International Transport Forum

Building Supply Chain Resilience: a Review of Challenges and Strategies

06

Discussion Paper 2014 • 06

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BUILDING SUPPLY CHAIN RESILIENCE: A Review of Challenges and Strategies

Discussion Paper No. 2014-06

Report for the Joint APEC – ITF Supply Chain Resilience Workshop
(26-28 March 2014, Christchurch, New Zealand)

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July 2014

OECD

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1. INTRODUCTION

For several decades, textbooks, articles and consultancy reports in supply chain management (SCM) have expounded the virtues of low inventory, just-in-time delivery, single-sourcing, centralization and tightly-coupled processes. Heeding their advice, many companies have effectively implemented this 'lean' approach and managed to achieve impressive cost savings and productivity gains. Over the same period, they have globalized their sourcing, production and distribution operations, creating complex webs of interdependency between factories, warehouses, freight terminals and shops around the world. This has enabled them to expand their market areas, off-shore their production to low labour cost countries and diversify their supply base, again all in keeping with what is generally considered to be good business practice.

By doing so, however, companies have increased the vulnerability of their supply chains to many different types of disruption. They have often traded higher efficiency for greater risk exposure. Lee (2004) describes this as one of the '*perils of efficiency'*. Some of the inventory that used to provide a buffer against internal and external variability has been drastically reduced. Some of the slack in logistics systems, which helped to absorb delays, has been eliminated. Companies have been placing greater reliance on fewer suppliers, carriers and transport nodes and often reducing the flexibility with which they

can switch, reroute and reschedule at short notice. All this might have been acceptable if the world had become a safer place, providing a more stable physical, economic and political environment for business activity. The reality has been quite the opposite. Over the past couple of decades, the incidence and intensity of natural disasters have been increasing, global markets have become more turbulent and threats from terrorism, piracy and cybercrime have multiplied. So companies have made their supply chains more sensitive to external shocks at a time when the risk of such shocks occurring has been increasing. The result has been a surge in the number of supply chain failures. At best these failures have caused temporary, localized disruption to a production or distribution operation from which the affected company has quickly recovered. At worst they have caused widespread industrial paralysis and threatened the health and well-being of large populations. The geographical extent and close integration of global value chains ensures that adverse effects originating in one location quickly diffuse both internationally and across business sectors. Given the scale of the resulting disruption, national governments and international organization have naturally begun to take a close interest in the problem, enquiring what can be done both to minimize the risk of a supply chain failing and to maximize the speed with which it can recover when disaster strikes, what is now termed 'supply chain resilience'.

Sheffi (2005) defines resilience as the '*ability to bounce back from large-scale disruptions'*. A resilient enterprise may also be able to minimize the depth of the disruption and hence the height of the required 'bounce back'. This is reflected in definitions of resilience from, respectively the OECD (Duval and Vogel, 2007) and World Economic Forum (2012):

'the ability to maintain output close to potential in the aftermath of shocks'.

'the ability of a global supply chain to reorganize and deliver its core function continually, despite the impact of external and/or internal shocks to the system'

Supply chain resilience has been the subject of numerous studies in recent years by academics, consultancies, insurance companies, logistics providers, government agencies and international organisations. Members of this supply chain resilience 'community' have taken differing perspectives on the subject, but cross-reference their work and generally agree on the major observations and recommendations. The various papers and reports that they have published provide a deep insight into the nature of supply chain failures and make extensive use of case studies to illustrate their causes and impacts. They also propose measures that companies and governments, individually and collectively can take to mitigate their damaging effects of fractured supply chains.

This paper begins by examining the nature of the risks to which supply chains are exposed and how these risks have been changing. It then shows how global supply chains have become more vulnerable over a period when the probability and seriousness of disruptions have been increasing. The following section briefly discusses changing managerial attitudes to supply chain risk. The remainder of the paper reviews the various ways in which companies and governments can enhance the resilience of supply chains.

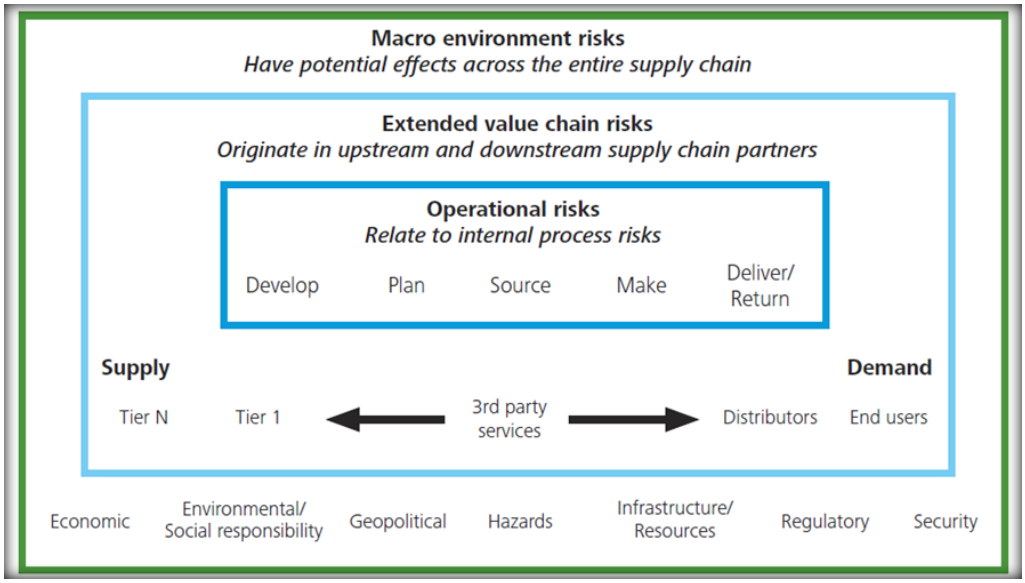
The paper is based on a review of academic, business and governmental literature mainly published over the past decade, though it also acknowledges the important contribution of earlier work to current thinking on the subject. Tang (2006a) provides a thorough review of this earlier research on the mitigation of supply chain risk and strategies to improve 'robustness'.

2. NATURE OF SUPPLY CHAIN RISKS

2.1 Classification of the Risks

Supply chain risks can be classified in various ways, primarily by source of the risk, the nature of its impact and the extent of its influence (Rao and Goldsby, 2009). The framework depicted in Figure 1, combines the first and third of these taxonomies (Deloittes 2012). It distinguishes external, macro-level, systemic risks which can disrupt complete supply networks, from risks which originate from an upstream supplier or downstream distributor in a particular supply chain and risks whose source lies within an internal process of the company undertaking the risk audit. Christopher and Peck (2004) also differentiate upstream 'supply' risk from downstream 'demand' risk from internal 'process' risk, but includes an additional category of 'control' risk associated with the relationship between companies in the supply chain.

