristics of that demand represent the core factor in how companies choose their strategic priorities. Concretely, when customers and governments, key stakeholders for any company, started to ask for products that were more sustainable in their intrinsic features and in how they were manufactured & produced, the change began (New, 1997).

Nowadays, thanks to the increasing amount of research and trials around sustainable business practices, the higher costs to implement those are more often justified by positive results in terms of corporate reputation and, most importantly, risk mitigation (Seuring & Müller, 2008). Hence, from a question of compliance to one of proactive exploration of the potential benefits stemming out of it. The

result of this ongoing paradigmatic change seems to be very encouraging: according to Seuring & Müller (2008) theoretical background, 53% of the examined papers depicted a win-win situation, where both economic and sustainable performances go hand in hand, therefore Pareto-optimal. Then, 30% of the cases reported a trade-off between the two parameters, thus opening to scenarios of necessary priority-setting. Lastly, in 17% of the sample the competitive advantage hasn't been identified in neither of the two parameters, but the only positive gain came from the compliance with standards and regulations.

2.5.2. Sub-tier suppliers: a broader perspective

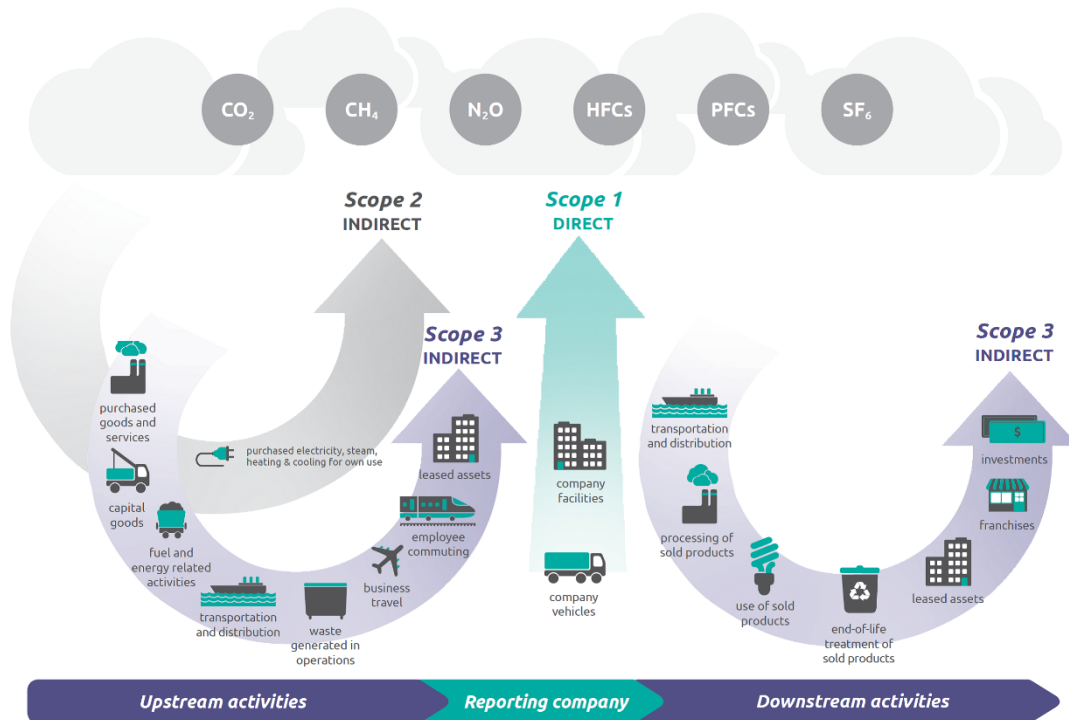
Certainly, large multinationals are attentively implementing more sustainable parameters in their decision-making. Sustainable KPIs are entering all the internal processes and many choices get assessed through a Triple Bottom Line point of view. However, the focus is mostly directed within the company, where the degree of control is high and new procedures can be easily implemented. What many companies are overlooking, and only recently trying to confront, is their network. These businesses are often referred to as “focal companies” for their dominant role in many value-chains, usually accorded by their direct contact with the customers or the rarity of the product/service provided (Handfield & Nichols, 1999). Due to their centrality, scholars and policy-makers are increasingly deeming focal companies as responsible not only for their direct impacts, but also for those of direct and indirect suppliers (Simpson & Power, 2005). For the same mechanism depicted before, whenever the pressure from demand and key stakeholders amplifies, the company must respond. Hence, copious efforts are spent in enforcing good environmental and societal standards to direct suppliers, who often reluctantly accept these and ask for some forms of compensation in exchange. Still, the greatest question mark is represented not by the so-called first tier suppliers, but by the large platoon of sub-tiers suppliers who operate in the dark, out of any supervision from the focal company (Reuter et al., 2010). Here can be found the last, toughest bastion against a sustainable way of doing business. What makes this

issue so difficult to be tackled is, firstly, the simple gap in knowledge that companies have around suppliers below the first tiers, commonly referred to as “the supplier’s suppliers” (Choi et al., 2001). Furthermore, a focal company often represent only a tiny fraction of the overall business of a sub-tier supplier (Plambeck et al., 2012).

Directly related to the discourse on sub-tier suppliers is a highly topical issue: the tracking of scope 3 emissions. But what would they be?

Let’s start by saying that nowadays one of the major indicators to grasp the degree of sustainability in a company is the amount of greenhouse gas emissions (GHG). The GHG Protocol is shared by both cities and corporations as the main KPI to be taken under surveillance (Ishinabe et al., 2013; Hillman & Ramaswami, 2010). This widely accepted standard defines how to assess direct emissions (Scope 1), then emissions associated with the supply of electricity, heat and cooling (Scope 2), to finally reach those emissions stemming from the whole value-chain that are not emerging from the purchase of energy (Scope 3) (Fong et al., 2014). Policy-makers and public opinion are usually accustomed to Scope 1 emissions, or rarely to Scope 2, while the Scope 3 ones haven’t yet been popularised that much. Unironically, these have also been quantified as the most troublesome source of emissions, as they cover nearly 80% of the total pie (Ducoulombier, 2021). In this regards, some elements pose challenges for the thorough understanding and management of such Scope 3 emissions. Firstly, the previously cited Supply Chain Complexity jeopardizes the possibility to gain a decent view of the chain at the granular level required for an optimal calculation. Secondly, often the data seems to be insufficient both in volume and quality to really grant the right visibility along the supply chain (Ducoulombier, 2021). Thus, these two challenges are providentially eye-opening on how important is to have a know-how of the sub-tier suppliers, since it’s in those submerged layers of the chains that Scope 3 emissions hide themselves.

Figure 9. Illustration on Scope 3 emissions



How can they expect to have contractual relationships or even enforce standards to entities whose identities or locations aren't known? Two main approaches, opposite in nature, have been recognized:

- Open relationships. The focal company continues not having direct relationships with the tier 2 and 3 suppliers. However, the role of the tier 1 direct suppliers become central, as they will be the one “delegated” to enforce relevant standards to sub-tier suppliers (Choi and Hong, 2002). The information moves linearly from focal company to tier 1 to tier 2 and all the focus of the focal company is reserved for strengthening the partnership with the direct supplier, who will play as amplifier for the focal company’s requests of compliance (Wilhelm et al., 2016). Obviously, while it requires less immediate effort, it still doesn’t give a complete control over the issue.
- Close relationships. The focal company establishes links with tier 2 or even tier 3 suppliers (Choi and Hong, 2002). This can be an informal one, with just mutual acknowledging and occasional connections, or a more formal one, with structured bilateral agreements regarding standards on

sustainability or transparency (Mena et al., 2013). The tier 1 suppliers here have less power, but they still play as facilitators for the focal company's exploration across sub-tiers. Needless to say, enlarging the pool of stakeholders implies a noticeable growth in complexity but, on the other hand, increase the knowledge that a company has over its indirect area of influence.

Although it may seem a regular problem to be tackled, it still is extremely difficult to map transparently and, even more, to establish direct links with sub-tiers suppliers. Since we are talking of a very on-the-edge challenge, the managerial practices to tackle this still have to be properly assessed in literature and the companies themselves are experimenting a lot on this field.

2.6. Sources of disruption

Since we have described value chains and investigated them through different lenses, now the next step is to look at those external shocks that reverberate throughout the whole system. These so-called sources of disruptions have been increasing throughout the years for a number of reasons, some of which link back to the previous chapters (Ex. Supply Chain Complexity surely plays a role in the extensive frequency and strength of similar events). According to a White House report (2022), the global frequency of disruptions, when confronting the time range between 1975-1984 and 2005-2014, have increased almost threefold. Furthermore, the growth is manifesting also on the magnitude of damage since it moved from an average of 5 billion dollar to a current 20 billion dollar average. Hence, it becomes interesting to deep dive what these sources of disruption can be and what characterizes them.

2.6.1. Climate changes

As mankind's most critical challenge for this century, it's of no surprise that climate changes are enlisted as potential sources of disruption. Stemming from

global warming, which is subsequently generated by human activity over nature, this phenomenon is pervasively altering all aspects of reality, from societies to, indeed, business operations (Stern Review, 2006). Although their effects aren't so flagrant, the sum of the small changes derived from them shake profoundly the basement over which operations are built upon. Actually, the real deal here is the degree of interdependencies linking all these causes and effects, creating a complex network of events that are difficult to be tracked by a single discipline and require a broad, holistic point of view to be grasped. The simple, direct consequence of that is having supply chain' leaders unable to clearly position themselves in this ocean of complexity, hesitantly sticking to how things have always been done or doing very little, unambitious additions (Hitchcock, 2012).

Given that the topic is incredibly vast, it makes sense to narrow down the topic to those physical impacts that can concretely wear down or even disrupt a supply chain. When talking about climate changes, the visible manifestations are rising in temperatures mean and variance, other than frequent occurrence of extreme, less predictable weather patterns. These are then reflected in many manners along businesses' supply chains, therefore a list could be convenient to capture the flavor of that:

- Dramatic changes in the agricultural industry as a whole. As the sector with the highest exposure, agriculture has been, and will continue to be, destabilized by climate changes (Jones et al., 2005). Even if we are talking about a specific sector, it's not difficult to foresee the ripple effect originated from here. The entire food industry, over which human life is built upon, directly depends on changes in the availability and volume of crops. Consequently, imagining an earthquake in the availability of workforce and the purchasing power is not impossible. Furthermore, agriculture provides raw materials for an infinite range of industries: timber, coffee, rice, cereals, meat, milk, wool, leather etc... Relevant mutations in

the availability and prices of these key materials would unleash tremendous consequences over the entire economy (Haverkort & Verhagen, 2008).

- Loss in biodiversity. This undervalued resource, the diversity and variance in flora and fauna, is suffering from the instability of the weather. What some considers a marginal problem would be the main source of disruption for the whole medical, biotechnological and pharmaceutical sectors, other than having severe consequences in innovation as a whole (E.g. Researches on new materials, architecture, chemistry etc...) (Dasaklis & Pappis, 2013).
- Shortages in utilities. In a world with less water and energy restrictions due to last-minute regulations, both services are going to be costly ingredients in the production mix (Letmathe & Balakrishnan, 2005).
- Higher probability of extreme events. These new weather patterns bring with them an increased variance in the manifestation of apical phenomenon like flooding, high winds, unlivable hot summers, desertification, rise in sea levels, hurricanes, diseases spread etc... Such events impact every human business or population, regardless of the industry or location (Stern Review, 2006).
- Continuous and more expensive maintenance. Variable temperatures and frequent weather manifestations, especially if sequential and unusual for the specific regions (E.g. Cold summers in Italy or hot winters in Scandinavia) are surely going to wear down more rapidly the very components that built up the infrastructures: nails, screws, asphalt, concrete etc... Therefore, not only the cost of maintenance will generally increase, but the frequency of audit will too follow the same trend (Piecyk & McKinnon, 2010).

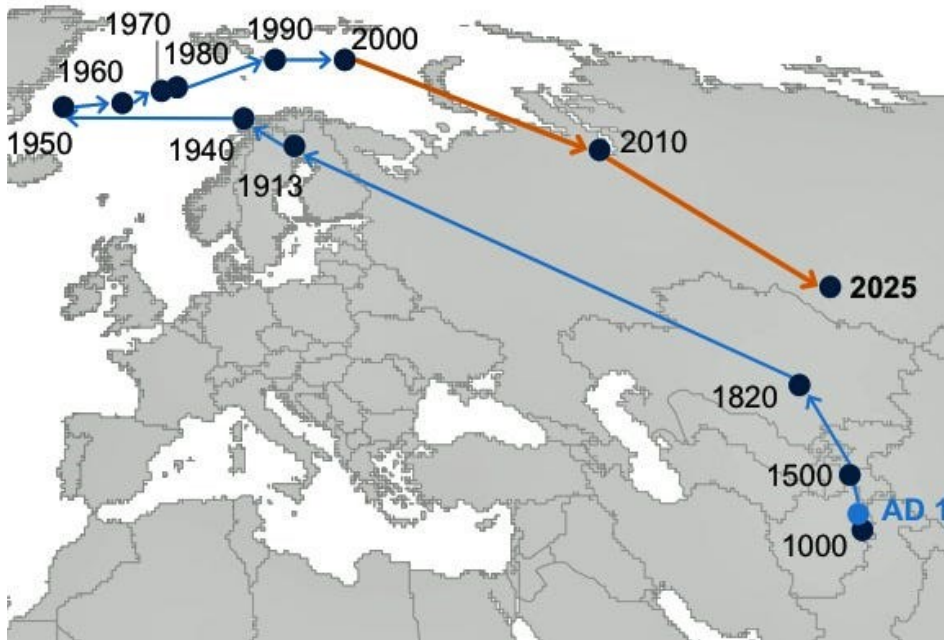
Although by no means exhaustive, this brief summary attempts to give an idea of the range of effects that climate change has on supply chain disruptions, as well as providing an understanding of the intertwining through which these amplify critical issues that may already be present.

2.6.2. Geopolitical dynamics

Since the beginning of the new century, the global geopolitical landscape has undergone a seismic shift, marking a departure from the relative peace and stability that characterized the latter half of the 20th century. The older generations, in front of the Berlin Wall fall in 1989, remember how much the atmosphere was pervaded by the promise of a new world order, defined by cooperative internationalism and economic globalization, that seemed within reach. Some thinkers even thought of it as the beginning of a nearly utopistic period where everything could only improve, like Francis Fukuyama and his idea of “The end of history”, which entailed having reached the final stage of human government through the Western form of liberal democracies and free-market capitalism combined.

However, this narrative of unity and progress has been challenged by the insurgence of new superpower rivalries and the revival of historical regional conflicts, thus jeopardizing the post-Cold War consensus. Moreover, the fact that the Westerners economic hegemony of the last centuries is being put to the test strengthen the urge to raise barriers and establish antagonistic relationships with the usurpers that are rapidly reaching a point of parity. This risk is clearly exposed in the below McKinsey Global Institute’s map, where it’s localized the “Centre of gravity of the world economy” through a weighted GDP esteem of the various countries. This median of the world economy is clearly shifting towards the East, at a speed that “Has never been registered before” says Richard Dobbs, one of the authors of such research.

