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## Thailand's 2011 flooding: Its impact on direct exports and global supply chains

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# Asia-Pacific Research and Training Network on Trade

## Thailand's 2011 flooding: Its impact on direct exports and global supply chains

*By Aekapol Chongvilaivan*

**ARTNeT Working Paper Series No. 113/May 2012**

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# Thailand's 2011 flooding: Its impact on direct exports and global supply chains

*Aekapol Chongvilaivan\**

## Abstract

While developing Asia has used fragmentation and industrial agglomeration as leverage to create impetus for sustaining its competitiveness, the downside risks of just-in-time procurement and production have not been sufficiently emphasized. Based on the experience of Thailand's flooding in 2011, this study examines the extent to which the supply chain disruptions are translated into plunges in production and export performance, and explores how companies can effectively manage the risks and cope with supply chain breakdowns. The analysis reveals implications that corporate culture and management mindsets need to take into consideration the potential sources and impacts of risks and to assess them systematically. Redundancy in principle offers a shock absorber, but investment in untapped inventory and suppliers can be prohibitively costly. Last, enhancing the flexibility of supply chains through information exchange and coordination in vertical relationships is crucial to ensuring resilience against high-impact, low-probability shocks.

**Key words:** Production networks; just-in-time procurement; supply chain disruptions; Thailand; flooding.

**JEL Codes:** F14, F23

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## **Introduction**

Fragmentation and agglomeration forces, together with the concept of just-in-time production, have made it possible for many countries to establish manufacturing production through vertical specialization and economies of scale even though they do not have a comparative advantage at all levels of manufacturing production. This is true for Thailand today, much as it was previously in Taiwan Province of China and, some decades before that, the Republic of Korea. As Thailand becomes a part of this production sharing and global production networks, it also becomes increasingly evident that supply chain disruptions could be a serious threat. Natural disasters and some types of man-made catastrophes can endanger the just-in-time approach to procurement and production because any disruptions to a single node of production may lead to a breakdown of the entire production chain.

In the last quarter of 2011, Thailand experienced its worst flooding in 70 years during which several key industrial estates were severely affected. However, that was not the first disruption of the global supply chain in the East Asian region. Since the end of the last century, the global supply chain has been brought to a halt on several occasions by natural disasters in East Asia, such as the major earthquake in Taiwan in March 2000, the outbreak of the SARS epidemic in southern China during 2002-2003, the Great Hanshin-Awaji earthquake of 1995, the Chuetsu offshore earthquake of 2007 in Japan and, more recently, the massive earthquakes in March 2011 (Fujita and Hamaguchi, 2011).

The 2011 flooding in Thailand created serious problems for the country's industrial manufacturers. The disaster highlighted the vulnerabilities of production and direct exporting when prevailing just-in-time procurement and management have not fully envisaged the potential damage resulting from supply chain disruptions as well as the pivotal role played by building up resilience in supply chains. The total production and supply chains that have been caused by such disasters has clearly shown that strategic assessment and management of disruptions constitute the root elements of supply chain management; if this lesson is ignored, Thailand will lose its competitive advantage as a hub of global production networks.

In view of this potential threat, this paper is based on existing studies of supply chain management and operations and the experience of Thailand's worst floods in the last quarter of 2011. The paper examines the impacts of supply chain disruptions on direct exports and vertical intra-industry specialization, identifies the sources of vulnerabilities associated with the proliferating production networks, and explores the options and strategies for businesses and the Government of Thailand to nurture the burgeoning production networks in order to ensure their resiliency in future disruptions. The following analysis indicates that among the hardest hit sectors during Thailand's flooding were key industries – e.g. the automotive, and electronics and electrical appliances manufacturing sectors – which experienced sharp declines in production as well as direct exports during the last quarter of 2011. Although the adverse impacts on production and exports appear to have been rather short-lived, as normal operations among most firms have quickly resumed and global demand remains robust, the floods have painted a bleak picture of long-term performance in terms of declines in stock prices, deteriorating competitiveness and trimmed market

shares, among others. The drastic consequences of the supply chain disruptions felt by companies in Thailand offers a key lesson that strengthening the resilience of supply chains not only offers immunity against disruptions, but also serves as a strategic tool that differentiates a company from, and positions it ahead of its competitors.