Figure 1. **Different types of risk to which a supply chain is exposed**

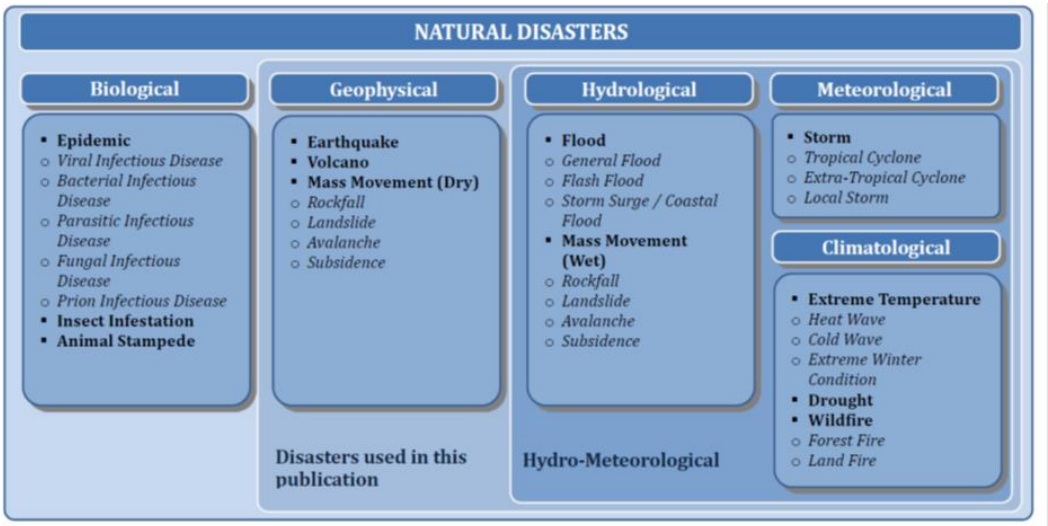


source: Deloittes, 2012

The Deloitte framework classifies the 'macro-risks' into seven categories, ranging from economic to geopolitical and natural hazards (Figure 1). The World Economic Forum (2013) aggregates them under four broad headings: environmental / natural, geopolitical, economic and IT / infrastructure. Empirical surveys decompose the 'macro-risks' into a series of incident types, sometimes on a hierarchical basis. For example, under the natural disaster heading are extreme weather events which can be subdivided into storms and temperature anomalies and the former further split by impact such as flooding or wind damage. The '*Annual Disaster Statistical Report*' compiled the Centre for the Epidemiology of Disasters (CRED) groups natural disasters into five categories: biological, climatological (droughts, heatwaves), geophysical, hydrological and

meteorological (storms) (Guha-Sapir et al, 2013) (Figure 2). Risk assessments by the World Economic Forum focus more on socio-economic risks to supply chains and, accordingly, subdivide them into a broad range of possible occurrences.

Figure 2. **Taxonomy of natural disasters**



Source: Guha-Sapir et al, 2013

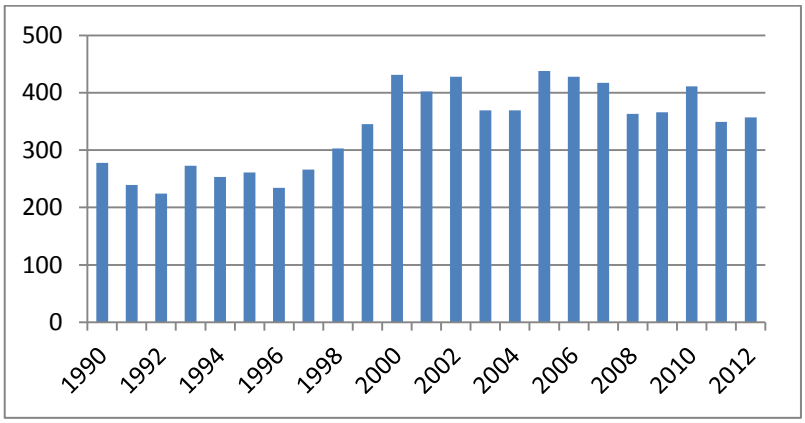
2.2 Relative Importance of the Risks

This can be measured in two ways:

1. Objective measures of the frequency with which incidents occur or the volatility of economic indicators.

CRED has been compiling a data base of emergency events (EM-DAT) since 1988. This suggests that the annual number of disasters increased from an average 268 in the 1990s to a mean of 394 in the 2000s. During the 2000s it has fluctuated but not shown a clear upward or downward trend (Figure 3).

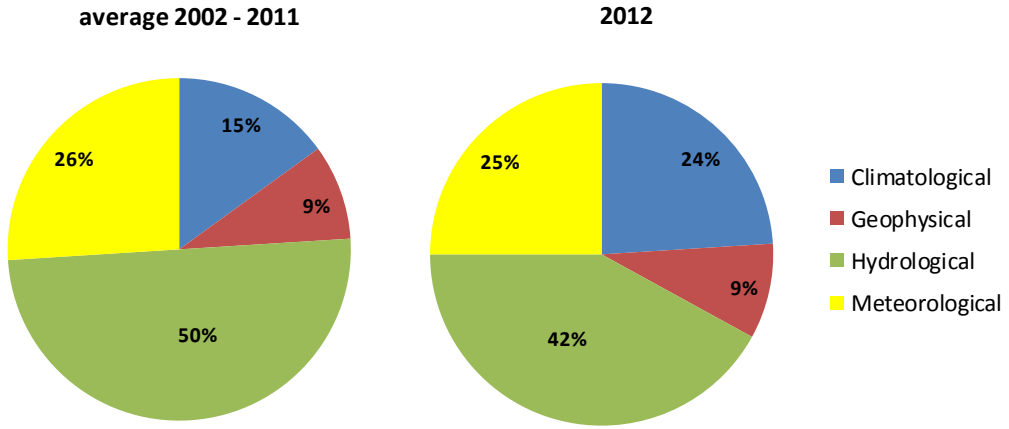
Figure 3. **Trend in the annual number of natural disasters recorded by CRED**



Source: Guha-Sapir et al. 2013

CRED uses two metrics to measure the impact of these disasters: *economic cost and death toll*. It does not consider the implications for supply chains. It recognises, too, that '*disaster trends are greatly influenced by single, high-impact events*' (p.21). Munich Re (2013) estimates that there were 880 natural catastrophes in 2013 involving an insured loss, capturing many more events in their definition and monitoring.
Trends in the main causes of natural disasters also vary a lot from year to year. For example, a comparison of the disaster profile in 2012 with the average profile for 2002-2011 reveals a relatively high incidence of climatological events (Figure 4).