Figure 10. Global GDP Centre of gravity (McKinsey Global Institute)



The first important crack in the geopolitics relations started with the Trump presidency and the beginning of a trade-war between USA and China. This is a natural symptom of a subterranean need to determine who is the superpower worldwide. In fact, we are presently assisting to a split of the world between free-market Western-like democracies and allies of the authoritarian regimes of China and Russia. In this context, the idea of free trade as an intrinsic value fall by the wayside, and sanctions become an instrument of foreign and security policy rather than a economic lever to be studied (Maihold, 2022).

All the other nations, without direct hegemonistic aspirations, have been joining this race from the start more or less enthusiastically, with the aim of securing financial, military and diplomatic benefits. These followers are either trying to be regional “bishops” of the overlooking superpower or trying to leapfrog stages of economic development as emerging economies in exchange of their loyalty. Some are even playing across the two fields, placing themselves strategically as neutral agents and harvesting benefits from both sides (Yayboke & Carter, 2020). In general, siding with the US grants access to current cutting-edge technologies and protection under the first military power in the world, while China offers access to the main manufacturing platform worldwide, its availability of rare earths and the

promise of dethroning the US from their 1st superpower position (Whalen and Alcantara, 2021).

While China is acting diplomatically and financially through its Belt and Road initiative, the Western side is now trying to follow with its Partnership for Global Infrastructure and Investment, announced at the G7 summit in 2022 as a boost of 600 billion USD directed towards global infrastructure over the coming five years (Maihold, 2022).

Meanwhile, if we look at Europe, it's impossible to forget the ongoing war in Ukraine: started in February 2022, this tragic event is continuing with no end in sight, impacting supplies of essential commodities like oil, gas, grains and fertilizers (Tollefson, 2022). Europe, pressed by the abrupt inflationary pressure over the final prices of goods and services, set up a strong list of sanctions towards Russia and rapidly reconfigured the logistics to circle around the invading country, driven by both the shortages and the public opinion pressure (Bednarski et al., 2023)

Hence, from one side we have the USA trying to reduce the dependency on China, especially for rare earths and strategic electronics like semiconductors or components for military devices, while Europe is trying to decouple from Russia for energy, grain and fertiliser. Unsurprisingly, it is estimated that up to 26% of the global exports may potentially be relocated in the next five years (Maihold, 2022). Thus, a perspective of weaponization of the supply chains, used as an additional competitive ground for superpowers, is a concrete reality that forcefully necessitate just as many concrete responses from multinational companies.

2.6.3. Inflation

Covid-19 pandemic brought a number of important setbacks to society, but one that provides good reflection points is inflation. To cite some numbers, in the US inflation increase from 1.23% to 4.7% in the timespan of a year, from 2020 to 2021 (Diaz et al., 2023). Key causes of this were, without a doubt, the number of supply

chain disruptions that had taken place at the time and the scarcity of certain commodity classes. The tricky aspect of the situation is that being the inflation fueled by the supply side of the economy, the monetary policy of central banks had little to no power on the field as it works, on the opposite, through molding of the demand side (Diaz et al., 2023). Here, it's the management of the operations and the striving for resilience in the supply chain that can really chisel the problem at the root causes. Two examples give us a measure of the magnitude of impact supply chain disruptions can have on inflation: during the pandemic, used cars faced such an abrupt rise that their value in the US rose of around 50% in a year (Mullin, 2023). It's no surprise that Alex Wolman, an economist, suggested that this alone was one of the main culprits of US inflationary pressure. In parallel, the other big protagonist had been the semiconductors, small components that usually account for a tiny part of a product's total cost. Nevertheless, their irreplaceability made them another ominous name among the "Inflation drivers" club. Many papers delve into how supply chain disruptions can promote inflationary distress. However, the aim is to go in the opposite direction: after inflation has started to rise, it's useful to investigate how this consequentially impact on its same primordial cause: supply chain disruptions. In other words, studying not how the cycle of negative feedback started, but how it evolves throughout time by bouncing back some aggravations to the disruptions themselves is what better suit our research scope.

Fluctuations in production and transportation costs, material availability, and consumer buying power can intensify inflation within supply chains. This supply chain inflation can become self-sustaining, as increasing costs diminish businesses' purchasing power (Oracle, 2023). Therefore, inflation influences the entire range of ingredients that build up the supply chain, spreading along the network of contacts through ripple effect (Vallejo, 2022; Maersk, 2023). How do exactly these effects act over the variables of the supply chains? In general, the main KPI to be observed is the PPI, the Producer Price Index. This standard measure, which tracks

the input costs for goods production, surged by 24.0% over the year leading up to June 22. The prices producers set for these goods increased by 16.5% during the same period, marking the highest rates since record-keeping began. Additionally, the cost of services rose from 4.2% in March 22 to 5.4% in the second quarter (Zurich, 2023). This includes energy, workforce, transport, fuel and all those words that have frequently been cited in the time subsequent to the pandemic. The increase on all these inputs is naturally reflected on the total cost of production for businesses, that find themselves with lower margins and even negative ones. If the products are not profitable, entire ranges of goods might simply disappear as intrinsically unfitting to this new panorama, being it for their intense consumption of energy or extensive use of semiconductors in the manufacturing process. Especially when considering goods that are instrumental to other productions, it's easy to foresee the ripple effects bouncing all over the chains and strangling the capacity of companies to simply provide goods. To mix up things a step further, the demand in itself doesn't follow the historically established patterns. Negative effects of inflation include an increase in the opportunity cost of holding money; uncertainty over future inflation which may discourage investment and savings. According to the Mundell-Tobin effect, consumers will favour durable, long-lasting goods that are also holding value instead of short-term, frivolous ones (this doesn't count for those goods that are considered vital and have an extremely rigid demand curve) (Saylor.org, 2023). Therefore, while managing frail cost equilibriums, companies also needs to restudy the structure of demand that they used to know before, furtherly increasing the headaches for decision-makers. Indeed, the worsened disruptions push even more the inflationary trend, fueling an upward spiral that becomes difficult to drag-down.

2.7. Antifragility: a pioneristic concept

In such a hard-to-read context, a new concept is emerging to shake up previous risk management theories: antifragility. Given a fragile system, which tends to be

weakened in front of an external disorder, we define an antifragile system as one in which shocks and randomness are seen as a source of strengthening and improvement (Nikookar et al., 2021). In this panoramic, firstly raised up by Nassim Nicholas Taleb (2016), resilience doesn't represent the polar opposite of fragility, but it's just a neutral state where a system absorbs the negative effects to then return at its previous state.

Following the ambitious line of thought from Wieland (2020), we try to broaden the panoramic in a radical way. While supply chains have always been interpreted as static systems, "beings" that are clearly confined from their surroundings (Nilsson & Gammelgaard, 2012) and, therefore, treated deterministically by managers, they are actually way more intertwined with the context than it is usually imagined. It is usually assumed that certain conditions are stable (long-term availability of natural resources; business-friendly global environment etc...) and that supply chains can be cut out from their environment to be studied as isolated phenomenon. Taking these two assumptions as starting point, it is no surprise that we end up with monolithic representations which often hide fragilities underneath (Borgatti & Li, 2009). Instead, we should look at the supply chain as an organic system, a becoming (Nilsson & Gammelgaard, 2012). A similar view immediately makes undesirable to categorize the chain in a fixed optimal state. An organic system within an everchanging environment implies acknowledging the effects of nature and people in every single node of the chain and opens up to a framework in which any disturbance or shock becomes a window of opportunity (Davoudi et al., 2013). Achieving antifragility means transitioning from a "safe from failure" design to a "failing safely" ones, more similar to how organic entities thrive into the nature (Holling, 1996). In other words, it is not about simply resisting disturbances and avoiding them, but more about recognizing that the system can be resilient up to a certain "critical point" after which a change in its structure, processes and behaviours must adapt (Holling, 1996). To make a concrete example, urban planning is increasingly renouncing to the modernist approach,

based on rationality and cold logic, since it acknowledges that how the cities are used and lived by the people is simply unpredictable (Evans, 2011). A general golden rule tend to be that the more a system is interconnected with human actors, the more it must take into account a degree of evolution as if it is an organic system (Davoudi et al., 2013).

What is proposed by Westley (2002) is to enlarge the scope of supply chain management with a new paradigm called “Managing *in, through, out, up* and *beyond*”:

- Managing *in* is another name to describe our current conceptualization of supply chain management, where we focus on studying and changing the elements within the chain itself
- Managing *through* involves a trial-and-error approach to supply chain management. The idea is that of deploying small interventions as experiments to learn from and explore new practices to be further implemented
- Managing *out* concentrates on the relationship with all the stakeholders linked to our chain. Those are not only business related, but includes local communities, families of the employees etc...
- Managing *up* deals with the alignment with the overarching political context. Fundamentally, here supply chain management and lobbying overlaps
- Managing *beyond* is the most meta-oriented approach. This is a periodic self-reflection on the processes and structure that founds the supply chain, creating “what if” scenarios with the aim of stress-testing it and bring new, radical, out of the box solutions to the discussion

All these new directions should be acknowledged when considering supply chain management. Consequently, this discipline should also open up to courageous collaborations with peculiar experts like sociologists, environmental scientists etc...

Thus, antifragility becomes the next, pioneristic step on the path to a better adaptation over a more chaotic environment. Hence, while evaluating the potential of the previously enlisted practices in building up resilience, we are also going to examine whether they can become foundations of an antifragile supply chain.

2.8. Practices to build up resilience

Once described the possible sources of supply chain disruption, it's necessary to understand which practices, if implemented effectively, can mitigate exposure to the destabilizing effects described above. In general, the most immediate approach to increasing resilience is to generate redundancy and optionality (Taleb, 2016). This can take various forms: increased safety stocks, relying on two or more suppliers for the same item (dual/multi-sourcing), geographically diversifying suppliers and logistics routes, etc... Both these ideas imply investing in having a "Plan B" in case something goes wrong, and they do so by increasing the range of options available to supply critical components and tackle potential bottlenecks. This is done at the expense of increased costs and complexity to be managed, because facing 4 different suppliers for an item instead of one requires more time and resources.

However, much research is ongoing around these two concepts as these are considered the best practices to detect and mitigate supply chain risk of disruption. The aim of the present dissertation is, instead, to explore those practices that haven't completely become mainstream and widespread, which therefore need further investigation to define their applicability and possible limitations. The practices which will be explored across this document are:

2.8.1. 3D Printing

Addictive Manufacturing (AM), often recognized with the widespread name 3D printing, is an approach in manufacturing characterized by enhanced

customizability and flexibility. Objects are built layer by layer following digital blueprints, where each layer is a deposition of one or more intended materials. This new method allows to produce components with rather complex geometries and shapes without the use of large machinery investments, furthermore, granting an unprecedented degree of flexibility in the range of producible components: in the blink of an eye, the average 3D printer can switch from producing a plastic model of a train to a copper cube.

As highlighted by Serohi (2021), the deployment of a similar technology in a supply chain system can lead to a reduction in operation complexity. In particular, 3D printers become enabler of mass customization, thus combining the economies of scale in large volumes with a wide range of customizability. For instance, Hewlett Packard (HP), the famous computer manufacturer, makes extensive use of 3D printers to bring devices tailored on the customer's needs while maintaining reasonable economies of scale.

Coming to the contributions of this innovative manufacturing system for the resilience in supply chains, we mainly identify two key drivers.

Firstly, the use of 3D printers require radical changes in the inventory mix: instead of components coming from various vendors, we will have raw materials like powder and liquids from which it will be either possible to manufacture the final product or critical components exposed to apical risks (Serohi, 2021). Building inventory out of less processed commodities purchased in bulk simplifies the procurement process and cut out intermediaries. The know-how, instead of being embedded in the bought component, is contained in form of a blueprint stored in a digital archive, which will then be the source for the 3D printers to be followed during the production process. Secondly, 3D printers permit to reduce the dependency on the critical nodes within global trade routes, like port hubs (Naghshineh & Carvalho, 2022). Instead of having all the goods manufactured in a big plant offshored in Asia, companies can split their capacity over a widespread

network of smaller production sites relying on 3D printers, thus building resilience out of geographical diversification and enabling policies of reshoring/nearshoring. For sure, the economies of scale of a concentrated manufacturing powerhouse are incomparable to the smaller one given by a network of 3D printers, but the latter surely opens up to scenarios of optimal risk hedging and lower logistics costs.

2.8.2. Digital Twin

The digital twin is defined as “*a virtual copy of a product or system that allow real-time replication and analysis of the product/system itself*” (Jones et al., 2020). Labeled as one of the most strategic technology trends in 2019 by Gartner, the digital twin represents the seamless implementation and integration of the Internet of Things (IoT) concept. Thanks to the widespread deployment of sensors across the blocks building up the supply chain, it would be possible to recreate a digital version of the supply chain itself in its key features. Thus, a digital twin of the physical supply chain. The true groundbreaking value addition is in the principle of speed, as described by Ehie & Ferreira (2019): the large amount of data gathered in real-time by this widespread net of sensors, when elaborated, build the visualization of a virtual supply chain that showcase the changes happening along its many nodes. The key element here is, of course, represented by the accuracy in the infrastructure playing as foundation of this digital twin: ideally, this could go from a gap between virtual twin and real twin of days, hours, minutes or even to the utopistic real-time representation of it (Funk & Reinhart, 2017). The technological bridge between reality and virtuality is relying on technologies like 5G to rapidly channel the inputs from the sensors to the representation of the chain. Therefore, the twin is not a replacement for the actual system, but only a visualization shadowing it with different degrees of accuracy.

But then, once we have this nearly perfect replica of a real system, what do we do with it? Indeed, the first contribution relies on the ability to trace the root of disruptions and observe its propagation across the chain, generating a ripple effect (Dolgui et al., 2018). The digital twin should be able to showcase both the indirect

effects stemming from the original disruption, but also to filter out non-pertinent variables and zoom-in specific areas or nodes which need to be investigated (Macdonald et al., 2018), thus granting both a complete high-level overview and a narrow down up to a granular level. As we have said in various occasions, visualizing and understanding the complexity embedded in the supply chain is a crucial part in the process to prevent and mitigate risks. Thanks to this transparent visualization of the chain, it becomes then possible to shape supply chain design more dynamically: it becomes possible to react against short-term emergencies, develop mid-term recovery policies and set up long-term strategic directions (Ivanov, 2019). The most on the edge models should even allow to stress-test the digital twin itself through generation of simulated shocks, thus permitting to assess the vulnerabilities and the pain points in a wide range of scenarios (Barykin et al., 2021). Therefore, the digital twin ends up becoming a platform which gives justice to the organic nature of the supply chain in all its complexity and ever-changing dimension.