This paper presents several options and strategies for companies to strengthen resilience of just-in-time production chains to the risk of high-impact, low-probability events. Fundamentally, assessment and identification of risk sources need to be carried out systematically. The key problem is that while corporate culture and mindsets have a major influence on efforts to improve production efficiency, they downplay the downside risks of lean operations. Redundancy, in terms of extra inventory stockpiles and multiple-sourcing schemes, essentially serves as a shock absorber in case delivery of parts from any production node goes wrong. However, this paper highlights the fact that redundancy incurs exponential costs in terms of arising inefficiencies and management outlays, and is thus constrained by the cost-benefit trade-offs. Finally, as industries continue to flourish by using just-in-time procurement and since a shift towards just-in-case procurement can only be made with limitations, information exchange and coordination between companies and their suppliers need to be enhanced by strengthening the flexibility of the three supply chain building blocks – procurement, conversion and distribution.

Section 1 explores two strands of literature that are relevant to this study, namely East Asia's proliferation of production networks and management of supply chain disruptions. Section 2 provides a primer of production networks in Thailand, while Section 3 examines the impacts of Thailand's floods on production and direct exports. Section 4 proposes options and strategies for enhancing just-in-time production such that the risks of the disruptions can be effectively managed, and the damages of the disruptions, if present, can be mitigated. In conclusion, section 5 discusses the implications on building resilient production networks.

## **1. Literature review**

The proliferation of production networks is central to the debate on globalization and the rapidly changing international trade patterns in East Asia, whereby firms across regions and countries are linked through vertical intra-industry specialization. Most typically, capital-intensive intermediate parts and components are produced in advanced economies such as Japan and the Republic of Korea, while labour-intensive assembly and provision are carried out in developing countries such as China, Malaysia, Thailand and Viet Nam (Chongvilaivan and Thangavelu, 2012). Several recent studies have highlighted the growing significance of production networks as a driving factor of closer trade ties among the East Asian countries. Athukorala and Yamashita (2006), for example, estimated that the share of East Asia in total world exports of parts and components increased from 29.3% in 1992 to 39.2% in 2003. Ando and Kimura (2005) and Ando (2006) further found that intra-industry trade in East Asia had been dominated by trade in machinery parts and components, suggesting the prevalence of production fragmentation and vertical specialization in the region.

Given the increasingly important roles of production networks, the existing literature has been largely devoted to deliberations on cost-saving, efficiency-



enhancing incentives through location advantages and economies of scale, which, in turn, essentially catalyse the rapidly growing production networks in East Asia. Jones and Kierzkowski (1990) introduced a conceptual framework of production fragmentation, where the physical dispersion of production nodes necessitated costly service links such as transportation, telecommunications and other coordination tasks. Jones and Kierzkowski argued that technological advancement and lowering trade barriers led to a significant decline in service link costs and allowed the production process to be fragmented across different locations to leverage on economies of scale. Deardorff (2001) incorporated production fragmentation into the standard models of international trade, and showed that fragmentation could be a driving force of factor price equalization. Several subsequent studies have substantiated these theoretical expositions by examining the interacting combination of intra-firm/arm's-length fragmentation and agglomeration of multi-firms in East Asia. Fujita et al. (1999) and Fujita and Thisse (2002) underlined the trade-off between economies of scale at the firm level and transportation costs as a driver of industrial agglomeration. Kimura and Ando (2005) posited that location advantages – such as low wage levels, factor/resource availability and well-developed infrastructure – reduced costs of service links, both in terms of distance and of uncontrollability, and enabled industrial clustering to keep efficient procurement and networks of parts and components in a just-in-time manner.

Apart from the spatial economics and agglomeration theory, global production networks can also be explained from the perspectives of supply chains and operations management in which manufacturers are induced to rely on a reduced supplier base, as opposed to the conventional approach to an abundant collection of suppliers. The key idea is that buyer-supplier relationships allow firms to demonstrate similar potential and performances without the necessity of ownership and strenuous barriers to exit. By reducing their supplier bases, firms gain a wide array of benefits including trimmed switching costs, limited shipping errors, higher quality, and quantity- and relationship-based discounts, through sharing information, technology and planning efforts (see, for example, Wilson et al, 1990; Treleven, 1987; and Bartholomew, 1984). Scott and Westbrook (1991) underlined several other gains provided by a small supplier base, such as improved communications, more efficient conflict resolution, less probability of opportunism and declined risks from externalities. Brown and Inman (1993) noted that downsizing supplier bases and single sourcing were the primary business strategies pursued by Asian manufacturers as well as the primary catalysts of the Pacific Rim supply chain processes.