Figure 4. **Proportions of different types of natural disaster occurring annually**



Source: Guha-Sapir et al, 2013

This is confirmed by the World Meterological Organisation's designation of 2012 as a '*year of multiple extremes'*. The National Resources Defence Council (2013) reporty that 3527 monthly weather records were broken for heat, rain and snow in the US that year. Much of Russia suffered a severe drought, new temperature extremes were experienced in Australia and, although not classed as a natural disaster, minimum summer ice cover in the Arctic dramatically contracted (to 50% of the average cover in the 1970s). 2012 was also the year of Superstorm Sandy, classed by CRED as a meteorological disaster, which caused extensive supply chain disruption in the US. One has to exercise caution in linking short-term weather trends to longer term climate change, though as Christiana Figueres, head of the UNFCCC, recently noted extreme weather events '*are giving us a pattern of abnormality that's becoming the norm. We are experiencing climate change*' (Guardian, 8 March 2014).

Weather events have been increasing in their frequency, intensity and duration imposing greater stresses on supply chains. This is confirmed by the second category of empirical data discussed below.

Because of their devastating effects, particularly on human life and welfare, natural disasters often gain greater media exposure than economic and political disruptions, though they too can carry serious consequences for supply chains. Christopher and Holweg (2012) have devised a composite index of '*supply chain volatility'*, combining a range of socio-economic indicators that affect the management of companies' supply chains. The trend in this index over the period 1970-2012 suggests that we have entered what they call an '*era of turbulence'* when many of the supply chain models developed during an earlier '*period of relative stability'* may prove inadequate.

2. Surveys of companies' experience of negative events impacting on their supply chains.

Regular surveys of this type are conducted by the Business Continuity Institute (BCI) / Zurich Insurance. In recent years, these have been supplemented by surveys undertaken by the World Economic Forum, as part of its Risk Response Network initiative. In the most recent survey by Business Continuity Institute / Zurich Insurance (2013), three-quarters of the companies consulted reported at least one significant supply chain disruption during the previous year, with 22% experiencing more than five. In the 2011 and 2012 BCI surveys, adverse weather was by far the most important natural cause of supply chain disruption, with almost 70% of companies reporting some adverse effect and 12% claiming it had a 'high impact' on their supply chain operations. Only '*unplanned IT / telecoms outage*' was deemed to be a more common cause of supply chain interruption overall. In 2012 extreme weather was rated the second most important '*trigger of supply chain disruption'* by the WEF survey of 55 executives in five sectors, behind '*other natural disasters'*, and ahead of '*conflict and political unrest, terrorism and sudden demand shocks*'. BCI also observed that cyber attacks and transport network disruptions rose 'considerably' in 2012.
Both these surveys reveal that supply chains are subject to disruption by a broad range of natural, economic, political, infrastructural and technical events. It is quite common too for these events to coincide. Major supply chain interruptions are often caused by a combination of circumstances. If one considers all the possible permutations of things going wrong *'the number of risks to a supply chain is endless'* (Sheffi, 2005).

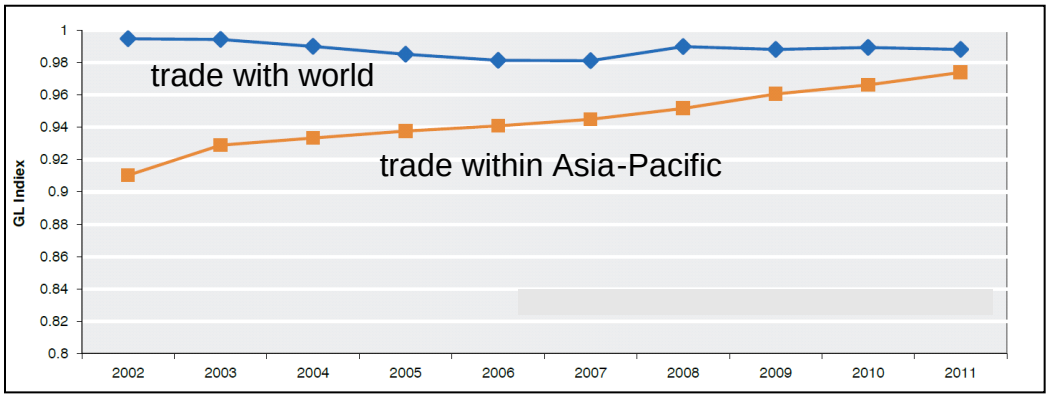
3. INCREASING EXTENT AND COMPLEXITY OF VALUE AND SUPPLY CHAINS

3.1 Growth of Intermediate Trade.

Between 1990 and 2010, the total value of 'intermediate trade' between countries that were neither the origin of the raw material or the destination of the final product increased by 430% (at current prices by end use). The growth of intermediate trade has been particularly pronounced in the APEC region, substantially exceeding the increase in the region's trade with the rest of the world (ESCAP,2013) (Figure 5). ESCAP uses the example of a hard drive assembled in Thailand to illustrate the high degree of intra-regional inter-dependence as components for this piece of electronic equipment are sourced from eleven other APEC countries.

The increase in intermediate trade can be considered a crude indicator of the proliferation and increasing complexity of cross-border value chains. Value is now being added more incrementally in more locations that are more widely separated. As this international transfer of value is manifest as physical flows of product there is a corresponding increase in the complexity of physical supply chains, increasing the freight transport intensity of the global economy. Statistics on the growth of intermediate trade also under-estimate the increasing degree of inter-linkage in supply chains, in two respects: first because they fail to monitor the same process occurring within national borders and second because many of the additional nodes and links inserted into supply chains are logistical and do not result in the addition of 'intermediate' value.

Figure 5. **Intra-industry trade intensity of the Asia-Pacific industrial sector,2002-2011**



Source: ESCAP, 2013
Note (GL = Grubel-Lloyd index of Intra-industry trade intensitylevel.) (

Increases in the number and length of supply chain links are the result of several inter-related trends:

1. Increasing technical sophistication of products, requiring more components and more intermediate sub-assembly work.
2. Vertical disintegration of manufacturing operations, involving the outsourcing of particular production processes.
3. Off-shoring of many of these processes to lower labour cost countries.
4. Growth in the number of emerging markets with the capability of performing these outsourced and off-shored tasks.
5. Major improvements in international transport and communication networks facilitating these supply chain trends.

The increased vulnerability of supply chains is not simply a function of the number and length of the links they contain. It is exacerbated by the spatial concentration of freight flows through a few critical nodes and corridors and the time compression of activities performed at the various nodes.

3.2 Concentration of Freight Flows by Node, Corridor and Cluster

Logistics service providers and their clients have been under strong competitive pressure to centralize their operations. Centralised sortation is fundamental to the logistical model employed by global express parcel carriers. Many of the large container shipping lines have reduced the number of ports they serve, concentrating traffic through the limited number 'hub ports' capable of handling the huge Panamax and post-Panamax vessels that now handle a large share of global trade at relatively low cost per TEU-km. The dramatic growth in the capacity of these vessels over the past twenty years, which has partly driven this hub port strategy, has carried a risk penalty. This was illustrated when the MSC Napoli ran aground off the south coast of English carrying around 1000 tonnes of nickel, around 20% of the available supply of the metal in the world market at the time. Some heavily-trafficked maritime channels are also regarded as weak links in global supply chains. It is estimated, for example, that roughly a quarter of global sea-borne trade passes through the relatively narrow and shallow Malacca Strait (Khalid, 2010).