2.8.3. Cross-functional teams

According to Bode et al. (2011), in most of the cases supply chain disruptions do not emerge completely out of the blue, but rather leave behind a trail of early warnings which signal their arrival. Therefore, the central topic of discussion switch on how best to detect and interpret such signals so that any impact is less severe or even avoided altogether. These signals can vary a lot in nature: they can be manufacturing problem stemming from lack of capacity, constant bottlenecks in certain nodes of the supply chain, escalation in geopolitical tensions etc... In order to efficiently catch those inputs, a proposal for companies would be to *“have permanent/temporary cross-functional teams, with members coming from different operative segments, because a possible SC disruption in one functional area may also have implications for other functional areas”* (de Vries et al., 2021). As perfectly expressed, such cross-functional teams can either be a permanent or a temporary entities, triggered by specific situations. The people joining them

should be a representation in small-scale of the companies, including high-level professionals from various area that may play a role in preventing any sort of disruption (Durach et al., 2015). Some examples include local manufacturing plants managers, demand planners, country managers in some key areas for the company's business, finance managers etc... Nevertheless, this special task-force may reach very soon a quantity-induced crisis due to the sum of all the signals coming from many, different areas, thus setting the team's performance on a declining trend (Rudolph & Repenning, 2002). Actually, the biggest challenge of such a team composition relies on the information integration process, where the non-critical information quickly gets filtered out during the decision-making phase. To avoid such dynamics, the best solution has proved to be the appointment of one or two central members who act as intermediaries, orchestrating the signal-gathering process and synthesizing a big picture by assembling the inputs from the different areas involved (Davison et al. 2012; Hollenbeck et al., 2010). Teams without a centralized structure, therefore with all members retaining equal shares on the decision-making process, the outcome often is a large pile of inputs without any sort of interconnectedness, where each member is more likely to blindly focus on his own work domain while overlooking warnings from other domains, in spite of their risk level (Miller, 1978). Without any sort of rapid, hierarchical internal information integration, the whole architecture of a cross-functional team lose its efficacy. Furthermore, such a task-force, if guided properly through sound leadership by the central decision-maker of the team, may have the indirect positive impact of strengthening synergies between areas and departments that aren't often strictly linked to each other, encouraging a broader understanding of the corporate environment. When properly established, this cross-functional team should be at the forefront of disruptions' prevention and buffers set up to increase the overall resilience.

2.8.4. Artificial Intelligence

As the likely biggest innovation in recent years, we couldn't exclude AI from this set of practices. Although it has always been very much present in the debate around implementation of innovative technologies across industries, after the emerging of Large-Language Models (LLMs), the curiosity surrounding it has skyrocketed all of a sudden. These new AI models showcase human-like capabilities in a range of previously unexplored fields, like text production, understanding of context and points of view, data analysis and interpretation (Bubeck et al., 2023). Moreover, these new tools are available to nearly everybody having an internet connection, and most importantly, accessible without any specialistic knowledge. In fact, while Machine Learning systems were already present before the worldwide popularity of ChatGPT, they were understood and trained only by experts with long experience and technical theoretical backgrounds. The possibility of now having an interface capable of interacting with virtually any human in their own way is what really makes it so groundbreaking (Hitch, 2023). The direct consequence is that professionals from any fields and industries will have this personal assistant to be used as a sparring partner for their work, thus opening new scenarios for productivity growth and time-saving (Bubeck et al., 2023). Some, like Bill Gates (2023), advertise them as the engine fuelling the upcoming fourth industrial revolution.

How does AI enter the supply chain management domain then? Given that a supply chain emerges from the set of interactions between humans and organizations, considered the blocks building up the chain itself, it depends on how a multilayered tool like AI is implemented across. To understand this, Hendriksen (2023) developed an interesting conceptual framework to establish the variety of applications and trade-offs in using AI across the supply chain. His categorization follows two key dimensions: the level of AI integration across the supply chain and the role AI plays in decision-making. The relevant trade-off exposed here is that AI can totally bring groundbreaking results in productivity and be a paradigmatic change in the discipline of supply chain, but on the other hand it can

create dangerous pitfalls and foster “AI-driven bullwhip effects” (Panigrahi, 2023). The rule of thumb here is that the higher the integration and the role in decision-making, the more polarized this trade-off becomes, adding an astonishing degree of value while opening up to future scenarios of equally huge risk of disruption (Hendriksen, 2023).

Figure 11. AI implementation matrix (Hendriksen, 2023)

	Partial integration	Full integration
Assistive role	AI specialistic assistance	AI all-encompassing assistance
Autonomous role	AI independent specialist	AI independent manager

This would be the final framework, following the two previously mentioned dimensions. Let’s analyse each quadrant:

- *AI specialistic assistance.* This is probably the most straightforward and easy to imagine use of AI. It is an assistant for very specific tasks, like demand forecasting or inventory management. It can be seen as a sophisticated tool used to enhance human capabilities, although without showcasing any degree of autonomous decision-making and being limited to only certain blocks making up the supply chain.
- *AI all-encompassing assistance.* This goes a step further from the previous case in the degree of integration across the supply chain. AI here represents a whole system embedded in every step of the processes, ranging from forecasting to delivery, operation management etc... Hence, AI expands itself all-across, having full-visibility and coordinating the flow of goods and information. However, this system is still controlled by humans, who

submit in it their strategic decisions and leave the operational deployment to the AI.

- *AI independent specialist.* Here, we go a step further in the other dimension, where we see an AI that begins to leave behind its tool-nature and acquires a degree of decision-making in some very niche areas. For instance, we can imagine its first deployment in some order/warehouse management functions as a pilot. The biggest restriction is the limitedness of the area where it can have autonomy.
- *AI independent manager.* This is the most extreme case, more of a utopia (or dystopia, for some) where AI has full control and managing power over the whole supply chain. Every process is supervised by it, like a system which analyses the flow of goods and information within itself while autonomously making adjustments along the chain to pursue some predefined goals. Here, the humans wouldn't supervise anymore the supply chain, but they would monitor the AI itself and only setting the priorities which needs to be attained.

As we can see, the topic of AI implementation in supply chain management is vast and naturally cross-disciplinary. It starts from very actual adoption of it to scenarios where the humans only have to “control the controller”. Therefore, in a similar context exploring how companies are currently approaching this pioneristic practice and how they plan to further improve their relationship with AI becomes even more intriguing, thus perfectly pertinent for the research we are following.

3. Research propositions

After outlining a broad theoretical framework, demonstrating the numerous interconnections between topics such as resilience, sustainability, and supply chain, it is now necessary to organize this vast sea of knowledge into a structured and ordered framework. In other words, codify this information to advance hypotheses, which will serve as guidelines for the field research phase (in the form of questions) and as a system to organize the results obtained. These theoretical propositions, based on the theoretical background, must then be tested by empirical evidence to give rise to a new synthesis of value.

The idea is to structure everything around five research propositions: the first, related to the recognition of crucial risks of disruption; the second, in which the use of four innovative practices for achieving greater resilience in supply chains will be explored; the third, in which the centrality of the concept of resilience within supply chain management will be defined; the fourth, where the role of sustainability in supply chain transformations and its synergies with resilience will be assessed; and the fifth and final one, in which the resulting changes in business models, particularly in light of the roles that resilience and sustainability play within the new supply chains, will be discussed. How each RPs is linked to the three founding research questions is highlighted in *Table 1*.

Table 1: *Research questions & Research Propositions*

<u>Research question 1</u>	• RP1
What are the risks recognized as the major potential causes of disruption in the supply chain of multinational companies?	Geopolitical dynamics, inflation and climate changes are recognized as crucial risks of disruption by companies
<u>Research question 2</u>	• RP2

<p>Are the selected four practices already applied by multinational companies to mitigate the risk of disruption in the supply chain? If not, is there a recognized potential application of these practices?</p>	<p>3D printing, Digital Twin, Cross-functional teams and AI are innovative practices implemented to mitigate risk of disruption along the supply chain</p>
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Research question 3

To what extent are the concepts of resilience and sustainability prioritized within the supply chain of multinational companies? Furthermore, are they considered drivers for the development of new, competitive business models?

- RP3
Resiliency is considered the predominant priority for the success of a supply chain

 - RP4
Sustainability is a competitive advantage in a supply chain and presents positive synergies with resiliency

 - RP5
Resiliency & sustainability are drivers for the development of new, competitive business models
-

3.1. Most relevant risks and sources of disruptions

In the whole chapter 2.6. it had been explained how the number of disruptions have been increasing dramatically from the past (three times more disruptions in the time window from 2005 to 2014 rather than 1975 to 1984). Given the three key risks that have been highlighted – geopolitical dynamics, inflation and climate changes – it's valuable to assess concretely how critical these are considered by businesses. Furthermore, it would also be of great value to understand whether

there are other risks that have been left out of the theoretical background while deserving a bigger focus in light of their centrality in corporate environments.

RP1: Geopolitical dynamics, inflation and climate changes are recognized as crucial risks of disruption by companies

3.2. Four practices to enhance resiliency in supply chains

1st practice to improve resiliency: 3D Printing

As already explained in chapter 2.8.1, 3D printing seems to be an innovative practice to be implemented in order to enhance the resiliency of a supply chain. Typically used for prototyping and product customization, its high flexibility and agility could also be the key to bringing production closer to the end consumer. The main benefits would include avoiding major global logistics hubs, which are often congested due to increasing traffic on main trade routes, and maintaining an inventory largely composed of raw material powders, thus usable in various types of production. A prime example could be a small critical component that, instead of being imported from China, could be produced in very short time at the same production plant, significantly shortening the value chain and reducing exposure to disruptions that could occur upstream at the supplier's location or during transit. Are multinational companies already using this technology for this purpose? If not, do they foresee an implementation for this purpose, or are there issues not highlighted in the literature?

2nd practice to improve resiliency: Digital Twin

In chapter 2.8.2, we saw how the Digital Twin can also represent a new, innovative practice to better understand the dynamics along the supply chain of a multinational company. This system is literally a digital duplicate as faithful as possible to the real supply chain, depicted in its key nodes thanks to the vast

amount of data coming from numerous sensors connected according to the Internet of Things model. The idea is to have a digital version of the supply chain capable of visualizing any change with a lag of days, hours, minutes, or ideally, in real-time. Once the structure is set, the potential use cases are numerous: studying the propagation of disruptions through ripple effect along the network, artificial stress-testing to highlight potential weak points, gaining greater visibility along the entire supply chain, and facilitating the implementation of mitigations in the short, medium, and long term. Given that it is a very futuristic technology and can be applied in various ways, the aim is to understand if multinationals already have some kind of tool of this type, or if there is general interest in this direction. Additionally, it is intriguing to understand how such a tool would be used concretely and which use cases are identified as the most valuable.

3rd practice to improve resiliency: Cross-functional teams

In chapter 2.8.3, it was discussed how the use of cross-functional teams can address the need to better understand the growing complexity in today's supply chains. Bringing together professionals from various fields into one team, with different skillsets, backgrounds, and experiences (e.g., a person from manufacturing, one from finance, one from sustainability, one from public relations, etc.) could allow, thanks to this abundance of perspectives, the identification of potential warning signs of a pending disruption. Teams of this type could periodically not only react to disruptions already underway, in true emergency task-force style, but instead act proactively to prevent such disruptions from occurring, thus solving the problem at its source. Undoubtedly, such teams benefit from the variety of know-how and subjectivity present, but it is easy to see how this can also become an obstacle. The danger is that a real common front is not created, but that impending disruptions continue to be approached in silos, highlighting and emphasizing only those risks directly related to one's own area of expertise. The aim is to understand whether such organizational clusters are already implemented within companies and how: are there permanent cross-functional teams with that specific

assignment? Are they only called upon as task forces to mitigate a disruption? How is the governance structured within them to avoid opportunistic and narrow-sighted pushes?

4th practice to improve resiliency: Artificial Intelligence

AI, as a practice, was extensively discussed in chapter 2.8.4., and this is unlikely to be surprising. It is currently the buzzword of innovation, impacting various fields and reaching levels of versatility and ease of use that were previously unimaginable. Specifically, the use of Large Language Models (LLMs) has opened doors to diverse applications of this technology, including data analysis, text production/editing, automation of routine processes, user communication, and context understanding.

How does AI enter the supply chain management domain? Since a supply chain emerges from interactions between humans and organizations, its effectiveness depends on how a tool like AI is implemented. While AI can significantly enhance productivity and bring a paradigmatic change to supply chain management, it can also create pitfalls and foster “AI-driven bullwhip effects.” The principle here is that higher integration and a more critical role in decision-making increase this trade-off, adding substantial value but also significant risk of disruption.

Therefore, the aim is to understand how much AI is considered within multinational corporations, and particularly in which areas it is seen as having the most potential for application. Additionally, exploring the extent to which it would be integrated along the supply chain and the degree of independence granted to it would be of great interest in trying to define the added value that such technology could bring to the table.

RP2: 3D printing, Digital Twin, Cross-functional teams and AI are innovative practices implemented to mitigate risk of disruption along the supply chain

3.3. The concept of resiliency in supply chain

As mentioned, the idea of resilience is identified in natural sciences as the ability to absorb an external shock, minimizing its impact and returning to the previous state. Sometimes, this is also interpreted as an opportunity for improvement: the shock can even be seen as a “wind of creative destruction” in Schumpeterian terms, necessary for the improvement of the subject under stress. This is a more pioneering area of resilience research, which leads to the concept of antifragility, the ability to benefit from chaos and disruptions. How do these two concepts relate to the supply chain of a multinational company?

Starting from one of the greatest innovations in the industrial sector, which directly involves the supply chain, we know that Just-In-Time (JIT) is a production method based on minimum inventory, optimization of processes, and delocalization of activities. In a sense, it is the ultimate expression of Ricardo's theory of comparative advantage. This protocol has been adopted and adapted by almost all large multinationals over the past few decades, primarily due to a liberal and globalizing economy that favoured offshoring and the formation of long global value chains. However, a series of phenomena such as rising geopolitical tensions and protectionist pushes have increased supply chain complexity, significantly undermining the JIT production as a standard. Indeed, emblematic events like the COVID-19 pandemic have led to a deep rethinking of the current production model of many multinationals. Inventory and proximity of production facilities are no longer seen as inefficient wastes to be streamlined, but rather as protections against the variability of the world itself. Words such as redundancy and proximity seem to have become the new guidelines today.

The aim is to verify how deeply the idea of resilience, in all its nuances, is rooted and prioritized within multinational companies. Additionally, it seeks to understand whether this trend, highlighted in the literature, is truly present or if business reality diverges from these theoretical assumptions. Specifically, instead

of studying the extent of this trend on a large scale, it becomes intriguing to explore how it is expressed within companies.

RP3: Resiliency is truly considered the predominant priority for the success of a supply chain

3.4. Sustainability as a competitive advantage in supply chain

In the beginning, sustainability entered the corporate world as a top-down imposition and occasionally as a request from the customers. Companies began complying, gradually adapting their operations to meet new standards, and little more. Apart from a few sporadic cases where sustainability was a central pillar of the value proposition, the general attitude was one of mere compliance. In several instances, it was even manipulated as a blunt marketing tool in the form of greenwashing. Today, fortunately, thanks to increasing attention from consumers and policymakers, as well as new avenues shown by research, sustainability is starting to be perceived as a concept capable of adding value and revealing new, innovative paths for company growth. Various companies are beginning to frame their economic activities within a Triple Bottom Line perspective, where every initiative is evaluated from three key perspectives: economic, environmental, and social. Thus, from a perspective of mere compliance, sustainability is becoming a proactive paradigm to be followed, providing new frameworks through which challenging and renewing rigid processes and methods within companies.