While the past studies have pivoted around the business and production models of fragmentation and agglomeration, one aspect of the production networks that is capturing increasing attention among business buffs and academics, but which remains largely unexplored in the economics literature, are the downside risks of the just-in-time supply chain. The concentration of suppliers and/or providers advocated by the just-in-time procurement policy essentially spawns the risk that disruptions of any single node, in the case of high-impact, low-probability events will result in a breakdown of the entire supply chain (MacBeth and Ferguson, 1994). Among the very few studies of the impacts of supply chain disruptions on production and trade, that carried out by Fujita and Hamaguchi (2011) examined the impacts of the 9.0-magnitude earthquake and the tsunami in Japan in March 2011 on the production networks of automotive manufacturing in East Asia. They estimated that the disaster

had cut car assembly as well as export capacity by 39% in the case of Guangdong-China in April and 48.5% for Thailand in May, mainly because the lean inventory of automotive parts allowed normal operations to last for only three days.

In addition, Ando and Kimura (2012) employed the decomposition of export changes to study stability and robustness of Japan's production networks in machinery following two massive shocks, the 2008/09 global financial crisis and the earthquakes in 2011. Although the industries were substantially affected by the two events, they showed that Japan's production networks exhibited exceptional resilience as machinery exports appeared to rebound quickly in both cases. Interestingly, firms tended to introduce structural reforms during the global economic slump, since the impacts were likely to be massive and prolonged, while the structural adjustments appeared to be insignificant following the earthquakes as the effects were relatively transitory.

Much research on operations management has demonstrated that supply chain disruptions critically exacerbate performance of firms, both in the short- and the long-term. For example, Kalwani and Narayandas (1995) argued that the risks of disruptions exacerbated competitiveness of firms due to losses of partnership control, complacency, and specialization with long-term suppliers. Hendricks and Singhal (2003) showed that supply chain disruptions significantly cut back firms' growth rate of revenue and resulted in higher equity risk. In their subsequent study, Hendricks and Singhal (2005) employed a sample of 827 disruption announcements and provided further evidence that firms experiencing those disruptions had tended to exhibit negative abnormal stock price performance and higher equity risks; the adverse effects had typically caused greater deterioration than expected, depending on the firms' ability to effectively cope with suppliers and customers in the aftermath of the disruptions. In view of past experience, plus the fact that studies have unanimously highlighted the growing concern that ripple effects of the disruptions are significant and persistently set back performance, managing the risks of, and bolstering resilience against supply chain disruptions are crucial to ensuring competitive advantage and survival of a firm.

## **2. Roles of Thailand in global supply chains**

### *(a) Proliferation of production networks*

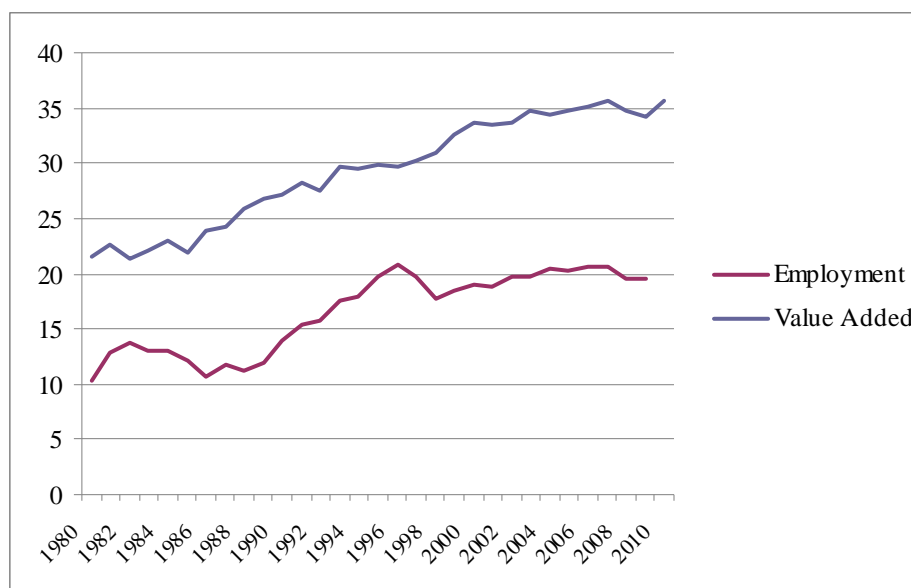
The proliferation of production networks in East Asia has often been cited as the source of Thailand's sustained growth of output and employment in the past two decades (see, for example, Punyasavatsut, 2007; and Poapongsakorn and Techakanont, 2008). Globalization, including the advancement of information and communication technology (ICT), has made production fragmentation and sharing possible, thereby shaping a new global competitive environment and trade pattern. Although Thailand's international competitiveness has been hard pressed since the 1990s by, among other factors, the flourishing low-cost production bases such as China, India and, to a lesser extent, Viet Nam, the manufacturing sector continues to expand strongly.