Producers and retailers also have a strong incentive to centralize their inventory. This allows them to exploit the so-called 'square root law' of inventory, drastically cutting safety stocks while maintaining the level of product availability (Maister, 1976; McKinnon, 1989). They can also take advantage of economies of scale in warehousing and justify investment in more capital-intensive materials handling systems. Concentrating a large proportion of total inventory in a single location can be very hazardous, however, as illustrated by the UK clothing retailer Primark, whose sole warehouse was destroyed by fire six weeks before Christmas in 2005. Half of the company's total inventory was destroyed.

Many manufacturers have also centralized the production of specific products. Even where they have retained several plants, they may have adopted a 'focused factory' strategy specialising in the manufacture of particular product lines in particular locations and supplying national, continental or global markets from there. The resulting economies of scale can be impressive, but the consequences of any production stoppage severe, not only for the manufacturer, but also for customers heavily dependent on the output. This is well exemplified by what has become probably the most cited industrial disaster in the supply chain risk literature, the fire which destroyed a Phillips factory in New Mexico making a vital component for mobile phones. Its notoriety does not stem from the cause of the fire, a lightning strike, or Phillip's contingency planning, which was industry-standard. It is the differential impact of the disaster on the supply chains of two of Philip's major customers, Nokia and Ericsson, which has been discussed at length. As Chopra and Sodhi (2004) observe, the 'two dramatically different outcomes from one event demonstrate the importance of proactively managing supply chain risk' (p.53). The case study also illustrates the potentially dire consequences of single-sourcing a vital component from a supplier whose production is confined to one facility.

Even multiple sourcing can be risky when suppliers of similar products cluster in a particular region. Clustering is considered good practice in regional development terms as it yields a range of agglomeration benefits, but it accentuates supply chain risk at an industry level especially where the region in question is risk-prone. The Thai floods of 2011, for example, seriously inundated industrial estates in the vicinity of Bangkok which meet approximately 40% of the world demand for hard drives.

3.3 Time Compression of Production and Logistics Activities

For over thirty years, just-in-time (JIT) has been the dominant paradigm in operations management. The practice of supplying goods only as they are required has been reworked and 'rebranded' several times (with terms such as quick response, lean and ECR), often adapting it to the requirements of particular industry sectors, but the fundamental principle remains the same. JIT is more than just a means of cutting inventory. It is a whole business philosophy designed to minimize waste and maximize productivity. A near religious commitment to JIT now pervades most business sectors and is physically embedded in manufacturing processes, order replenishment systems, the availability of storage space across supply chains and the timetabling of freight services. The compression of order cycle times and depression of inventory levels has resulted in much tighter coupling of processes across the supply chain. This means that the effects of a failure at one point in the chain can now ripple much more rapidly, not just in a linear sense to lower tiers in the vertical chain but also 2-dimensionally across the horizontal links that connect supply chains. The term 'supply network' is increasingly being used to describe this web of inter-connected supply chains through which the effects of disruption can widely diffuse, often breaking the weakest links within a few days. Preston et al (2012) reckon that, '*One week seems to be the maximum tolerance*

of the 'just-in-time' global economy'. The impact of disruptions in different types of supply chain network is discussed by Greening and Rutherford (2011).

4. MANAGERIAL ATTITUDES TO SUPPLY CHAIN RISK

Early research on this topic uncovered widespread complacency on the part of the logistics and supply chain managers to risks of supply chain disruption. Managers, and businesses, that had never experienced a serious breakdown could easily dismiss it as something very unlikely, under-estimate its consequences and exaggerate their ability to react. Fear of the possible supply chain impact of the Millennium Bug, whipped up mainly by IT consultants and shown to be largely unfounded, raised many managers' awareness of the concepts of supply chain risk and business continuity for the first time. Since then the proliferation of supply chain disruptions, some of them gaining high media profile, promotional campaigns by consultancy and insurance companies and the formal inclusion of risk audits in definitions of good governance, have made supply chain risk management (SCRM) a core part of a manager's job. The Sarbanes Oxley Act, passed in the US in 2002, placed an obligation on publicly-quoted companies to inform their shareholders of the risks to which they business are exposed including supply chain risks. Complying with this legislation can give companies an 'opportunity to revisit and redesign the organizations' infrastructure and return to the basics of supply chain management and operations processes…' (Protiviti / APICS, 2003, p.13).

Standard approaches and toolkits have been developed for dealing with supply chain risks which are now widely, though far from universally, implemented. Many of them are 'cause-neutral' in the sense that elicit a generic response to disruptions regardless of what caused them. In auditing risk exposure, however, managers must estimate as accurately as possible the likelihood of a specific type of disruption occurring within given time-frame and the magnitude and extent of its impact. This process is often deficient, in at least two respects:

(i) *Audits are predominantly retrospective and fail to anticipate new classes or risk*: for example the volcanic ash cloud which shut-down European aviation for 6 days in 2010 caught all businesses, and governments, off-guard. Another potential hazard, according to the UK National Risk Register (Cabinet Office, 2012), which currently attracts little attention is 'severe space weather' including solar flares capable of disrupting global telecommunication networks. National risk registers compiled by governments such as that of the UK are designed to help companies anticipate and plan for new eventualities.

(ii) *Tendency to prevaricate and under-estimate the rate at which risk profiles change*: this applies particularly to what Preston et al (2012) call '*slow motion crises'* that build over many years. It is illustrated by many companies' current assessment of climate risk. '*The prevailing view of many logistics managers is that climate change is just another risk factor to build into their business continuity models. Allowance is already made for bad weather in the management of supply chains and all that may be required is a bit more contingency planning to accommodate extreme weather conditions. Longer term climate impacts, most*