Resilience and sustainability are increasingly present in multinational companies, but it's crucial to recognize that these companies are part of a larger value chain extending beyond their direct influence. To truly implement these best practices, they must permeate the entire value chain, including direct and sub-tier suppliers. Without this, upstream disruptions or unethical practices could undermine the efforts of the focal company. Given that sub-tier suppliers are often small, remote

entities, it's essential for multinationals to first gain awareness of them and then ensure they adopt these practices.

The aim is not to measure on a large scale how prioritized sustainability is, but rather to assess whether and how it is seen as a competitive advantage within companies, especially in the supply chain context. Furthermore, it becomes even more pertinent and interesting to explore what added value and positive externalities it can bring, challenging preconceptions and stimulating new perspectives. In addition, the goal is to understand how much of a priority the identification of sub-tier suppliers is considered, whether and how companies have already implemented systems to gain visibility on this aspect, and what added value the companies themselves perceive in doing so.

RP4: Sustainability is a competitive advantage in a supply chain and presents positive synergies with resiliency

3.5. Resilience & sustainability: drivers for business model transformation

After discussing resilience and sustainability, examining them in all their nuances to understand their effects and potential synergies in a supply chain context, we aim to understand how these have impacted the business model of multinational corporations as a whole. Multinationals are, in fact, complex entities given the intrinsic nature of their business, their transactional reach, and, quite simply, their size in terms of employees and revenue. Within this mechanism, called a business model, which acts as the beating heart of this organism, we want to understand how pervasive resilience and sustainability truly are: are they merely accessory additions to an established system, or do they represent a drastic paradigm shift, a profound shake-up of the “way of doing things” as previously established?

RP5: Resiliency & sustainability are drivers for the development of new, competitive business models

4. Methodology of research

4.1. Research design

Given the research question, the collection of primary data through a set of active interviews with key professionals across different industries resulted to be the most fitting methodology, according to the exploratory nature of our investigation (Eisenhardt, 1989). The idea was that of gathering unfiltered opinions from the respondents, without trying to encapsulate preemptively their answers into fixed frames (Yin, 2009). Interviews become a tool to dig deeply into the beliefs, experiences and viewpoints of professionals working every day in the supply chain domain. Not only that, but through bilateral exchange of ideas, they also become a tool for co-construction and evolution of knowledge (Gubrium & Holstein, 2003). Therefore, by encouraging open-ended, one-on-one conversations, these interviews aim at approaching complex phenomena in a wider range of nuances, grasping the subtle interdependencies that often ends up left behind in quantitative research.

The contents broadly explored in the theoretical background and then organized in research proposals get here deep dived during the interviews with the final aim of testing the theoretical assumptions with the concrete experience of professionals that breath these topics on a daily basis.

In order to broaden the exploratory scope of our research and test it across different fields, the interviews are not solely from one company but are also drawn from various industries. While we acknowledge that such qualitative results cannot be generalized, it is important to introduce a minimum level of counterbalance to avoid placing too much emphasis on elements that are intrinsically linked to a specific industry or company. Therefore, this diversity will enhance our collection of unique perspectives on the issues outlined above.

The key insights stemming from this set of multilayered answers collected will then be showcased in the Findings section. Lastly, in the Discussion section, the

theoretical concepts will be compared to the experience-based findings to reach a final synthesis that will represent the fruit of this explorative effort.

4.2. Data collection

To collect valuable insights from the interviews, it was important to set in advance a pool of open-ended questions to nudge the discussion towards the topics of interest, while avoiding any type of biases or arbitrary enforcement (Rubin & Rubin, 2005). These had to be, at the same time, designed in alignment with the research objectives and leaving space for co-construction of meaning (Johnson & Weller, 2002). While most of the questions were ideally addressing the core contents of the research, some at the beginning had just the purpose of building up a comfortable and trusting environment, as making the interviewee feel at ease generally permits to penetrate more in-depth (King & Horrocks, 2010). The 10 questions utilized as guidelines during the interviews are showcased in Annex 1.

The research includes a total of 6 interviews, out of which 3 from a single company and 3 from other companies playing in different industries. Out of the total, 3 have been held remotely and 3 in person. On average, the interviews lasted between 40 to 60 minutes each. All the interviewees have been chosen as a convenient sample, where the first volunteers were scouted through the author's work relationships and university network; then, through snowballing effect (Lincoln & Guba, 1985), the final pool of candidates was found. The criteria to select the candidates were a focus on supply chain management & procurement, better if with a stronger upstream nuance and some risk management responsibilities, coupled with the fact of working for large multinational companies, filtered for the one operating on at least 3 continents across the world and having a minimum of 25 000 employees. The willingness to investigate multinational companies stem from the fact that, due to their sheer size and leadership position in a sector, the best-practices implemented often tend to trickle-down to the whole industry, thus making them trendsetters. At the same time, global supply chains include a mesmerizing number

of players and agents, indeed, but each supply chain is characterized by one or more 'elephants in the room' that exert a disproportionately large influence over the other pieces of the chain, therefore making these especially useful as research subjects. In the sample there are both junior and senior profile, allowing for a multilayered view on, especially, the questions regarding the deployment of innovative practices to improve resiliency in supply chain.

4.3. Interviewees

To better understand why the interviewees made for an interesting sample in this research, it's important to consider their unique roles within the context of their corporations. Each interviewee's position offers valuable insights shaped by their specific responsibilities and the broader organizational environment they work in.

In *Table 2* it's possible to find a crisp list of the interviewees. Below are detailed descriptions first of the companies, and then of the interviewees themselves:

- *Interviewee 1 – Novo Nordisk*

Novo Nordisk A/S is a Danish multinational pharmaceutical company headquartered in Bagsværd, with production facilities in nine countries and affiliates or offices in fifty countries. The company specializes in manufacturing and marketing pharmaceutical products and services, particularly in diabetes care medications and devices. Its main product, semaglutide, is used to treat diabetes under the brand name Ozempic and obesity under the brand name Wegovy. Novo Nordisk employs over 60,000 people globally and provides 50% of the world's insulin supply, producing more than one billion pens per year to serve over 50 million people. In 2023, Novo Nordisk's market capitalization exceeded Denmark's GDP, making it the company with the highest market cap in Europe. The company is verticalized on very few treatment areas—primarily diabetes and obesity—while gradually

expanding now into cardiovascular diseases. This strategic approach, unrivalled in the pharmaceutical industry, leverages on their accumulated expertise in closely-related therapeutic areas. Given the complexity of supplying life-saving drugs to millions globally, Novo Nordisk offers valuable insights into large-scale pharmaceutical operations. The author's internship at Novo Nordisk facilitated the gathering of information for this research, thus explaining why three interviewees from the company are included in this research. Nevertheless, to avoid redundancy in the material exposed, the people have very different roles and responsibilities, allowing to get a thorough perspective over the supply chain of a single company.

Interviewee 1 is a sourcing analytics partner in Novo Nordisk, more precisely in a Strategic Sourcing department. He has a background in supply chain management and has worked as a supply chain consultant for some years before joining Novo Nordisk. His interest sparks when depicting the relationship between technology and risk management. In this role, he provides category managers with detailed forecast insights, which are firstly created through elaboration of raw data gathered within the supply chain. He is also directly involved in the optimization of the corporate data infrastructure and the development of a new digital risk management tool designed to assess the degree and types of risk along the upstream supply chain. This tool is based on both external data, collected from third parties data providers, and internal data, especially qualitative one manually inserted within the system by category managers.

Hence, Interviewee 1 is a tech-savvy professional, with a deep interest for risk management and an entire career spent in various role across the supply chain domain.

- Interviewee 2 – Philips

Philips is a Dutch multinational conglomerate headquartered in Amsterdam. Formerly one of the largest electronics companies globally, Philips has since refocused its efforts on health technology, divesting its other divisions. The company now employs around 80,000 people across 100 countries and is organized into three main divisions: Personal Health, Connected Care, and Diagnosis & Treatment. In 2016, Philips spun off its lighting division into a separate company named Signify N.V. through an IPO. Signify manufactures electric lights, light fixtures, and control systems for consumers, professionals, and the Internet of Things (IoT), and continues to produce lights under the Philips brand. The demerger was driven by Philips' strategic shift, as the medical technology business accounted for more than 40% of its sales, while the lighting arm remained highly profitable, selling products in 180 countries. Introducing the company historical detachment is of essential importance since the interviewee operates within the spin-off Signify.

Interviewee 2 is a Demand Planner within Philips, precisely in the Signify spin-off, with more than 10 years of experience. Furthermore, he has been tapping in the role of Supply chain Coordinator for the last 2 years and just recently in S&OP management. Concretely, he has been studying and forecasting the demand of products for the EMEA market, especially for Italy, Israel and Greece. Fundamentally, this can be done thanks to the collection and elaboration of data on the market through statistical modelling to predict the needs at a SKU level (Stock Keeping Unit) for the next 1/2 years. Unsurprisingly, this implies being continuously and closely in contact with the major internal stakeholders like Supply Chain operators, Sales, Marketing etc... to make as futureproof as possible the forecast, allowing the company to prepare the right capacity to satisfy such predictions. In his most recent S&OP function, there's an even more high-level look at the supply chain, addressing

it as a dynamic organism that thrives when its components are efficiently aligned towards a shared goal. The ideal match between supply and demand, here, must also take into consideration the potential risks and disruptions that might snatch such balance. Hence, the mix of deep operational know-how and helicopter view over the supply chain offers an interesting breeding ground for this research.

- Interviewee 3 – Novo Nordisk

The presentation of the company will be skipped in this occasion, given the throughout overview already given in the description of Interviewee 1.

Interviewee 3 is a Risk Management Advisor in the Strategic Sourcing department within Novo Nordisk. She has an academic background in Security Risk Management. In her current position, she is the main advisor to category managers for all the matters concerning risk identification and mitigation. Given the localization in a Procurement department, she is especially focused on all the potential risks stemming from the sourcing activities: geopolitical, regulatory, single-sourcing, cybersecurity etc... She operates both through consultancy within specific ad hoc projects and critical contexts, but also as creator of new processes to foster the resilience and the consciousness towards risk. Furthermore, she is clustered in the same team as the Sustainability Consultants, therefore having a privileged seat in observing how the two concepts of resilience and sustainability influence each other in various ways.

- Interviewee 4 – Bosch

Bosch is a German multinational engineering and technology company with 429,000 employees and registered revenues of €91.6 billion in 2023. As the largest automotive supplier by revenue and the biggest supplier of services globally, Bosch's extensive network includes over 440 subsidiaries and regional entities, covering nearly every country in the world with its

manufacturing, engineering, and sales operations. It is not listed in the public market, despite the astonishing size, but instead is 94% owned by the Robert Bosch Stiftung, a charitable institution that, despite funding through its shares, holds no voting rights and focuses on health and social causes unrelated to Bosch's business. This organization is an intricate matrix, where the headquarter channels the general strategy while the local subsidiaries, thanks to a high degree of independency and local management, operatively deploy it within country-specific context. As it can be easily imagined, the network is one of the key asset of the company, but it requires a smooth balancing between top-down directives and local adaptation of those. Bosch operates across four main business sectors: mobility (hardware and software), consumer goods (including household appliances and power tools), industrial technology (including drive and control), energy and building technology. The latter, especially important being it the one hosting our Interviewee, is dedicated to home technology, communication, and especially thermotechnology. Thermotechnology involves products for home comfort, such as heating systems, water heaters, and heat pumps, which are increasingly important due to green electrification. It also includes cooling systems like air conditioning and connected accessories.

Interviewee 4 is a Demand Supply Planner within the Energy and Building Technology of Bosch Italia. He has a Supply chain management academic background and 4 years of professional experience, ranging from the large-scale retailing to the editorial industry. His main responsibility lies in the forecast of the key business lines for Bosch, possible to accurate study of the historical and market trends. Together with his team, he is exposed to different functions across the supply chain: stock/warehouse optimization, order management, inbound supply etc... Given the centrality of the network organization in Bosch, all the decisions have to be pursued taking into account

the directives of the headquarter, therefore even the local functions must operate in synchrony with all the other nodes of the network. Even within the local unit, a constant dialogue with internal stakeholders, like product managers, sales representatives and procurement officers represents a key part of the job. Thus, seeing how the decisions from the headquarter reverberates throughout an extensive network of local units can give to this research a much grounded, operational perspective, which will uncover insightful elements.

- Interviewee 5 – Prysmian

Prysmian S.p.A. is a multinational company headquartered in Milan, Italy, specializing in the production of electrical cables for the energy and telecom sectors, as well as optical fibers. With over 30,000 employees, Prysmian operates 23 plants in North America, 48 in Europe, 13 in South America, 7 in the Middle East & Africa, and 13 in Asia. The company is listed on the Borsa Italiana in the FTSE MIB index, with a highly dispersed ownership structure; BlackRock is the largest shareholder with just 5.2% of shares. Prysmian is the world leader in the production of cables for wind farms, producing and laying underground and submarine cables for electricity transmission and distribution, as well as specialized cables for various industrial applications and medium- and low-voltage cables for construction and infrastructure. For the telecom sector, Prysmian produces copper cables, optical cables, and optical fiber cables for data, video, and sound transmission. Additionally, the company designs and produces key systems and provides post-installation maintenance upon customer request. From a procurement perspective, Prysmian is divided into three main categories: base metals, raw materials (non-metal components within cables), and non-raw materials (indirect procurement for products and services not directly used in cables). This structure is reflected in the global matrix organization, with both central strategic representation and various local operations across different regions.

Interviewee 5 is a Buyer within the Base Metal procurement department located in the Prysmian global headquarter, with some shorter experiences across Belgium and Netherlands within policy-making & sustainability. He has an academic background in Economics. In this role, he is responsible for the purchasing of the aluminium commodity for all the EU plants. This is done through continuous study of the market trends and nourishment of the relationship with the suppliers, which tend to be few, big and very verticalized. Key part of this responsibility, naturally, includes ensuring the business continuity and the resiliency of the supply chain through a tailored sourcing strategy. Secondly, lot of attention is also put in the maintenance of an optimal level of stocks and the supporting of the material flows among the various European plants. Thus, the experience of a buyer in such a big company, exposed to dynamics of all the regions in the world, offers us a unique insight over how resiliency and sustainability act in the supply chain of huge, ad hoc international projects.

- Interviewee 6 – Novo Nordisk

The presentation of the company will be skipped in this occasion, given the throughout overview already given in the description of Interviewee 1.