As shown in figure 1, the manufacturing sector – where firms and operators, by and large, utilize supply chain production and just-in-time procurement (Kimura

and Obayashi, 2011) – has, since the 1980s, contributed increasingly to the Thai economy in terms of both output and employment. In particular, the share of manufacturing value-added in GDP increased from 20% in the 1980s to approximately 35% in 2010. Likewise, its share of total employment doubled from 10% in the 1980s to 20% in 2009, notwithstanding some declines observed during the global economic slowdown in the early 1980s and the 1997 Asian financial crisis.

**Figure 1. Contributions by manufacturing industries to total employment and value-added**

(Unit: Per cent)



Source: World Development Indicators, World Bank.

That striking performance can be explained by the fact that businesses, both local and foreign, as well as multinational corporations (MNCs), have progressively resorted to global production networks by contracting out what they once did for themselves as well as engaging in trade in parts and components, in order to achieve more efficient operations and production. Amiti and Wei (2009) asserted that there were at least four channels through which production fragmentation boosted efficiency of firm operations. First, the use of supply chain production allows a firm to trim the less efficient stages of production and specialize in the more efficient ones, thereby enhancing the average efficiency of the production activities undertaken in-house. Second, sourcing parts and components, especially relatively technology-intensive activities such as computing and ICT, helps a firm restructure its operations and push forward the technology frontier. Third, production fragmentation leads to the learning effects whereby a firm acquires specific knowledge and skills from the contractual partners, such as new product design, managerial techniques, quality control and standardization. Last, production networks essentially augment varieties of parts and components, and the wider range of available materials and services is ultimately translated into superior productivity and performance.

Table 1 lists the number and share of manufacturing firms involved in global production networks, in conjunction with their ownership structure and export activities, based on the 2003 Manufacturing Industry Survey provided by National Statistical Office (NSO) of Thailand. On average, approximately 19% of manufacturing firms in Thailand take part in global production networks through the use of imported parts and components. Interestingly, the proportion of firms involved in global production networks appears to be particularly pronounced in high-tech manufacturing sectors such as communications equipment and apparatus, electrical machinery and apparatus, and office, accounting and computing equipment.

**Table 1. Number and percentage of establishments under foreign ownership engaged in export activities and global production networks**

Industry	Foreign ownership	Exports	Production networks
Food and beverages	118 (5.24)	309 (13.73)	211(9.37)
Tobacco	2 (4.26)	3 (6.38)	n.a.
Textiles	62 (7.95)	121 (15.51)	101
Wearing apparel; dressing and dyeing of fur	19 (5.64)	64 (18.99)	46 (13.65)
Leather footwear products	29 (10.43)	64 (23.02)	72 (25.90)
Wood and cork, except furniture	12 (3.60)	67 (20.12)	63 (18.92)
Paper and paper products	27 (14.44)	46 (24.60)	50 (26.74)
Publishing, printing and reproduction of recorded media	10 (4.31)	8 (3.45)	27 (11.64)
Refined petroleum products	8 (22.22)	9 (25.00)	16 (44.44)
Chemicals and chemical products	70 (18.72)	80 (21.39)	127
Rubber and plastics products	82 (18.64)	147 (33.41)	122
Other non-metallic mineral products	45 (6.22)	99 (13.69)	84 (11.62)
Basic metals	19 (13.29)	28 (19.58)	34 (23.78)
Fabricated metal products	78 (9.99)	100 (12.80)	163
Machinery and equipment	55 (17.57)	72 (23.00)	105
Office, accounting and computing equipment	6 (42.86)	5 (35.71)	6 (42.86)
Electrical machinery and apparatus	41 (29.08)	47 (33.33)	61 (43.26)
Communications equipment and apparatus	59 (41.84)	63 (44.68)	75 (53.19)
Medical, precision and optical instruments	21 (21.88)	24 (25.00)	37 (38.54)
Motor vehicles, trailers and semi-trailers	48 (27.27)	48 (27.27)	65 (36.93)
Other transport equipment	26 (15.03)	25 (14.45)	40 (23.12)
Furniture manufacturing	97 (11.64)	219 (26.29)	172
Recycling	n.a.	n.a.	n.a.
<b>Total manufacturing</b>	<b>934 (10.54)</b>	<b>1 648 (18.60)</b>	<b>1 677 (18.92)</b>

Source: Chongvilaivan, 2011.

Note: Numbers in parentheses are percentages.