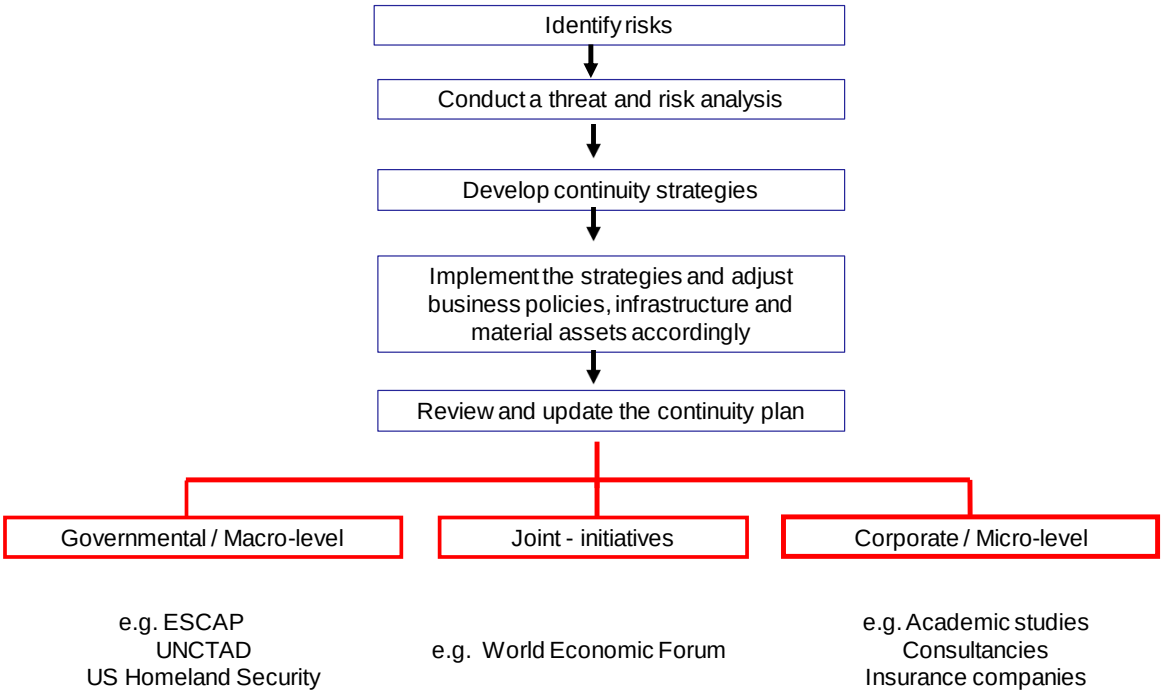
notably sea level rise, are considered unlikely to pose a serious threat to logistics systems for many decades and can be left to future generations of managers to deal with' (McKinnon, 2012). The EU EWENT project found that among the businesses they surveyed there was a poor understanding of the probability of 'weather-hazards' occurring and the possible extent of their impact, and little willingness to increase the robustness of their organisations and supply chains to cope with extreme weather (Ludwigson, 2012).

5. ENHANCING SUPPLY CHAIN RESILIENCE

ESCAP (2013) proposes a five stage procedure for improving supply chain resilience (Figure 6). This starts with a risk audit and then analyses the effects of these risks on the supply chain. 'Continuity strategies' are devised to deal with these risks should the adverse events actually transpire. Strategies are then implemented and the continuity plan reviewed and updated at regular intervals in the light of experience.

This framework is applicable to both companies and government agencies. In some cases each stakeholder group can act independently: in others it makes sense to work together on joint risk-mitigation / supply chain resilience initiatives. The following sections examine what the corporate sector and governments can do to improve supply chain resilience.

Figure 6. **Procedure for Improving Supply Chain Resilience.**
Based on ESCAP (2014)



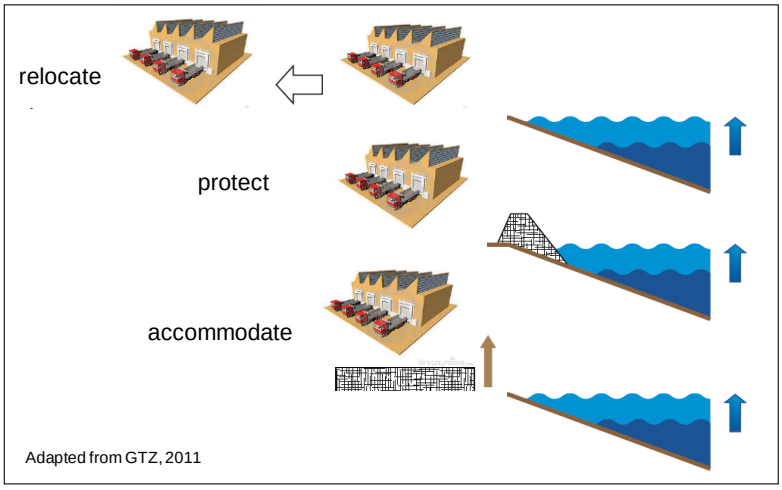
5.1 Corporate Initiatives

From the 'supply chain resilience' community of academics, consultants, logistics providers and insurance companies have emerged numerous check-lists of actions that companies can take to improve the resilience of their supply chains (e.g Centre for Logistics and Supply Chain Management, 2003; Sheffi, 2005; Tang, 2006a, World Economic Forum, 2013) . They are differently expressed and specified in varying amounts of detail but, broadly speaking, there is a general consensus on the key measures that should be taken. These can be grouped under nine headings:

(i) ***Foster a risk management culture***: In the early days of risk management, it was quite common for companies to appoint a risk manager and vest responsibility for business continuity in him / her. It is now recognised that effective risk management depends on staff across the business being sensitised to risks and trained to recognise and deal with them. As BCI /Zurich Insurance (2013) observe, '*Risk management has to be embedded in an organisation from top to bottom and has to include a consistent set of key performance indicators*'. In a supply chain context, this risk culture cannot just be confined to a single organisation: it must cross organisational boundaries. This can be encouraged by so-called supply chain 'captains', businesses that occupy dominant positions in the chains and exercise significant influence over upstream suppliers and downstream distributors. There is also a role for trade associations and government agencies in promoting industry-wide good practice in SCRM.

(ii) ***Mitigate risk within internal production and logistics systems****:* Peck (2007) found examples of companies trying to off-load risks when outsourcing activities. This merely transferred the risk, often to weaker players in the chain who were less capable of dealing with it, effectively increasing the vulnerability of the chain as whole. Contrary to this practice, good risk management starts at home, in other words within a company's corporate boundaries. Once the main risks have been identified and assessed, appropriate business continuity measures can be applied. In the case of transport, that might involve altering the allocation of freight between modes (so-called modal split), increasing the ratio of truck trailers to tractors or multiple sourcing from more carriers. Where, for example, factories or warehouses are found to be in high-risk locations the main options are usually to relocate, protect (e.g. by building a flood barrier) or accommodate (i.e. by adapting the building to minimise damage) (GTZ, 2011) (Figure 7). The choice between these three options will depend on several factors including the probability and seriousness of the threat, the criticality of the operation and the age and insurability of the asset. For new facilities currently at the planning stage, account should be taken of the future risk profile of the site extending several decades into the future, during which the climate and related geophysical processes could change quite significantly.