Interviewee 6 is a Senior Category manager in Novo Nordisk within the Strategic Sourcing Inbound Materials & Services department. He has an education in supply chain, has worked both in the transport infrastructure industry and as a consultant, always in the Procurement domain with more than 10 years of experience. His key responsibility, as a category manager in raw materials, is to work with internal stakeholders and external suppliers to secure the supply of materials necessary for the production on a long-term horizon. While role intrinsically require a deep focus upstream, to better approach it in

a strategic manner it's important to predict the trend of the future demand and market dynamics. A seasoned professional experience, a deep knowledge of the market segment and a vast range of skills (Supplier relations, contractual clauses, strategic acumen, negotiation, financial understanding...) are the palmares of a category manager, who needs to be a jack of all trades to bring value to his company. In this specific historical moment, the organizational need that mostly calls for the time and efforts of the Interviewee 6 is the securitization of business continuity, obtained through a wise planification of the sourcing strategy to avoid and mitigate future risks.

Table 2: *Sum up of all the Interviewees*

	Company	Role
Interviewee 1	Novo Nordisk	Sourcing Analytics Partner
Interviewee 2	Philips	Demand Planner
Interviewee 3	Novo Nordisk	Risk Management Advisor
Interviewee 4	Bosch	Demand Supply Planner
Interviewee 5	Prysmian	Base Metals Buyer
Interviewee 6	Novo Nordisk	Senior Category Manager

5. Findings

The interviews have proved themselves as invaluable sources of information. Through them, it has been possible to structurally gather the know-how, the experience and opinions of various professionals, all capable of giving a new nuance to the vast range of topics we are trying to face. This vast amount of data has been aggregated in codified categories, allowing for a clearer exposition of the insights and the unique contributions found in the different interviews. Furthermore, citations from the interviewees will be used to better capture the flavours of each testimonies. Hence, let's start by exposing the categories of findings one by one.

5.1. Most relevant risks and sources of disruptions

When asked which were identified as the most relevant risks and sources of disruptions, all the interviewees had a common touchpoint: the geopolitical risk. This could take different shapes and is perceived as the switch of many negative snowball effects. As perfectly summarized by interviewee 3,

“In the current turbulent political climate, multinational companies have to reposition themselves in the global system and constantly navigate an everchanging geopolitical landscape”

According to some, this sense of instability can take various shapes, but the perception of the modern world has drastically shifted after Covid-19, which has been recognized by half of the interviewees as a *“game-changer that has turned the rules upside down in just a handful of years”* (Interviewee 2). The stability in the geopolitical atmosphere is utterly important since companies like to play where the rules are clear, not where there's room for ambiguity and unpredictability. Therefore, dialoguing with governments and policy-makers becomes more and more challenging, wearing down businesses impact over the world. The most

obvious and palpable manner in which geopolitics turbulence affects supply chains is in the availability and prices of materials. Starting from the first one, nearly all the interviewees has mentioned the difficulty in supplying themselves with materials and services that were excessively concentrated in concerning regions of the world: some examples that have been made were semiconductors and microchips from Asia or base metals like aluminium and energy from Russia. Each industry suffered for industry-specific reasons: one could not afford to lose business continuity, one was overly reliant on the raw materials purchased since it was the biggest slice out of the total spend for the production of a component, another manufactured products that were intrinsically energy-intensive etc... As a consequence, the high concentration of critical materials in a bunch of regions is giving to these a monopolistic power that weight heavily on the shoulders of businesses. As Interviewee 5 clearly explains, *“If you play in an industry, like the metallurgic one, where the fixed costs are extremely high per se, and you inflate variables cost like energy across a very energy-intensive sector, then many producers can struggle to keep the equation regulating their business going on”*. An example made is that of aluminium in EU, where *“30-40% were coming from Russia in the pre-sanction period. It’s easy to imagine how many changes the market as undergone due to this abrupt turning point”* (Interviewee 5). Therefore, geopolitics dynamics are unanimously considered the most relevant source of disruption out there and are probably destined to remain this way for some time, according to Interviewee 6:

“Geopolitical risks are almost a daily concern now. I think the generation before us used to believe that the world was very stable and predictable. It has been proven to not be the case anymore over the last few years”

Therefore, tensions raising from geopolitical contexts reverberates across the supply chain, fuelling those disruptions that are already present along it.

Apart from this unequivocal common thread across various industries and companies, another risk that was mentioned in half of the interviews was the unpredictability of the demand. This seems to be more difficult to penetrate and be understood, as “the visibility of the demand has dramatically shifted, especially after Covid-19” (Interviewee 2). Interviewee 2 gave a very thorough motivation of what are the main markers emphasizing this problem:

“Most of the companies use 2 KPIs to investigate the future demand: the forecast accuracy and the bias. The former goes to measure the accurateness of the product mix in some way, while the latter, on the other hand, measures the deviation of the forecast from the actual demand, thus marking whether you are under or over planning. Unfortunately, visibility, as I said before, has changed enormously, therefore the statistical models that help in this kind of activity no longer perform as efficiently as they might have been doing in the beginning. Hence, we must find a manner to reshape these tools to better reflect the future demand evolutions”

But, what is the effect stemming from such difficulty in decrypting the future demand? The main one is the bullwhip effect, which is the mismatch between demand/offer and the impediment in closing it within a certain timeframe. The reasons behind it can be manifold: from lack of materials to change in regulations. A very good example of how a policy can abruptly shake a market is presented by Interviewee 4 with the so-called 110% bonus promoted by the Italian government in past years to renew housing environments with more ecofriendly and optimized systems: *“For instance, if we think about the 110% Bonus, it has generated an unprecedented demand for heat pumps. This provoked a severe disruption in Bosch, which was not able to satisfy the local demand and was compelled to redirect these products towards Italy drawing on stocks from external EU countries”*. To put it simply, the problem here manifests itself with overstock in front of restricted demand and low stock in front of rampaging demand, driving inefficiencies on both company and customer’s sides.

Then, other risks and sources of disruptions have emerged, assisting in creating a coloured mosaic of occurrences that could endanger the supply chain of a company. The third most cited event has macroeconomic origin: inflation. The uncontrolled rising of the prices seems to be especially for multinational companies, which are exposed globally to similar events. A detailed overview comes from Interviewee 5:

“Certainly inflation is an important factor. Our company, for example is exposed both geographically, due to its global presence and suppliers from different markets, and geopolitically. When inflation becomes global, there are some sectors that may suffer more and others a little less, therefore it is necessary to continuously monitor the situation, negotiate, contain costs and see what can be passed on to customers. In some large projects, the price is negotiated in advance and this carries risks, especially when contracts last 5-6 years”

Then, we can mention also climate changes, as its effects tend to be very indirect and misleading:

“Climate change is something where it’s difficult to have a full understanding of how it is impacting supply chains globally, due to opaqueness of supply chains. It’s not a risk that manifests on a routinary basis, but it interrelates indirectly with other risks, amplifying their magnitude” (Interviewee 3).

Lastly, also strikes, as carriers of noticeable slowdowns and inefficiencies, and the M&A dynamics in the suppliers market, where brownfield acquisition over a supplier may endanger another company’s business continuity, that have been respectively cited by Interviewee 5 and 6, were considered sources of disruption worth to be mentioned. The key insights on this subject are summed up in *table 3*.

Table 3: Chapter 5.1. key insights

Most relevant risks and sources of disruption	<ul style="list-style-type: none">• Geopolitical risk is the main variable to be addressed as considered the primary root cause of all current risks and disruptions (<i>Int. 3-5-6</i>)• Difficulty in forecasting and reading future demand due to increased complexity (<i>Int. 2-4</i>)• Inflation can be an insidious risk for supply chains (<i>Int. 5</i>)• Climate changes still have to be seized in their magnitude, but they play as catalysts of further disruptions (<i>Int. 3</i>)
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5.2. Four practices to enhance resiliency in supply chains

The key insights stemming from the interviews are summed up in *table 4*

5.2.1. 1st practice to improve resiliency: 3D Printing

Let's see how the first practice, 3D printing, was perceived by the interviewees. On average, most of the interviewees didn't honestly know whether or not this was applied in their industry for risk mitigation purposes, while two of them were quite sure that it was not used at all. However, since the technology was used for customization of products on the commercial side to better capture the taste of the customers, they all agreed that a similar potential application could be tested, and that there was probably no awareness of a similar deployability. Although this optimistic attitude towards such proposal, most of them spotted a series of criticalities and issues in such path. The biggest one was the scepticism of

regulations towards such technology for the production of key components, as clarified by Interviewee 1.

“Although I can see the advantage in flexibility terms, many industries, like the pharma one, are too rigid regulations-wise. This is due to safety measure and compliance with standards. Having a 3D printer producing 20 different types of objects would sometimes require an approval for every single process, making it an important effort”

Other relevant problems with that are the lower rapidity of production, confronted to traditional manufacturing and the lower economies of scale to be leveraged as a trade-off with flexibility. Ironically, two interviewees linked it in a rather opposite way to nearshoring: Interviewee 2 saw 3D printing as purposeless because *“I don’t really see the case for it since we already have similar benefits, risk-wise, by manufacturing in Europe following a nearshoring strategy to shorten our supply chains”*; on the other hand, Interviewee 4 saw it as a driver for nearshoring *“I would love to see such a deployment of 3D printers, because that could help in bringing closer the production and the end market”*. Nevertheless, even when confronted to all these noticeable obstacles, there might be a way to deploy this technology.

“Like products that are manufactured in low volume but are of intrinsic high value may find a case there. For instance, in the pharma/biomedic industry, devices destined to rare diseases that are produced in volumes of a couple of thousands on a yearly basis” (Interviewee 1)

Interviewee 6, although unsure of whether or not this technology was employed with resiliency purposes in his current company, said that this was one of the use cases of 3D printers in his previous workplace:

“The key advantage of 3D printers is the agility they provide. This not only means customization to quickly satisfy ad hoc requests from clients and testing out designs

for products concretely, but also producing into an optimal scale with a very short lead time and without needing important storage space”

For how he described it, this could then be described as a nearshoring driver.

5.2.2. 2nd practice to improve resiliency: Digital Twin

The second practice proved some difficulty in being defined and visualized by the interviewees for its intrinsic on-the-edge innovative property. While most of the interviewees were quite sure that a similar practice was not currently used on a daily basis, they all confirmed that there was either an ongoing exploration on this field, either they could foresee the value a similar technology could bring to their jobs. Of course, some flaws could still be identified: *“This might be an interesting aspect, although it would generate an astonishing amount of data which then need to be processed. Therefore, the risk within a large and vibrant system like a supply chain, is that the raw quantity of information might slow everything down”* (Interviewee 2). Some others resized it as in a more realistic, grounded implementation

“There’s an ongoing project exploring this... however, first it would start within the company, along our internal supply chain and production processes. It would take some time to scale this to our upstream suppliers. Considering that we are currently finding it tricky to map who our sub-tier suppliers are, imagine integrating these into a digital system to have a real-time tracking of our supply chain, how complex would that be” (Interviewee 3).

The question remains: what benefits would such a practice bring to the table? In general, the degree of visibility and the enhanced transparency along the entire chain, which is always a way to untangle the rising upstream complexity. Two different interviewees saw a use in predictive planning of supplies, thus minimizing the gap stemming from a bullwhip effect thanks to this enhanced helicopter view. Another practical deployment could then be the estimations for the carbon footprint

“A real-time tracking would be of great use to calculate the carbon footprint, thus understanding all the routes undertaken by our products and evaluating whether it might be possible to optimize it for an enhanced commitment towards sustainability” (Interviewee 3)

On the same wavelength, Interviewee 6 stressed how useful this would be for reporting

“In front of a crisis, there is always an analysis to be made to screen from where the crisis is coming and what exposure do we have. Not only internal stakeholders, but external ones might want to know what our exposure is, and to map everything out and explain consumes days of people time. Ideally, with this we could go straight to the point of how to mitigate risks that have been rapidly identified and quantified by the system itself, and this would be extremely efficient”

Lastly, we have Interviewee 6 who was quite enthusiastic about a similar hypothetical implementation and foresaw two different use cases for this technology: in the first case, an overall optimization of resources

“Maximization of productivity in the resources available is key. Imagine, instead of having 10 people working on one supply chain, you can have half of them to do the same thing. Thanks to the empowerment granted by this tool, you would have a setup similar to the control towers you have for airplanes’ operations management”

In the second case, a system capable of simulating different scenarios

“With the visibility given by this platform, you could adopt a predictive approach towards the exposure of your supply chain. Instead of waiting for the event to affect the whole supply chain and then become aware of it, which may take weeks, you could predict how a certain event may affect the chain in a specific way. You can anticipate the cause-effect chain and virtually stress test your own supply chain”.

Nevertheless, the most interesting testimony undoubtedly comes from Interviewee 5, who was the only one confirming that a similar solution is already in place and under continuous improvement

“We have a partnership with a company providing us with a solution to track in real-time the materials we purchase. It connects to carrier data, such as ship pilots and GPS sensors on trucks, allowing us to see the real-time location and route of our materials. For example, I can determine if a ship I was expecting has been diverted around the Cape of Good Hope under South Africa, instead of passing through the Panama Canal. This, I feel, is a concrete and appropriate example of a newborn solution which may evolve into an all-in-one platform”

Therefore, there are solutions at their preliminary stages pointing in the more theoretical digital twin direction, leveraging on IoT and extensive use of sensors.

5.2.3. 3rd practice to improve resiliency: Cross-functional teams

Coming to the third practice, we see how cross-functional teams got interpreted in various ways, resulting in a profusion of different points of view. Two main threads were dominating in the discussions: either the team was not permanent and intended as a task-force to face exceptional crisis

“I see a similar team reacting to extreme situations which are taking place at the moment, rather than a fixed team dedicated to predict future crisis. For instance, during the Covid period there was a team made of different profiles with various backgrounds and roles within the company, especially coming from supply chain. This unit was rapidly assembled to contrast the situations of emergency and trying to manage disruptions on a short-term basis. Indeed, when the need for rapidity with respect to what was happening outside diminished, then the team ceased to exist” (Interviewee 2)

Or, on the other hand, this setup is applied in a fixed manner at a top management/board level

“the higher up you go in a company, the higher the probability of finding a cross-functional team focused, among other things, on managing risk” (Interviewee 1)

The potential explanation of why having a fixed cross-functional team for risk management doesn't seem to be so feasible in practical terms, even though cross-functional teams are already considered a thing in corporate environments, comes from Interviewee 5

“It's indeed widely recognized the value of having people with rather different backgrounds and skillsets, as it always brings an added value to have many diverse perspectives on a problem because it often drives to consider a broader range of potential solutions. Clearly, having a similar team who works the whole year on risk management instead of an ad hoc task-force would be more effective, but on the other hand this setup would be way more expensive. In the very end, it all comes to consider whether the investment is worth the benefits and, apart rare exceptions, the answer would be negative”

Interviewee 3, however, confirms that they use a similar setup, in a way. The difference rely on the fact that, instead of having a team with cross-functional personalities, different teams of specialists tend to closely work together as a macro-organism

“There are teams who continuously work closely with each other: the intelligence team monitoring the geopolitical landscape is directly in contact with the public affair team who's managing the communications towards the external world and the public authorities. Then, both need to involve operational teams from time to time to have a clearer understanding of the state of the core business. Therefore, when something happens, it arises quite naturally that these teams will be facing the issue as a unified front, while also working ahead of the disruption manifestation itself. It combines the proactive strategic thinking ahead of risks with the ad hoc reactive response when a risk actually materialises”

This spontaneous synergy links us to the idea of having processes to truly capture the informative signals and treat the risk in the right manner

“If a company has put in place structured processes to react with flexibility in front of external shocks, I don’t see the need for a permanent team. The point is that the people behind such processes should have the right instruments to correctly react in front of common risks, deploying the suitable actions to mitigate them and escalating the problem when necessary. A cross-functional team would be useful as a task-force that intervenes when an unpredictable crisis has already unfolded”
(Interviewee 2)

To strengthen this concept, Interviewee 1 also depicts how the process to escalate risks upwards works *“The higher you go in a company, the easier it is to find these cross-functional teams who manage risk from a high-level perspective. To do so, though, they gather and filter key insights from the various teams below, each reporting the risks that they encounter and foresee on a daily basis or in their function: sourcing team gives his take, sustainability team provides another perspective, supply chain design team highlight other aspects etc... Therefore, every department upscale the risks that are seen as the most relevant on a regular basis, and then those will be assessed at a higher level by the top management”*.