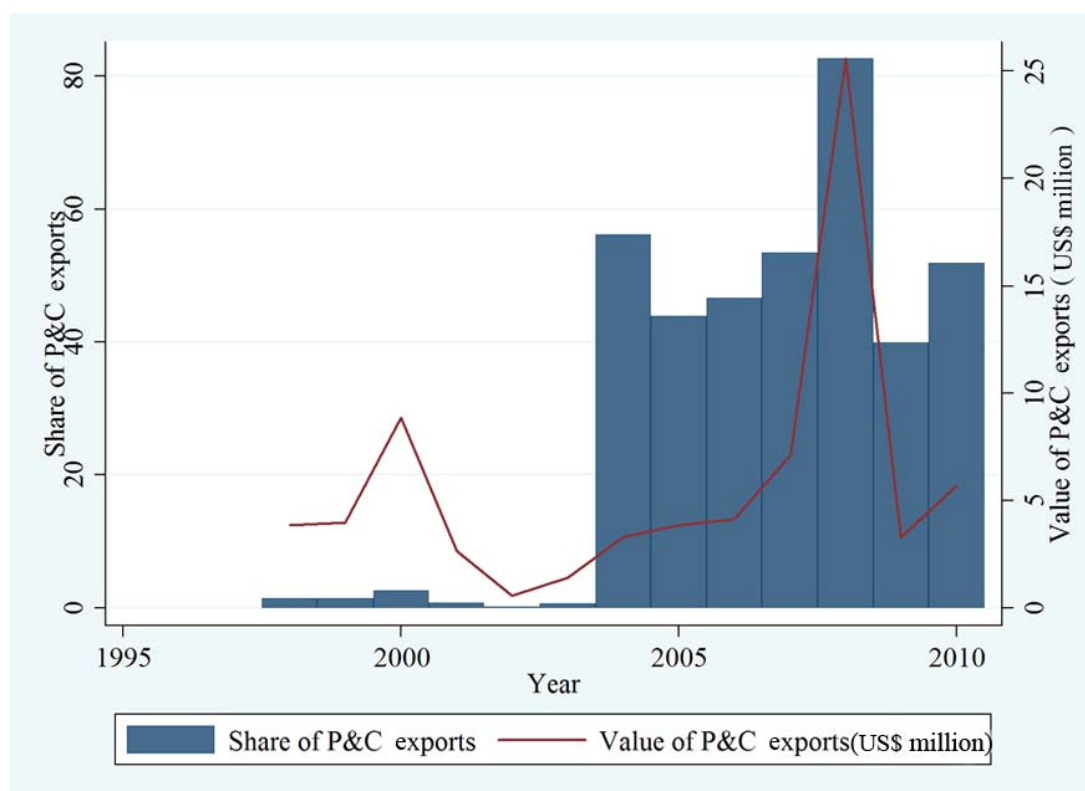
Moreover, it can be seen from table 1 that the sectors with a high proportion of firms involved with global production networks tend to exhibit a relatively high intensity of export activities and MNCs. For example, more than 40% of firms

operating in the communications equipment and apparatus sector are MNCs with involvement in exporting activities. The same pattern appears to characterize various other industries such as electrical machinery and apparatus; and office, accounting and computing equipment. The observation that firms with global production networks tend to be associated with foreign investment and exporting activities, suggests that production networks go hand-in-hand with the process of globalization.