Figure 7. **Options for dealing external threats to logistics assets**

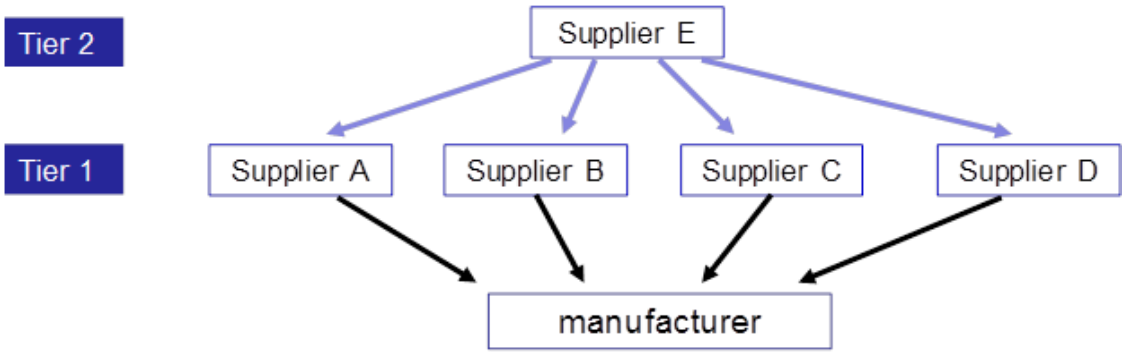


Source: GIZ, 2011

(iii) ***Strengthen supply chain collaboration***: This has been one of the prime objectives of supply chain management over the past thirty years, though mainly for reasons other than risk management. Initiatives such as Efficiency Consumer Response and Collaborative Planning Forecasting and Replenishment have been designed primarily to cut inventory levels and smooth the flow of product between organisations. More recently, transport optimisation has become a priority of these supply chain initiatives. There is now increasing interest in incorporating risk more formally into these collaboration schemes, though still relatively few examples of risk management programmes being designed and implemented at a truly supply chain level.

(iv) ***Share risk information with supply chain partners***: All the supply chain resilience studies are unanimous on the need for risk visibility across the chain. It is, however, very difficult to satisfy, particularly given the complexity of modern supply chains and the fact that they traverse many countries with different business cultures, management styles and regulatory frameworks. In its survey of senior executives the World Economic Forum (2013) found that *'availability of shared data / information'* was the second least effectively managed *'supply chain component'* and this was closely associated with *'fragmentation along the supply chain, extensive sub-contracting'* and a lack of *'supplier visibility'*. As numerous supply chain crises over the past decade have revealed, many companies' knowledge of their supply chains extends only as far as the first tier supplier. A survey of 388 senior executives by UPS / Economist Intelligence Unit (2008), found that 42% of their companies monitored only first-tier suppliers; only one in five attempted to monitor risk across the complete supply chain. A lack of upstream visibility makes it difficult to move to a lower risk sourcing strategy. A firm might decide, for instance, to spread it upstream risk by multiple-sourcing without realising that most of these first tier suppliers (A, B, C and D) purchase a common component from a single supplier (E) at the second tier (Figure 9). Unknown to the manufacturer, therefore, it is still exposed to single sourcing risks but a higher level in the chain.

Figure 8. **Single sourcing from a second tier supplier**



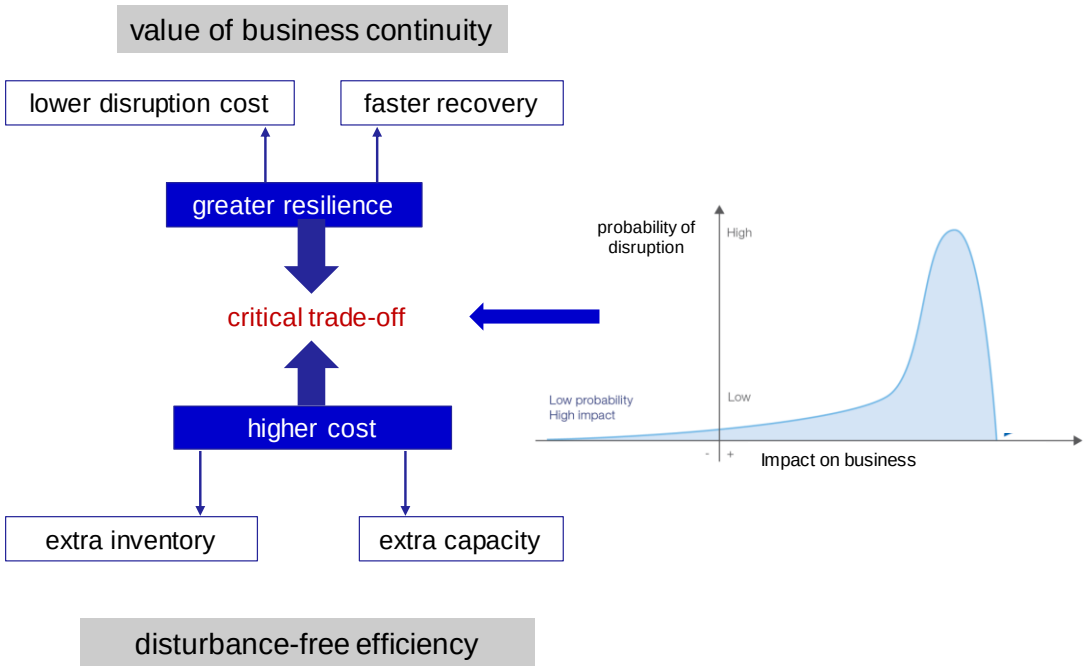
The problem is not simply that companies are commercially 'myopic'; it is also that suppliers often have good reason to withhold information about their risk exposure as it may weaken their competitive position. So while full risk transparency is a noble aspiration, it is subject to numerous practical constraints.

(v) ***Increase the agility of the supply chain***: like collaboration and information-sharing, this is something that many businesses now strive to do anyway to improve their competitiveness. In his classic paper on the 'triple-A supply chain', Lee (2004) defines agility (one of his three As) as '*the ability to respond quickly to sudden changes in supply and demand*'. His prescription for supply chain agility actually subsumes the development of *'collaborative relationships'* and better '*information flows'*, suggesting a degree of circularity in the discussion of supply chain resilience. He also concedes, however, that the pursuit of agility can entail '*building inventory buffers by maintaining a stockpile of inexpensive but key components*'. Unlike the 'lean' school of supply chain management whose priority has been to drive inventory down to very low levels, advocates of agility argue that the key is to have the right amount of inventory to deal with contingencies (Christopher and Towill, 2000). There have been several attempts by academics to reconcile the lean and agile paradigms in a way that balances efficiency with the need to ensure continuity of supply (e.g Naylor et al, 1999; Goldsby et al, 2006).