Nevertheless, what looks like a smooth way to identify and evaluate the size of various risks might incur into a vicious obstacle, implicitly linked to this bottom-up prioritization of risks. Interviewee 3, who’s also directly involved in such process, lucidly paint the problem that may arise and, subsequently, offers the solution to the latter:

“An important element to be acknowledged is that risk is subjective. Therefore, this also entails a political dimension, where everyone is trying to upscale their specific branch of risk even by playing with people’s feeling of insecurity to do so. Hence, irrational decision-making may hide behind the corner. This is why scenario thinking and analysis is becoming more and more of an established practice: by

accepting that foreseeing all the different possibilities is impossible, you can use scenarios to simulate the numbers and magnitude of risks that might be arising in the way. Still, having 20 different opinions, or angles, gathered through a bottom-up process is indeed great. However, given that a company has, by definition, limited resources, it'll be necessary to have a central decision-maker to allocate the right resources among this pool of risks”.

5.2.4. 4th practice to improve resiliency: Artificial Intelligence

The last practice is also one of the most intriguing, probably, since we are talking about the most buzzed word worldwide from 2023 onwards. When introducing AI, all the interviewees undoubtedly confirmed that all their companies are somehow exploring, piloting and trying to find ways to implement this groundbreaking innovation. Some are trying to evaluate the solutions offered by external vendors, while others are instead slowly developing systems internally to better suit their needs. Each interviewee could see a different use case, therefore it might make sense to list all the examples mentioned:

- **Forecasting.**

Probably the most popular and talked-about, forecasting processes can be enhanced by AI due to its rapid and accurate data elaboration capability. As clarified by Interviewee 2 *“Forecast is simply the deployment of statistical models to better predict the current and future market demand. Luckily, while facing a more unpredictable customers’ audience, this system have come to help us to accurately breakdown needs at a single-product level”*. Since it’s not just an incremental innovation but a radical one, the degree of complexity and interdependencies across data that AI can manage is way more important than traditional machine learning, allowing to identify complex patterns and granting an automatic renewal of the database as soon as new information enters the flow.

- **Market screening & scenario analysis.**

According to many interviewees, it would be expected that AI could rapidly skim through the noise of modern medias to filter out the little nuggets of information that are really valuable. The outcome would be to have a system capable of informing in real-time of key events from the world that may be a source of disruption or to lay the playing ground over which the scenario analysis is going to be rooted. *“I would expect AI to identify weak but valuable signals on the market and to flag those to the appointed person, given its enhanced complex reasoning. For sure, it is capable to analyse way more data confronted to a person, because even if we tried to put 10 people reading newspapers from all around the world, they would probably not have the same thoroughness and effectiveness in skimming through the noise that an AI could have”* (Interviewee 4). In parallel, with regards to scenario planning, we have the opinion of Interviewee 6 *“If we can rely on a solid and thorough enough database, we may have AI highlighting trends and scenarios to peek into the future. Then, however, it would still be the added value of human intelligence, HI, to arbitrate between these different possibilities and their likeliness”*.

- Delegation of repetitive tasks

Although this is not unique to supply chain, one of the most straightforward and appreciated utilization of AI is for taking care of tedious, low-value adding day to day tasks. AI can streamline administrative operations like data entry, scheduling appointments, routinary customer service, leaving the people those tasks requiring creativity, critical thinking and strategic decision-making. A good example is brought by Interviewee 1 *“When you look at banking apps, the moment you make some inquiries, there’s a chatbot to assist you in the first place. This preliminary interface covers on average more than 50% of these inquiries because only a small amount really entails some extraordinary needs. Just with this, you’ve already drastically reduced the workforce needed for customer assistance”*.

- Sub-tier suppliers mapping.

It has already been widely introduced how crucial is to have knowledge of those suppliers underneath your direct suppliers in various places. On this regards, AI seems to be at the forefront of this quest. By analysing data from various internal/external sources (supplier databases, purchase orders, shipping records, customs data etc...) AI algorithms can detect patterns and picture a comprehensive map of the supply chain network which includes also those sub-tier counterparts that are not in direct contact with the primary company.

- Order management

This domain is where the automation capability of AI gets fully exploited, being able to handle large volumes of orders with rigorous precision while monitoring live the status of the delivery. This potential is even more expressed when integrated to existing ERP platforms, as described by Interviewee 4 “*We have been using ERP platforms like SAP for decades, but although it has automated features, it is for sure not an AI. Nevertheless, SAP itself is piloting an AI add-on based on several parameters and data stored in the platform (like product information, manufacturing location, lead times etc...) to reduce even more the amount of attritions found during the handling of orders, aiming at fully automating such process*”. This exact ratio works in the same manner with functions that share similar necessities but are based on different KPIs, like transport planning and inventory management. A concrete example of a real implementation of AI is also provided by Interviewee 5 “*We do have a tool with some predictivity capabilities, with some reserves. An AI, when facing a ship incurring into a delay, can draft predictions based on historical data in order to estimate how the lead time will be influenced by that event. Of course, it's not bulletproof, but it has been providing some interesting guesses recently*”.

- Contract review

Another task where AI could truly give an important plus is contract reviewing. Although the whole procedure cannot be fully delegated to AI, it is of course possible to leverage on it for first screening, to flag inconsistencies and non-compliance issues. “*Indeed, I would also think of contract review as a field of*

application. Modern contracts can easily be 200-300 pages long, so do we really need lawyers and category managers to lose hours of time on this mundane activity? Can't we use AI for a first, gross screening of those clauses and paragraphs that need dedicated attention?" (Interviewee 6). This is one of those field where the advanced natural language processing reached by latest Ais can really open up to new use cases and ways of working, other than ensuring a continuous improvement of the tool that has plenty of material to train with.

Naturally, when discussing about AI and its applications, it's unavoidable to touch upon the degree of independency in decision-making that this tool should have. Where does it make sense to rely on this?

"If you are able to find an area where the risk is minimal and it can really enhance the productivity, why not giving it a try? This may work for operations at low strategical impact, like the automation of some recurrent processes that can be speeded-up with some prompt decision-making. To make an example, you can have an AI to draft you an RFQ autonomously, but it can't be sent to a supplier without a check from a human. Most of the critical information on metal are not found publicly, but they lay on the brains of the experts in that market. Furthermore, suppliers are not robots: you can propose the same price to two suppliers who look equal in theory, then having an enthusiastic answer from the first and a disappointed reclaim from the second. Why is that? Simply, this last stage, the nearest to the supplier in flesh and blood, is where the strategic thinking and the negotiation dominate"

Furthermore, AI freedom isn't something to be established by a single individual, but as a compact front within the company's governance framework. On this regard, Interviewee 6 thought that

"For the small orders of purchases, under a certain threshold of volume/value, it may be tested the independent decision-making of AI. However, it's crucial to have

it defined as an organization that, for certain non-critical contracts under predefined threshold of volume and value, AI can automatically assess, approve or discard the proposal”

5.2.5. Other unique practices

After having touched upon all the 4 practices that we were expressively focusing on, we then asked our interviewees to freely express their opinions and give suggestions on which practices they would consider to enhance the resiliency of their companies’ supply chains. While some had no suggestions, other gave very different opinions, most of which converging into a common point: people. Precisely, how organizations are designed around people.

“In the end, it’s about how a company is organized and what is its corporate culture, rather than technologies. Companies should be oriented towards Lean structures, thus avoiding all the internal rigidities. Then, also following a step-by-step continuous improvement approach and identify problems through root causes analysis. Although Lean isn’t properly innovative, most of the companies haven’t yet adopted to a more agile corporate culture” (Interviewee 2)

Interviewee 5 also support this point, specifically about smoothly gather the right people to face the incoming crisis *“The possibility to rapidly group together the right people with the right knowledge to face a specific issue is vital. We can forecast everything and deploy all the newest technologies, but it’s only when the people have the right autonomy in the right positions, each giving his unique contribution, that you bring home the results”*. Lastly, Interviewee 6 has stressed this point too, especially emphasising the role of people in fostering resiliency

“People are a crucial element. Saying “people” encompasses culture, skills, knowledge, experience, personalities etc... Therefore, when companies are challenged by high turnover rates, limiting their capability to share and retain know-how, they are assisting to their key assets being drained away. In the end,

without the people even the most advanced technologies like AI, Digital Twin or 3D Printing can't function effectively”

Apart from this majorly shared opinion, only two other practices were expressed as potential additions. The first is the use of stress-tests, already mentioned on the chapter around Digital Twin, but here thought to assess people readiness to disruptions

“These simulations are created artificially by inducing a delay or a lower capacity availability. These tests help verifying whether the people and the established processes are ready to react to an abrupt external shock, when one really takes place. Similar methods have been recurring as a best-practice in the banking sector for some time, then subsequently acquired by other industries” (Interviewee 2)

The second is the operational reallocation of excess stocks among different EU areas, as portrayed by Interviewee 4 *“Spotting and reallocating excessive stocks among the different subsidiaries in EU has proved to be a brilliant way to maintain a high level of customer service and satisfaction, although, of course, moving volumes of goods around Europe impose some bureaucratic transitions”*.

Table 4: Chapter 5.2. key insights

Four practices to enhance resiliency in supply chains	1) 3D Printing	<ul style="list-style-type: none"> • Unclear evaluation of its application for resiliency-improvement • Ambiguous relationship with nearshoring (Int.2-4) • Main bottlenecks are regulations and reduced leverage on economies of scale (Int.1-2)
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- Use-case identified for high value/low volume productions
(*Int. 1*)

2) Digital Twin

- High enthusiasm and currently ongoing exploration on its applications
 - Firstly deployed internally, then extended to the whole chain
(*Int. 3*)
 - Use-cases:
 - Carbon footprint calculation (*Int. 3*)
 - “Control tower” management of supply chains → Already implemented in Prysmian (*Int. 5-6*)
 - Simplified root causes analysis & reporting (*Int. 6*)
 - Scenario planning & virtual stress-testing (*Int. 6*)
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- 3) Cross-functional Teams
- Highly considered in a task-force framework to swiftly react to crisis (*Int. 2*)
 - Less considered as a fixed setup for proactive risk management due to excessive costs (*Int. 5*)
 - Gathering of multiple points of view is deemed as crucial (*Int. 3*)
 - Prioritization of risks performed through upscaling process (*Int. 2*)

-
- 4) Artificial Intelligence
- High enthusiasm and currently ongoing exploration on its applications
 - Autonomous AI decision-making allowed for recurring/small-sized tasks or below a governance-established threshold (*Int. 6*)
 - Use-cases:
 - Forecasting (*Int. 2*)
 - Market screening & scenario analysis (*Int. 4-6*)
 - Sub-tier suppliers mapping (*Int. 3*)
-

-
- Order management (*Int. 4-5*)
 - Contract review (*Int. 6*)
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5.3. The concept of resiliency in supply chain

When asked whether resiliency was a well-known concept and how important it was considered in their companies, all the respondents did not hesitate to say that it was labelled as a top-tier priority. Nearly all of them even took a step further, saying that it was seen as an even higher priority than cost. Especially after Covid-19, companies *“are moving from trying to predict everything upfront to make themselves futureproof for risks yet to be faced. In other words, from a quantitative to a qualitative type of thinking”* (Interviewee 3). This represents a change from the previous route dictated by JIT, as it entails *“actively introducing more inefficiencies such as stock, proximity within a regional setup and dual-sourcing to hedge against risks”* (Interviewee 3).

For companies, thinking in resiliency terms is a way to ensure business continuity, which is the actual goal and focus of their supply chain apparatuses. Customers expect to receive a timely delivery of products, even in the most adverse situations. Consistently meeting these expectations generates a sense of reliability that becomes the cornerstone of a company's brand and success, as well as transforming product flows into financial flows more quickly. This becomes even more important in some industries like the pharma one, where *“resiliency becomes essential and needs to be prioritized as you’re providing life-saving products”* (Interviewee 1). This reaches such a level of importance that, in risk assessments, *“you have a matrix with risk likelihood on one axis, and potential financial impact on the other, usually. In a classical industry, like the automotive one, you would focus on the ones that could inflict the hardest financial impact, if failed to be delivered. For instance Mercedes, when facing the shortages in microchips,*

directed the few available towards the manufacturing of premium cars instead of lower priced models in order to minimize the financial impact. However, since the pharma sector is a peculiar one, the thought-process is quite different: in fact, here we'll have on the second axis whether a product is life-saving or not. The question behind is simple: if we fail to make this product available, would these people have severe health complications?" (Interviewee 1). Another angle to better understand the primary attention devoted to resiliency in respect to cost comes from economies of scale and market share preservation. Firstly, in a competitive market relying on well-optimized economies of scale is key to get ahead of the numerous competitors that a company is facing. This is well-explained by Interviewee 5 who confirms that *"it's inadmissible that a plant stops due to lack of raw materials. The economy, and especially the cable industry, is so competitive that the profits are really stemming from the pure volumes of production. These are the rules of the game and failing to do that might be disastrous"*. The second point touches upon market shares dynamic and how important it is to preserve a market share throughout time, as highlighted by Interviewee 6 *"Companies that are not resilient enough lose market share when facing disruptions, and such a scenario is way more expensive than the investments required for preventive actions. In reality, cost-efficiency is a fraction of all the variables over which a supply chain is working on"*. While everyone agrees on how much resiliency is a priority nowadays, there's a voice who comes from out of the choir and try to go even a step further. In fact, Interviewee 2 reflect on resiliency taking a dramatically different angle *"The objective of supply chain management shouldn't be to absorb external shocks and blandly return to its previous state. On the opposite, shocks are alarms that underline rigidities in processes that haven't been touched for too long. In a way, they offer the opportunity to adapt the processes and promulgate change to better capture the new reality of the market. During the pandemic period, for example, the shock was so great that it called into question anything previously given for granted and re-assess every single process, adapting what was not efficient to what the new reality was. Somehow, despite all the difficulties, it*

has been in some way a hindrance, an added value to be able to change what were outdated logics”. Even if not explicitly mentioned, this goes as a favourable point towards antifragility and how, in general, crisis and disruptions should be approached as opportunities to rethink the current way of doing things, strengthening the processes even more thanks to the scars accumulated throughout time. The key insights on this subject are summed up in *table 5*.