(b) *Trends and drivers of trade in parts and components*

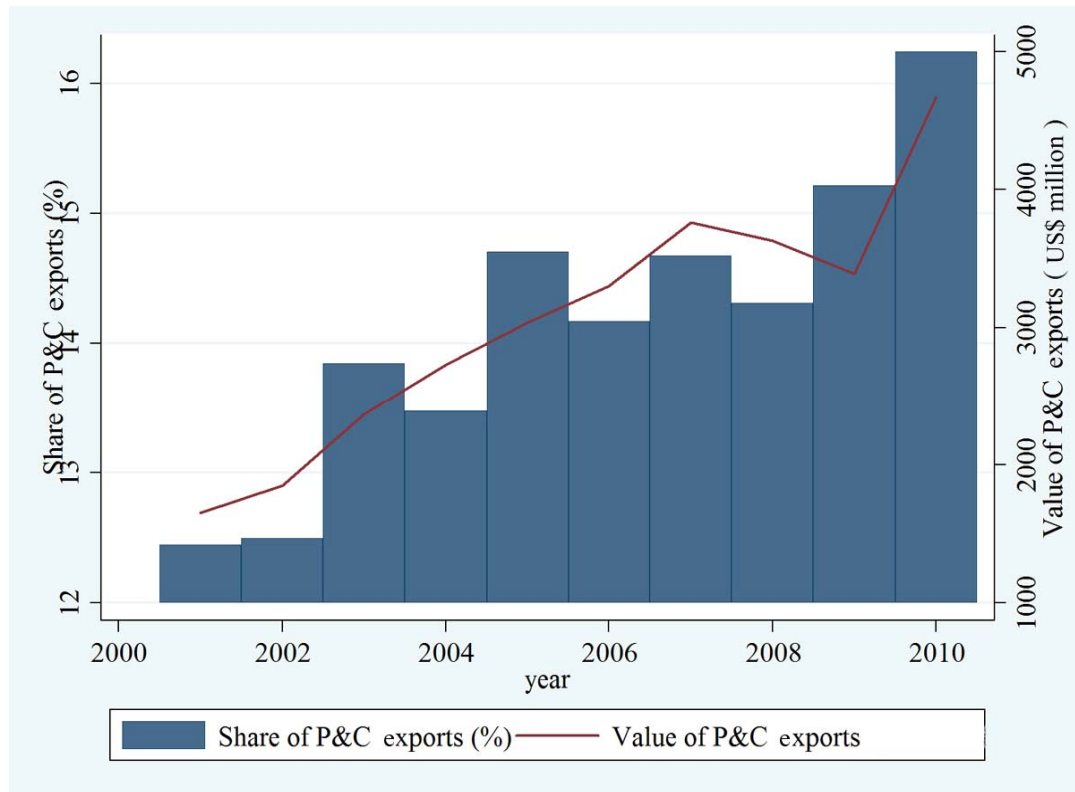
As production sharing and vertical specialization prevail, an industry becomes more reliant on trade in parts and components because in-house production relies on the use of intermediate inputs provided by foreign suppliers while outputs are exported for downstream production. It is therefore expected that the proliferation of production networks will be characterized by an increase in the share of parts and components in commodity trade (Kuroiwa, 2008). This section focuses on the trends and drivers of trade in parts and components in the major manufacturing sectors that were affected by Thailand's floods in 2011, i.e., semiconductors, electrical products and automotive manufactures (figures 2 and 3).

**Figure 2. Share of parts and components exports in total semiconductors exports**



Source: Author's calculation based on the United Nations' Commodity Trade Database.

**Figure 3. Share of parts and components exports in total electronics exports**

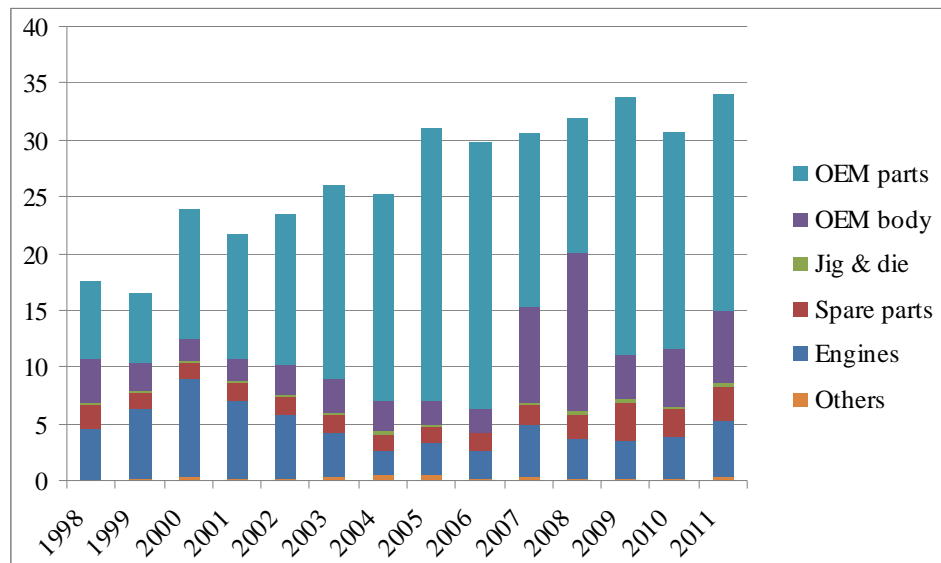


*Source:* Author's calculation based on the United Nations' Commodity Trade Database.

The semiconductor sector experienced the most drastic shift in the trade pattern. Figure 2 portrays the share of parts and components exports in total exports of semiconductors, based on the United Nations' Commodity Trade Database. Prior to 2004, the share of parts and components exports in total exports of semiconductors was somewhat negligible. However, a shift in the trade pattern away from trade in final products towards trade in parts and components is seen in 2004 onwards when the share of parts and components exports exhibited a sharp spike, reaching a peak of more than 80% in 2008. Notwithstanding the decline in global demand for semiconductors in the aftermath of the global financial crisis in 2008, trade in parts and components, to date, accounts for more than 50% of total semiconductor exports. In the electronics sector, the share of parts and components exports in total electronics exports likewise increased from nearly 12.5% in 2001 to more than 16% in 2010, even though a slight slowdown occurred during the global financial crisis in 2008.