(vi) ***Increase redundancy / inventory at critical points:*** this follows from the adoption of an agile approach to managing supply chains and forces companies to reconcile efficiency and resilience objectives. This trade-off is fundamental to SCRM (Figure 9). Building extra inventory and capacity into the chain to accommodate extreme events carries a cost, but this can be far exceeded by the financial impact of a supply chain disruption, in terms of loss sales, recovery costs, reputational damage and the share price. Several studies, for example, have suggested that a company's share price drops, on average, by 7-9% following the announcement of a supply chain disruption (Hendricks and Sighall, 2003; Gledhill et al, 2013 and Harrington and Smith, 2014). It is, nevertheless, difficult to model the efficiency-resilience trade-off in economic and financial terms, mainly because the probability and impact of a disruption can be very uncertain. This applies particularly to the so-called high impact low probability (HILP) events which so seldom occur that they cannot be predicted or may never have occurred before. For example, in December 2005, the largest explosion in post-war Europe occurred 40 kms north-west of London at a place called Buncefield when a large fuel storage facility went on fire. This did extensive

damage to an adjacent distribution park where many large retailers and manufacturers had located their warehouses. This was the first time that such an incident had happened in the UK and so was not on the 'risk radar' of the companies deciding to locate their distribution centres in the vicinity of a fuel depot. Factoring an event such as the Icelandic volcanic eruption, which paralysed European aviation in 2010, into the trade-off analysis would also be well nigh impossible (Preston et al, 2012). As Sheffi (2005) argues '*When thinking about resilience it may not be productive to think about the underlying reason for the disruption.....Instead the focus should be on the damage to the network and how the network can rebound quickly'*.

Figure 9. **Critical trade-off between greater resilience and higher cost**



UPS/Economist Intelligence Unit (2011) argued that it may not always be necessary to trade-off resilience and efficiency. They argue that, '*it may be possible to increase both. For instance, Whirlpool was able to boost both efficiency and resilience by consolidating its brands and increasing the use of standardized components*.' Clearly, companies should explore opportunities for simultaneously improving efficiency and resilience. Chopra and Sodhi (2004: p.54) talk about '*Mitigating risk by intelligently positioning and sizing supply chain reserves without decreasing profits'*. The potential still exists in many businesses to cut inventories, particularly of slow-moving products, without sacrificing much of the protection that stockholding affords. The skill lies in identifying and preserving the 'risk-critical' inventory whose elimination would seriously expose an operation or supply chain to the possibility of disruption.

Once the decision has been made to build more capacity and inventory into a supply chain as a contingency measure, the next question is where the extra slack should be located. This requires a critical path analysis to determine where high dependence on particular processes and stocks coincide with high risk exposure. This ensures that the extra slack is targeted on points of maximum vulnerability where the potential resilience gains are greatest. Critical points can be characterised by long replenishment times for

replacement products, tightly-coupled processes, low visibility and single-sourcing. As discussed above, getting the necessary data for a critical path analysis from upstream suppliers, perhaps several tiers above an OEM's assembly operation, can prove very difficult.

(vii) ***Monitor and analyse near-misses:*** In the aviation sector, there has been a long tradition of recording and analyzing near-misses to increase awareness of risks and find ways of minimizing them. This has helped to make flying by far the safest most of transport. Supply chain managers are now being encouraged to adopt a similar practice to gain advanced warning of potential failures. Sheffi (2005) has constructed a 'near-miss' pyramid with a broad base of minor accidents which would have little or no consequences rising to an apex comprising potential disasters that would cause extensive damage and loss of life. Analysis of events at the lower levels of the pyramid can reveal minor vulnerabilities that individually, or more likely in combination, might lead to serious disruption. The workforce and managers must therefore be sensitized to near-misses and encouraged to log them, preferably through formal reporting systems.

(viii) ***Stress-test systems regularly:*** By definition, business continuity measures are seldom deployed, with the result that complacency can set in and the ability to react rapidly in an emergency can degrade. It is important, therefore, to test systems and procedures regularly to make sure that staff know how to deal with contingences and check that back-up systems are in place. Anecdotal evidence suggests that stress-testing of logistics IT systems is now quite common. Companies like Nike also regularly stress-test the various production and distribution facilities they operate (Wong and Schuchard, 2010). Chopra and Sohdi (2004) give examples of different types of supply chain stress test, showing how they can be tailored to specific types of risk.

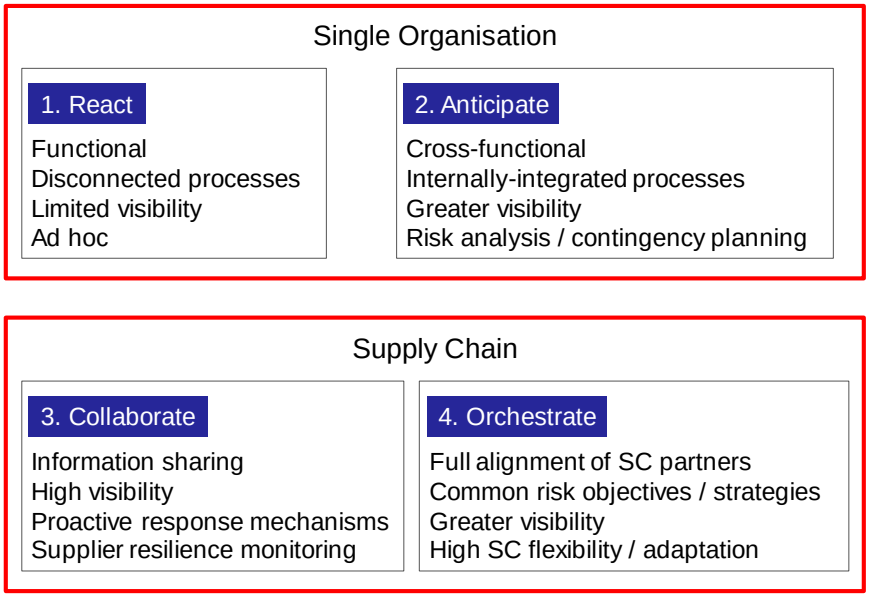
(ix) ***Insure against supply chain risk:*** Several large insurance companies, such as Zurich and Allianz, have seen a business opportunity in insuring companies against some forms of supply chain risk. One 'Contingent Business Interruption' policy, for example, '*covers the loss of income of an insured (company) when a supplier or a customer suffers a physical loss resulting in disruption of the insured's own business'*. It can also be '*triggered if the insured is still forced to slow or halt production – and therefore loses profits – because the supplier with damaged operations cannot deliver critical raw materials or parts, or the customer does not request the parts from the insured*' (Allianz, 2013). Policies of this type also cover companies against external threats to their supply chains posed by natural disasters. It is not known how much use is currently made of these policies and to what extent they may be affecting the SCRM behaviour of businesses. There is a possibility that the security offered by insurance cover may discourage some companies from managing supply chain risk as effectively, creating a 'moral hazard' situation. This is not to deny, however, that insurance can play an important role in a company's SCRM strategy.