Table 5: *Chapter 5.3. key insights*

The concept of resiliency in supply chains	<ul style="list-style-type: none"> • Top-tier priority in supply chain management, even higher than costs • From Just-In-Time to Just-In-Case. Instead of trying to predict the future, building up buffers to be futureproof (<i>Int. 3-6</i>) • Preliminary explorations to apply the concept of antifragility to supply chains (<i>Int. 2</i>)
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5.4. Sustainability as a competitive advantage in supply chain

We discussed about how much nowadays sustainability appears in everyone’s mouth, inevitably declining towards being a buzzword for greenwashing rather than a ground-breaking approach to business. Trying to zoom-in, investigating how and how much sustainability relates with the concept of resilience in supply chain becomes an interesting topic to delve into. For sure, all the candidates agreed that sustainability is of primary importance downstream: the strong link with brand value and customer engagement have been highlighted numerous times in literature, and here confirmed by our small interview sample. Often, the core business of the companies seems to be linked in their value proposition to sustainability, thus making it a key asset in the marketing of the product and the

promotion of the brand. But what role does supply chain play in this? Well, the foundation over which the “sustainability asset” is built upon are cemented in the supply chain of a company: although this way of thinking is shared across all the interviews, we take two specific examples. Interviewee 3 said that *“In Bosch we have products like the heat pumps that undergo a continuous technical improvement to optimize more and more the energy consumption. In other words, we sell less pollution. Indeed, this is possible only thanks to the meticulous attention that is devoted to both the environmental and social sustainability along the supply chain, thus allowing to promote our products in that way”*. Nevertheless, the supply chain isn’t only instrumental for the sales downstream, but actually benefit by embracing sustainability in its processes. In this regards, the role of authorities and policy-makers is pivotal in enforcing and facilitating this match between supply chain management and sustainability. The mechanism is explained in detail by Interviewee 6

“If we take a public authority at the forefront of sustainability, the European Union, we see that they adopt a very top-down approach: the directives emanated firstly fall upon the big players, who are then supposed to trickle-down these standards and best-practices to their whole supply chains, thus covering a huge slice of the entire economy. For big players becomes more advantageous to filter their supplier by how sustainable they are because this makes it faster and easier to comply to the legislations. On the opposite, less on-the-edge suppliers will probably need help to adapt, translating it into time and people that the big player has to devote for such scope”

The role of policy-makers and government has been cited also by Interviewee 2, who said that

“Sustainability, when approached proactively, makes you futureproof. If a new regulation comes into effect and a supply chain revolves around a material that is now labelled as unethical or non-compliant, you are suddenly facing a disruption.

Striving for sustainability hedges against the volatility of politics that may quickly redefine the regulations”

Another, intuitive way in which sustainability plays a role in supply chain management relies in what it signals to the outside world: *“In the reality of facts, sustainability is something you start to work on when your business has already strong fundamentals. Therefore, if a supplier is already fully compliant with all sustainability regulations, that means they are not bankrupt, let's say, because they would have other priorities. Especially if it's a proactive investment that is stepping further than the minimum regulations, it means that the supplier is probably profitable enough to invest in advance in this specific matter”* (Interviewee 6).

Although these claims may find most of the interviewees more or less aligned, some expressed even more pioneering opinions, diving into the synergies between risk management and sustainability: *“The mutual bond between risk and sustainability becomes evident when talking about climate change risk. This is a risk that interacts indirectly and foster all the other risks, while also being endogenously strengthened by companies themselves. Advocating sustainability as a company and motivating other companies is a good manner to limit a risk that's so complex to be faced”* (Interviewee 2). Even, sustainability may be intended as the pillar of a framework to review, rethink and redesign the traditional way of doing things. Two interesting examples of this brainstorming action through sustainability are brought forward by Interviewee 5:

“Approaching problems with the lens of sustainability can brought positive externalities which indirectly bolster resiliency. For instance, the efforts spent in R&D to develop more sustainable materials also benefit the diversification from the single-sources that monopolizes certain commodities, thus bypassing the problem of scarcity. Or again, the current attention towards the reduction of emissions, especially in logistics, has increased the popularity of reshoring, implying an optimization in transport costs and improvements in delivery lead time”

Next, a field where sustainability and resiliency surely share common ground is the research and investigation of sub-tier suppliers. Slightly more than half of the interviewees confirmed that there's a strong interest in shedding light over the suppliers of their suppliers, while the remaining still believed that there may be some interest in this direction, although they are not directly involved and this exploration may be taking place in the headquarters of their company, not in the local realities. But what motivates so much attention?

In general, there's a growing interest in understanding what's hiding behind the surface, especially in procurement. Interviewee 6 explains that

“Cost-efficiency, lead time improvements, risk prevention, sustainability... all these are approachable only when you have the visibility of what's happening along your value chain. And, attention, I'm not talking about supply chain, but value chain, which entails how and where the value is created, other than identifying whether there are deficiencies. Through a value stream mapping framework, you get the visibility required to direct investments, improve processes and mitigate risks, in case”

In some industries with certain characteristics, this become even more important: *“In the metal market, where there are only a handful of gigantic, vertical integrated manufacturers, knowing the degree of integration and those players who have critical dependencies is vital. Not only this information is a key input in the mapping of scope 3 emissions, therefore covering a prominent position in the sustainability reports, but also permits to target strategically the audit to our suppliers, which otherwise can become fairly expensive if deployed as a sweep check”* (Interviewee 5). Given the importance of sub-tier suppliers visibility, why isn't it just possible to ask those suppliers in the Tier 1? Of course, this is at time possible. In fact, often the people have a certain know-how on this subject simply because of their long permanence in a sector and the continuous networking with suppliers and players in that same sector. However, most of the times the suppliers may be discreet and cautious on revealing these information because their

suppliers platoon could be a competitive advantage for them. It's indeed rare that suppliers are going to expose their tier 2/3 suppliers so light-heartedly. Efforts in relationship building may even reach a point where such information is disclosed freely, but this is very dependent on each case. Nevertheless, authorities and policy-makers, coherently with their top-down approach to initiate a trickle-down effect from bigger to smaller players, are legislating to facilitate a higher degree of transparency

“Since some suppliers won't disclose their chain so freely, authorities are trying to foster openness and transparency as a mean to reduce information asymmetry. Eventually, people will better understand where things are coming from”
(Interviewee 6)

Some examples of these regulations have also been brought to the table: UFLPA, CSDDD, scope 3 reduction... In parallel, companies move faster than public authorities. Unsurprisingly, new innovative methods are being developed to bypass the suppliers' stubborn silence. One, here cited by Interviewee 3, will further on become a more central topic of discussion in relation to resiliency as a whole: *“We are indeed exploring new solutions to study the network underneath our direct suppliers. Encouraging signs are coming from AI, which seems to be able to support a similar investigation”*. The key insights on this subject are summed up in *table 6*.

Table 6: *Chapter 5.4. key insights*

Sustainability as a competitive advantage in supply chain	<ul style="list-style-type: none"> • Regulatory trickle-down system on sustainability standards & positive signalling from virtuous suppliers (Int. 2-6)
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- Sustainability as a framework for innovation in supply chain (E.g. New materials) (Int.5)
 - Visibility over sub-tier suppliers is a key ingredient for any further development. Either achieved through supplier relationships management or innovations (E.g. AI) (Int. 2-3-5-6)
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5.5. Resilience & sustainability: drivers for business model transformation

When asked how groundbreaking have been resiliency and sustainability as drivers to transform their companies' supply chains, the interviewees were all agreeing as a unique voice that resiliency was indeed treated as one of the highest priorities in their business. According to some, even more important than costs

“If we lose or if we are not able to sell, we are going to lose much more than having slightly more optimized resource consumption. Therefore, resiliency it's surely more important than cost, in the current status” (Interviewee 1)

Furthermore, in some companies resiliency has become a beacon to refer to during any business decision *“There's a supply chain design team who has established some principles which serves as standards in face of any sourcing decision. Therefore, usually for every item, it's compulsory to have 6 months' worth of stock, to move away from single-sourcing and to prefer proximity”* (Interviewee 3).

However, the picture becomes trickier when coming to sustainability. Here, the interviewees broke in two halves: one saying that it's not yet as much of a paradigm shift as with resiliency, the other saying that it truly is considered a game-changer.

The first group confirmed that not only is this still a work in progress, with many stakeholders yet to recognize the link between sustainability and risk management, but also that sustainability often becomes the first aspect to be compromised during any crisis, as confirmed by Interviewee 2 *“Although it is considered a key asset, when facing a disruption this is often the ones that, among all the priorities, might be the first one to be compromised”*. Nevertheless, this approach isn’t shared by all the interviewees and their companies. Two different interviewees thought that it is so much of a priority that companies underwent organizational restructuring just for the sake of better pursuing the opportunities emerging from sustainability. A clear example is provided by Interviewee 5:

“It became necessary to change the structure of the organization in order to follow the change in the vision. Actually, the main motivation behind the last restructuring of the company, divided in 3/4 business units, was mainly driven by the necessity to fully capture the trend related to sustainability in telecom, digital solutions, electrification and transmission. These are all under the bigger domain of energy transition towards more sustainable approaches. Another change, again, is having a Head for sustainability directly reporting to the CEO. To put it simple: if tomorrow the sustainability department was to be dismantled all of a sudden, we would lose a tremendous amount of value proposition as an organization”

At the same time, both Interviewees 4 and 6 agreed on the fact that sustainability is pervading every aspects of their daily work life: from the tasks and the objectives they are pursuing, where a lot of emphasis is put upon the importance of tracking carbon footprint and raise awareness on the value added by sustainability, up to some metrics used to evaluate the successfulness of projects delivered. The key insights on this subject are summed up in *table 7*.

Table 7: Chapter 5.5. key insights

Resilience & Sustainability: drivers for business model transformation	<ul style="list-style-type: none"><li data-bbox="766 284 1361 627">• Resilience is key as it allows to preserve market shares and customer service. Compass for any strategic decision-making (E.g. Redundancy & proximity are guiding principles) (<i>Int. 1-3</i>)<li data-bbox="766 649 1361 990">• Sustainability is still catching up at a growing speed, but is already taken into account for some elements (E.g. Motivating organizational restructuring & raising visibility along the whole chain) (<i>Int. 4-5-6</i>)
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6. Discussions

After laying out a solid theoretical foundation, supported by a rich bibliographic base, and establishing research propositions that have served as a "compass" in guiding the direction of this research, it is now necessary to compare the theory with the empirical evidence that has emerged from the findings. Therefore, in light of the grounded insights, it will be useful to comment and compare if and how this evidence fits within the theoretical framework already described in the theoretical background and in the research propositions.

6.1. Most relevant risks and sources of disruptions

The main risk is undoubtedly geopolitical, serving as a precursor to many other cross-cutting risks. China, despite being a fundamental element, is seldom concretely mentioned, as if it has already been taken into account by businesses. Armed conflicts, both actual and potential, seem to be the critical issue and the true element of instability. The most frequently cited example is Russia, with the subsequent sanction dynamics and the resulting inflationary pressures on various commodities such as aluminium and energy. A trade war is something that can be easily imagined and addressed in the minds of the leadership, while after decades of significant international stability, conventional wars are far more elusive and challenging to be interpreted.

Another significant risk is the unpredictability of demand, with the consequent bullwhip effect phenomenon, already mentioned in chapter 2.2.3. This is primarily driven by the increasing complexity along the supply chain, already highlighted as a source of unpredictability in chapter 2.2. Other secondary causes, such as the aforementioned geopolitical dynamics and sudden new regulations, like the 110% Bonus in Italy, add to the complexity, making it increasingly difficult for

companies to estimate demand, which consequently will be hard to match from the supply side.

In general, all the risks highlighted by the empirical evidence confirmed the ones already mentioned in the theoretical background. Therefore, we can conclude by once again emphasizing the primary concern for a geopolitical landscape that has not been this uncertain for a long time and the newfound difficulty in understanding market demand dynamics.

6.2. Four practices to enhance resiliency in supply chains

6.2.1. 1st practice to improve resiliency: 3D Printing

Most interviewees were unaware of its use within their company, at least not with the intention of improving supply chain resilience. Nevertheless, many expressed curiosity about testing such a use of 3D printing, which is currently used for purposes of products' customization and prototyping. Several critical issues emerged, awareness of which could only be tested through the empirical experience of these professionals. Regulations, in some sectors more than others, could significantly hinder the use of 3D printers in manufacturing many products. Additionally, a difficult-to-overcome trade-off is the lower capacity to produce significant volumes compared to more traditional methods, making it impossible to fully exploit economies of scale. Lastly, the most controversial point was the relationship with proximity: contrasting opinions saw this technology as both a driver and an inefficient substitute for nearshoring. Only one testimony seems to substantiate concretely, based on technical knowledge of the tool and past experiences, the benefits in the form of shorter lead times and more agile inventory management. The overall assessment, given the various highlighted critical issues and insufficient direct testimonies, remains ambiguous, if not slightly negative.

6.2.2. 2nd practice to improve resiliency: Digital Twin

Despite this practice not being widely applied in their corporate fields (with one exception), the majority of interviewees confirmed that such a system is currently being explored within their companies and is anticipated to have significant daily applications. The biggest critical issue associated with this technology is the number of prerequisites that must already be in place within a company to enable its full implementation: the presence of a network of sensors and a sufficiently structured and extensive digital infrastructure to support IoT, advanced knowledge and relationships with sub-tier suppliers to truly extend the digital twin's reach across the entire value chain, and so on.

On the other hand, once the groundwork is laid for the installation of this digital twin, the benefits it brings seem far from negligible. Fundamentally, it would serve as a digital platform that, thanks to a higher degree of interactivity and visibility across the chain, would support the addition of various functionalities, as well described by the interviewees: demand planning, carbon footprint calculation, crisis management, trend analysis, scenario planning, and virtual stress-testing. This tool and its potential uses fit perfectly within the previously defined theoretical framework: in a world where complexity is an increasingly pervasive element in supply chains, especially due to geopolitical tensions, increasing visibility along the chain improves both reactivity and proactivity towards disruptions. It becomes easier to identify and effectively respond to an ongoing disruption while simultaneously testing the resilience of the supply chain and making actions on root causes significantly more targeted.

6.2.3. 3rd practice to improve resiliency: Cross-functional teams

Rather than gathering overwhelming evidences, the investigation around this practice played a fundamental role in highlighting the central role that people and organizations play in improving supply chain resilience. Generally, instead of having a dedicated cross-functional team working full-time on risk management proactively, two main scenarios emerged: either task forces are implemented when

it becomes necessary to address an ongoing disruption, or such proactive setups exist with a very broad perspective at the top management/board level.