The escalating trend of trade in parts and components is also seen in the automotive industry. As figure 4 shows, the share of parts and components in total exports of automotive products approximately doubled from 17% in 1998 to almost 35% in 2011. A breakdown of parts and components exports into various categories shows a clearer picture. The proportion of original equipment manufacturer (OEM) parts increased considerably from one-third of parts and components exports in 1998 to more than two-thirds in 2011, signifying that producers of automotive parts and components in Thailand had become part of the global supply chain of car production.

**Figure 4. Share of parts and components exports in total automotive exports  
(Unit: Per cent)**



Source: Author's calculation based on the dataset provided by Thailand Automotive Institute.

Several structural and policy drivers fuelled the expansion of production networks and, thus, trade in parts and components in Thailand. First, the deteriorating competitiveness in relatively advanced economies – particularly in Japan after the Plaza Accord in 1986 and, more recently, the Republic of Korea, Taiwan Province of China, and Singapore due to rising labour costs and excessive concentration of manufacturing – triggered dispersion forces whereby firms gradually shifted their low-end functions to the low-cost production bases in Thailand as well as other developing economies such as China, Indonesia, Malaysia and Viet Nam. In addition, several policy changes by the Government of Thai resulted in internationalization of parts and components production, on top of industrial clustering and agglomeration, thereby inducing foreign affiliates to set up production plants in Thailand. These included the establishment of industrial parks, tax exemption schemes, infrastructure investment, development of supporting industries and foreign capital liberalization, among others.

(c) *Industrial agglomeration and spatial linkages*

A core attribute of the growing production networks in Thailand – which create a fundamental risk that supply chain disruptions will set back domestic and global production – is the emergence of industrial clustering and agglomeration, whereby firms and suppliers tend to concentrate in only a few locations, especially industrial estates. The objective of this concentration is to tap benefits from lower transportation costs, well-developed infrastructure and more efficient coordination. The concentration of production plants puts the production networks at risk of a breakdown as a result of disruptions in operations.

Table 2 lists the number of production plants in Thailand's major industrial estates and provinces. It shows that production plants are heavily concentrated in a few provinces, i.e., Bangkok, the central provinces such as Ayutthaya, Samut Prakarn and Samut Sakhon, and the eastern provinces including Chachoengsao, Chonburi and Rayong. Samut Prakarn and Chonburi host the largest number of production plants, mostly in the automotive and electronics sectors, and many operate in major industrial estates such as Bangpoo, Bangplee, Amatanakorn and Laem Chabang. Poapongsakorn and Techakanont (2008) documented the fact that approximately 97% of all automotive factories were located in only three locations – Bangkok, the eastern and

**Table 2. Number of production plants by industrial estate**

<b>Area</b>	<b>Industrial estates</b>	<b>Non-industrial</b>
<b>Bangkok</b>	<b>248</b>	<b>10 168</b>
Bangchan	89	
Lat Krabang	102	
Gemopolis	57	
<b>Ayutthaya</b>	<b>282</b>	<b>1 302</b>
Ban-wa	135	
Bangpa-in	98	
Saharattanakorn	49	
<b>Samut Prakarn</b>	<b>568</b>	<b>6 013</b>
Bangpoo	409	
Bangplee	159	
<b>Samut Sakhon</b>	<b>188</b>	<b>3 915</b>
Samut Sakhon	113	
Sinsakorn	73	
Maharatnakorn	2	
<b>Chachoengsao</b>	<b>230</b>	<b>1 234</b>
Wellgrow	165	
Gateway city	59	
TFD	6	
<b>Chonburi</b>	<b>1,099</b>	<b>2 562</b>
Laem Chabang	93	
Hemaraj Chonburi	52	
Amata Nakorn	811	
Pin Thong	143	
<b>Rayong</b>	<b>733</b>	<b>1 614</b>
Map Ta Put	75	
Eastern Seaboard	314	
Amata City	213	
Eastern Hemaraj	53	
Padaeng	4	
Hemaraj Eastern Seaboard	59	
Asia	15	
<b>Whole country</b>	<b>3 747</b>	<b>135 269</b>

Source: Industrial Estate Authority, Department of Industrial Works, Thailand (as of 30 November 2011).



the central provinces, with more than 90% in just seven provinces – Bangkok, Samut Prakarn, the three eastern provinces (Chachoengsao, Chonburi and Rayong) and the two central provinces (Pathum Thani and Ayutthaya). Similarly, Hiratsuka (2011) pointed out that a wealth of electronics manufacturers from the United States and Japan had established their plants and production facilities mainly in Bangkok, the eastern and the central provinces, thereby making Thailand the world's largest final assembler of hard disks. For example, Seagate established its head-stack assembly in Samut Prakarn, Fujitsu started its hard disk business and final assembly of personal computers in Bangkok, IBM and Hitachi built their own production facilities in Chonburi and Western Digital Technologies founded its production of hard disks in Navanakorn Industrial Estate in Pathum Thani.