Stages in the Development of SCRM by Businesses:

Harrington and Smith (2014) has presented a four-stage maturity model to chart the progress of a company's SCRM activities (Figure 10). Developments at the first two stages are internal to the company and important prerequisites for the involvement of supply chain partners in risk management initiatives. At the entry level, companies are unprepared for contingencies and merely 'react'. At the second, 'anticipatory' stage they

engage in cross-functional business continuity planning and gain greater visibility of the risks. The third stage sees firms collaborating with suppliers and/or distributors to share risk information and undertake joint contingency planning. The final 'orchestration' stage is reached once all the members of the supply chain have aligned their risk management with a common set of objectives. Few supply chains have attained this degree of maturity, though it sets a benchmark for the future development of SCRM.

Figure 10. **4-stage Resilience Maturity Model**



Source: Harrington and Smith, 2014

5.2. Government Initiatives

As Preston et al (2012) explain, 'Beyond certain thresholds governments are the responders of last resort – they are often expected to step in and take charge of emergency responses during major crises.' It is for this reason that they cannot step back and leave businesses to deal with the HILP events that seriously and extensively disrupt supply chains vital to the national economy and well-being of the population. Many of the preparatory measures that governments take are targeted on the root causes of an external threat such as a pandemic, cyber attack or terrorism. They can have a more direct role to play in the mitigation of supply chain risk through the development, maintenance and management of infrastructure. In most countries this external threat to infrastructure comes mainly from extreme weather and sothe remainder of this section will focus on weather risk,

Climate-proofing Infrastructure to Improve Resilience

The IPCC (2007) has acknowledged that 'even the most stringent mitigation efforts cannot avoid further impacts of climate change in the next few decades which makes adaptation unavoidable'. Because of atmospheric and ecological time lags, there is likely to be a significant amount of climate change already 'in the pipeline' no matter how successful our carbon mitigation efforts prove to be. Much of the modelling of climate impacts assumes that the climate will change in a steady, incremental fashion over a long period giving us time to adapt our infrastructure, settlement patterns and economic

systems. It is possible, however, that climatic trends will be 'non-linear', changing abruptly as critical environmental thresholds are crossed.

Several academic studies have examined the exposure of transport infrastructure to the likely effects of climate change (e.g. Koetse and Rietvelt, 2009). These have been supplemented by numerous reports published by national governments, infrastructure providers and development agencies, many of them focusing on the infrastructural challenges posed by climate change in particular countries or regions. Rowan et al (2013) have mapped the inter-relationship between three categories of climate risk (sea-level / storms, precipitation and temperature) and seven categories of transport asset (bridges, roads / highways, railroads, airports, pipelines, electricity transmission and ports) split by mode and 'sub-mode'. A common conclusion of this and other studies is that the climatic tolerance limits within which much transport infrastructure is built will need to be widened to cope with the adverse effects of global warming. For example, what were considered one in a hundred year floods at the time of construction could become one in twenty or ten year floods, strengthening the need for flood protection, and, in extreme cases, the relocation or realignment of transport assets.

The climate-proofing of infrastructure can certainly help to secure supply chains against extreme weather conditions, but it raises a number of issues:

1. *Balance of risk and expenditure between infrastructure providers and users*: vehicles can be altered to increase their ability to cope with adverse weather independently of infrastructural interventions. For example, trucks can be equipped with winter tyres, reducing the need to de-ice the road network. Climate-proofing is therefore a multi-stakeholder activity, though it can be difficult to decide on the division of responsibility and cost.

2. *Nature and phasing of the response to climate change*: infrastructure providers have varying levels of response. In the short-term they can improve network resilience by increasing their emergency response capability. At the next level, they can make minor modifications to the infrastructure to minimise the risk of blockages occurring, such clearing adjoining land of trees. Sometimes such modifications can be made in the course of the normal maintenance cycle. At a higher level, more fundamental re-engineering may be required, such as bridge strengthening, the installation of new drainage systems and alterations to the gradient of embankments. It is difficult to know how the level of response should be ratched up as the incidence and severity of extreme weather events increases. This relates to the following issue.

3. *Disconnect between climate modelling and infrastructure planning*: highway engineers regularly complain that climate scientists are not furnishing them with the data they need to recalibrate their planning tools. This is partly because climate forecasting, particularly at regional and local levels, is within wide numerical bands, but also because of the variables used.

4. *Variations in the cost of climate-proofing different freight transport modes*: In any given country, it will cost more to secure one modal infrastructure against climate change than another. The allocation of funds for climate-proofing should reflect both this differential cost and the relative use of the respective infrastructures. This has implications for inter-modal competition in the freight market and may run counter to carbon mitigation efforts in the logistics sector.
5. *Transferability of expertise and best-practice in climate proofing*: in essence, climate change involves the migration of warmer climatic regions towards the poles:

Mediterranean conditions, for example, will move northwards into more temperate latitudes. By comparing the current impact of extreme weather on transport infrastructure in different climatic zones, it is possible to predict, for a given region, future climatic stresses (Koetse and Rietveld, 2009). One can also observe how infrastructure providers have adapted their networks to these stresses and thereby transfer knowledge and experience.

6. *Competing claims on infrastructure budgets*: it is likely that climate-proofing will account for an increasing share of infrastructure budgets, possibly diverting resources originally earmarked for expanding capacity. If, as a result, capacity is exceeded on key corridors, supply chains may gain climate protection at the expense of an additional congestion risk.

It is important too for governments to understand the inter-relationships between transport, energy and communications infrastructures as failures in one can impact severely on another, disrupting supply chains in several different ways at the same time (Royal Academy of Engineering, 2011Disruption of a major rail route from a coal mine to a power station, for example, can disrupt the power supply.

6. CONCLUSIONS

Many supply chains are relatively fragile and easily fractured when extreme natural, political or economic events occur. A host of inter-related business trends have increased their relative fragility over a period when the range and intensity of threats have multiplied. This explains why supply chain management and resilience have become such hot topics.

Extensive research over the past 15 years by academics, consultants and others has greatly improved understanding of supply chain risk profiles and resilience options. Numerous conceptual and analytical frameworks and planning tools are now available to help companies and governments devise risk and resilience strategiesAt the heart of these models lies a critical trade-off between efficiency and redundancy in the management of global supply chains. The high cost of supply chain disasters since the late 1990s suggests that this trade-off now needs to be recalibrated in favour of risk mitigation and resilience.

There is an important role for government agencies in promoting the adoption of good SCRM practice, particularly where supply chains cross national borders and international co-operation is required. National governments' prime duty, however, is to secure transport, energy and IT infrastructures against extreme events,and undertake the necessary contingency planning. Failure to do so, will increase the probability of supply chain disruption in the country, which will, among other things, reduce its locational attractiveness to increasingly risk-averse business investors.

There is a pressing need for multi-stakeholder SCRM initiatives involving shippers, logistics service providers, insurance companies, infrastructure operators as well as governments, to foster information sharing, collaboration and joint contingency planning.

Global supply networks, after all, are not just complex in a physical sense, they are also the product of a complex interaction between public and private organisations.

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