The most interesting insights and considerations emerged from subsequent reflections. Firstly, it was confirmed that cross-functionality is undoubtedly central to better understanding complex contexts. A greater number of angles and viewpoints offer more keys to understanding surrounding phenomena, making predictions about upcoming disruptions more accurate. Additionally, the importance of business processes was highlighted: they act as a true bulwark against disruptions and as a functional channel to escalate the most relevant risks to top management, having both reactive and proactive facets.

The organizational and HR aspects of risk management can also assume negative aspects. In particular, a consideration arises from the political nature of risk management, as the evaluation and prioritization of risks to protect against, consistent with the constraint of limited resources, remains an arbitrary decision, whether fact-based or not. This political and social dimension of multinational realities, and thus the complexity associated with the castle of processes and the hierarchical structure of a company, was only partially addressed in the theoretical background. Given its actual impact on risk management decisions within a company, and consequently on the resilience level of the supply chain, this gap opens the way for a track worthy of further exploration in the future.

6.2.4. 4th practice to improve resiliency: Artificial Intelligence

Predictably, AI has been one of the most compelling practices discussed. Given its recently acquired popularity, its use has not yet reached all levels within companies. Nevertheless, all interviewees expressed a keen interest and high expectations regarding the revolutionary potential of this technology in the supply chain domain. Due to AI's significant capability, compared to machine learning, to handle higher layers of complexity, this technology could find numerous practical applications across various supply chain functions. The most frequently cited

applications included forecasting, scenario analysis, delegation of repetitive tasks, sub-tier supplier mapping, order management, and contract review, among others.

In addition to the use of AI, a separate discussion is warranted on the level of independence these new systems should be granted in managing tasks or making decisions autonomously. On this aspect, while companies are prepared to collectively establish internal norms and processes to delegate very specific and low-value tasks to AI, several interviewees expressed their support. However, once tasks assume a more strategic tone, Human Intelligence (HI) remains the true compass to be followed.

6.3. The concept of resiliency in supply chain

Resilience is a top-tier priority, sometimes even higher than cost. COVID-19 marked an emblematic tipping point for supply chain management, prompting an effective transition from Just-In-Time (JIT) to Just-In-Case (JIC). What was previously considered waste is now renamed “safety stock.” To maintain business continuity, inefficiencies are tolerated under the banner of redundancy. This trend is not a doctrine but varies in severity depending on the industry: pharmaceutical and luxury are two examples of industries at the antipodes in this regard. To better understand whether building resiliency is necessary, frameworks like the Kraljic Matrix enhance decision-making, as discussed in Chapter 2.3.5.

The risk of market share loss is often considered an even higher priority than cost. JIT emphasizes cost optimization, but the loss of market share through “not-actualized sales” can be more dramatic for a company. If a product is unavailable where it is expected to be, it can be replaced by a direct competitor or a substitute good, causing a loss of customers who might become habitual purchasers of the replacement, leaving a permanent scar.

Antifragility, though not a well-known term, represents the idea of embracing shocks as opportunities for change, as suggested in several interviews. Preliminary

findings indicate that growing awareness of the inherent complexity of modern supply chains makes a priori prediction increasingly fallible. This suggests an initial shift from 'safe from failure' to 'failing safely,' a mindset shift detailed in Chapter 2.7, which would profoundly impact organizational structure. Shocks reveal pre-existing rigidities within companies, suggesting that rather than striving for pure resilience — the return to a previous state — businesses should use disruptions to adapt to a changed context. This approach will likely become a field of increasing study and exploration in the future, even though it is still too immature to be mainstream in corporate discussions.

6.4. Sustainability as a competitive advantage in supply chain

Sustainability is a feature sought in many products, and the supply chain is primarily an enabler of this attribute. It is recognized by all as the source that underpins any corporate sustainability program. If a company can boast of being truly at the forefront of sustainability, it owes this to the strategy implemented starting from the supply chain. Thus, the supply chain undoubtedly heavily influences corporate-level sustainability.

Currently, most sustainability efforts arise from governmental or policy-maker mandates, hoping to initiate a virtuous trickle-down effect from large multinationals to smaller and more remote entities. Regulatory push is a fundamental and primary driver that not only imposes minimum compliance levels but also often opens up to collaborations between public entities and private companies. This stimulates large enterprises to proactively move in this direction on their own.

Sustainability also serves as a filter in reverse marketing. In this context, sustainability becomes a significant competitive advantage for suppliers themselves. A supplier who proactively invests in becoming more sustainable sends an extremely positive signal, indirectly indicating robustness in

fundamentals such as finances and operations, as they can afford extra efforts in an area not essential for business existence. When verified by authoritative and universally recognized certifications, the status of a sustainable player facilitates engagement with industry-leading companies, saving them time and resources in ensuring the supplier's compliance with regulations. Practically, proactive investment in sustainability makes suppliers more future-proof and capable of avoiding regulation-based disruptions stemming from political volatility.

Sustainability also acts as a hedge against interdependent risks. The higher degree of complexity makes sustainability an approach to better address underlying risks that amplify the destabilizing impact of all others. Climate change, an inherently complex phenomenon governed by countless laws of nature, is an emblematic case. Although the direct link between climate change disruptions and the supply chain is not yet clearly visible, as it is difficult to quantify and measure, it is undeniable that incorporating sustainability into corporate strategies can provide a compass to at least begin understanding these dynamics.

On the topic of mapping sub-tier suppliers, half of the interviewees confirmed a strong interest in this direction, while the other half couldn't determine how much of a priority it may be due to working in local subsidiaries where they were lacking the necessary involvement to bring valuable insights.

Visibility into sub-tier suppliers is a necessary condition for implementing truly radical innovations, such as digital twins and the comprehensive measurement of scope 3 emissions. Therefore, its instrumental role in improving efficiency and sustainability along the supply chain is undeniable. The critical aspect, not sufficiently highlighted in the literature, is the practical difficulty in revealing this intricate network of sub-tier suppliers. The most intuitive and straightforward method would be to obtain this information from tier 1 suppliers, but unfortunately, these insights are often jealously guarded as a competitive advantage by the supplier. Aware of this situation, policy-makers are also trying to facilitate this information exchange through regulations like the CSDDD or the UFLPA, which

aims at reducing information asymmetry for end consumers and making them aware of the value-chain behind each product. Simultaneously, technology seems to be a viable path, as testimonies indicate that experiments are already underway using AI in this field to filter and aggregate the crumbles of information scattered around the internet and the different databases to assemble a reliable panoramic over the chain.

6.5. Resiliency & sustainability: drivers for business model transformation

All interviewees agree that resilience is considered a top priority in the supply chain, sometimes even surpassing pure cost considerations. This unanimous confirmation shows that the paradigmatic shift from Just-In-Time (JIT) to Just-In-Case (JIC), described in Chapter 2.3, is a robust trend expected to continue influencing practices in the coming years. The business model has been profoundly altered: processes and guidelines such as "6 months' worth of stock, moving away from single-sourcing, and preferring proximity" have been established in many companies to foster resilience and ensure business continuity.

The perspective becomes more ambiguous when discussing sustainability as a paradigmatic shift in the business model. In this case, only some are willing to consider it a game-changer, while others place it as a lower priority compared to resilience. The central issue, confirmed by all, is that sustainability still requires extensive communication and education within the corporate environment to be perceived as a competitive advantage rather than a set of rules to comply with. The sector from which the testimony originates also plays a significant role: some view sustainability as a key feature of their value proposition, which leads to it being seen as a necessary force to channel in order to generate additional value. In such cases, innovative approaches emerge, such as complete organizational restructuring aimed at best capturing this trend and the implementation of metrics

and parameters to measure any business or strategic decisions, considering their impact on sustainability, whether positive or negative.

It thus appears that, although the direction seems to be towards equal, radical importance of resilience and sustainability in multinational business models, resilience has already reached the podium, while sustainability is in a phase of catching up, with some sectors being more advanced than others due to the nature of their business.

7. Conclusions

As we conclude this discussion, it is time to revisit the three research questions that guided it and their respective answers. Firstly, geopolitical tensions have emerged as a primary risk and cause of disruptions, accompanied by inflation and climate changes, while demand opacity stemming from increasing supply chain complexity has proved itself to be a beacon of further instability in this sense. Most of these are rather unusual phenomena, seen in perspective compared to past decades, and therefore more difficult for today's leaders to manage.

The core section addressed the evaluation of four innovative practices for improving supply chain resilience. These practices, initially identified in the theoretical background, lacked targeted insights into their concrete applications in the business world. This research aims to add a knowledge block to this exploration through qualitative interviews with six supply chain and procurement professionals from four different multinational companies in various sectors. The goal is to critically study whether and how these practices are applied or tested within these industry leaders, and to enrich the initial theoretical use cases.

The first practice, 3D printing, yielded ambiguous and not broadly generalizable results. It may benefit from further interviews in other sectors, perhaps in heavy manufacturing or high technical complexity areas, where marginal benefits for business continuity could be more pronounced.

The second and fourth practices, Digital Twin and AI, were found to have similar discoveries. Both are pioneering technologies, still not widely applied but proactively tested by companies, with the potential to radically change the entire discipline of supply chain management. Listing potential use cases for these technologies provides significant input to current knowledge on the subject, broadening the perspective of business leaders and fostering beneficial innovation. Especially, these two are expected to play a crucial role in expanding the visibility over the whole supply chain, thus making it easier to navigate through its intrinsic

complexity. Given the wide range of areas where these two technologies might be implemented and are already experimented, from trend analysis to sub-tier suppliers mapping, it can be taken for granted that both are going to be protagonists of supply chain management in the future.

The third practice, involving cross-functional teams, also raised ambiguities regarding its practical application. Despite the undeniable added value of this practice, concerns were raised about the actual benefit given the high costs in terms of time and resources required to maintain a fixed setup for proactive risk management. Many considered that similar setups already exist in their companies, focused more on immediate crisis response rather than proactive risk management. Thus, while undeniably useful and already present, this practice needs to be evaluated on a case-by-case basis, depending on whether the heavy trade-off between costs and benefits is the most acceptable.

However, the most interesting evidence emerged from discussing this last practice: the human factor and the centrality of organizational structure. Indeed, three out of four practices are primarily technological in their innovative content, while only one is organizational/strategical. In contrast, many interviewees, when highlighting other potentially valuable or applicable innovative practices, emphasized the role of processes and organizational design within a company. Having a governance culture and infrastructure capable of responding systematically and thoughtfully to emergencies is the first line of defence against the negative impacts of disruptions, whatever they may be.

When examining the current context of multinationals' supply chains, the COVID-19 pandemic is identified as a pivotal moment, marking a break from previous economic and production systems. The shift from Just-In-Time (JIT) to Just-In-Case (JIC) has been repeatedly confirmed, opening the door to a world more focused on business continuity and prudent risk management rather than optimizing and speeding up processes. Not surprisingly, resilience is widely recognized, studied, and sought by companies, which now prefer robust supply

chains capable of absorbing numerous external shocks rather than relying on fragile, over-optimized equilibria.

In parallel, the study explored whether sustainability is perceived as a competitive advantage and tangible value added within the supply chain, as well as its synergistic aspects with resilience, rather than being viewed merely as a compliance issue with minimal standards imposed from above. Here, the responses were more ambiguous, with some emphasizing the added value of sustainability while others viewed it as a way less critical voice compared to resiliency. This discrepancy became even clearer when examining these two concepts as drivers of a paradigmatic shift in business models. Resilience was identified as the driver of a drastic change, particularly in relation to COVID-19, while sustainability received mixed opinions, largely influenced by the characteristics of different industries.

Thus, while this research reaffirms the steadfast presence of resilience in global multinational supply chains, a unified response regarding sustainability remains elusive. An interesting point, which partly justifies this study, is the need to further communicate the impact's extent of sustainability on supply chains and its, albeit difficult to quantify, significant synergies with resilience. This study has shown that practices such as nearshoring, supplier selection, and innovation frameworks are significantly influenced by a company's sustainability efforts, creating positive externalities and initiating virtuous cycles that generate value across various areas of the company and society. The effort to provide case studies through in-depth interviews with professionals from diverse backgrounds serves to amplify this approach. In this regard, greater focus has been placed on sub-tier suppliers mapping, a practice emblematic of how resilience and sustainability are interconnected and synergistically influence each other.

Furthermore, this discussion aims to provide managers and leaders within companies with insights and ideas, giving them a clear overview of the central role of resilience and sustainability, as well as the experiments on the four practices

considered, drawing inspiration from the discussions emerging from this research, further supported by the opinions of authoritative professionals. Ideally, this could promote a cross-sectoral exchange and spillover of know-how, a profitable exchange of best practices and ideas that could fuel the innovative drive of small, medium, and large companies.

Regarding the limitations of this study, the first is the qualitative nature of the investigation, which is well-suited to capturing the details and nuances of real complexity but unable to generalize findings universally. This is an intrinsic limitation of the chosen method but worth noting. The second limitation concerns the sample chosen: while six interviews with professionals from different nationalities representing four leading multinational companies constitute a noteworthy sample, additional material would undoubtedly have enriched the research incrementally. Nonetheless, time and resource constraints prevented a broader scope.

From here, opportunities arise for new lines of research aimed at further exploring the topics discussed: first and foremost, following this initial exploration of the subject, a quantitative study aimed at providing a more tangible measure of the actual importance of resilience and sustainability in multinational supply chains could be of significant interest; secondly, another thread could focus on analysing the impact of organizational and strategic practices, rather than solely technological ones, to further broaden the boundaries of this exploration.

Annex 1

Questions used as guidelines during the interview phase:

1. Would you like to provide a brief description of yourself, your background and your job?
2. What are the main activities and objectives within your department?
3. What are recognized as the biggest sources of risks that may disrupt your supply chain?
4. Is the concept of resilience considered a priority within your company's supply chain?
5. Does your company/department have any pre-established process to deal with supply chain disruption or does it proceed on a case-by-case basis?
6. Is sustainability considered as a competitive advantage in the overall supply chain management within your company? If yes, in which terms?
7. Do you have any interest in understanding the network of your sub-tier suppliers? If yes, do you have (or planning to have) any practices to touch that point?
8. Questions on the 4 innovative practices explored:
 - Is your company adopting *3D printing* within its supply chain? If yes, how precisely? If no, would you see a potential deployment for such a practice in the future?

- Is your company adopting *the digital twin* within its supply chain? If yes, how precisely? If no, would you see a potential deployment for such a practice in the future?
 - Is your company adopting *cross-functional teams* within its supply chain? If yes, how precisely? If no, would you see a potential deployment for such a practice in the future?
 - Is your company adopting *AI* within its supply chain? If yes, how precisely? If no, would you see a potential deployment for such a practice in the future?
9. Are you using other unique practices not mentioned here to improve the resilience of your supply chain?
10. Have resilience and sustainability been drivers of change within your business model?

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