The concentration of plants in the central region locations – a river valley area that is geographically susceptible to flooding – can be partly explained by two factors. On the one hand, proximity to the capital city, Bangkok, implies that firms can tap into well-established infrastructure as well as easy access to consumers and suppliers. Thailand's Board of Investment, on the other hand, has long encouraged local businesses and MNCs to set up plants in the industrial estates by offering various incentives. For example, foreign capital participation for export purposes was allowed in 1983. Areas for investment promotion were listed in 1983. In 1987, several regulations concerning foreign capital participation were further trimmed so that 100% foreign capital was viable in the production of a wide range of products. Foreign firms have also been entitled to full tax exemption for a certain period, depending on the industry and location in which they are operating.

In addition, the production of parts and components in Thailand is tied to the global production of final outputs, as the forces of vertical specialization have spread production nodes in various countries where comparative advantage exists in certain stages of production. This spatial linkage implies that a breakdown in any stage of production could result in disruption of the entire production chain. The roles of Thailand in the global production networks are typically pertinent to assembly of final products using capital-intensive intermediate inputs from developed economies, especially Japan and the United States. As figure 5 shows, Thailand's production chains, which are the most typical, are mainly related to downstream activities such as assembly and labour-intensive inputs by foreign-owned firms and MNCs through FDI from developed countries. The upstream, capital-intensive activities are related to imports of parts and components from developed economies, with the final outputs then being exported to markets around the world. This pattern of fragmentation is observed throughout various major industries in Thailand, especially the automotive and electronics industries.

**Figure 5. Typical pattern of Thailand's production networks**



*Source:* Adapted from Fujita and Hamaguchi, 2011.

*Note:* Arrows represent directions of exports.

### **3. Impacts of Thailand's 2011 floods on production networks and direct exports**

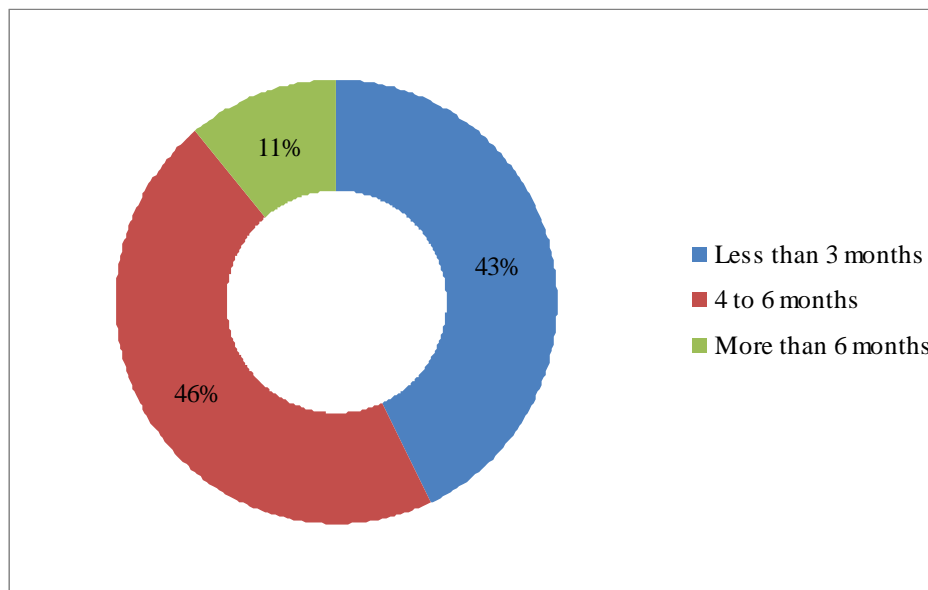
In the last quarter of 2011, Thailand experienced its worst flooding crisis in 70 years. Very heavy, widespread rainfall caused by monsoon storms inundated the central part of Thailand, including Bangkok, and parts of neighbouring provinces, where production factories and businesses are intensively clustered. The immediate impact of the floods on the Thai economy was a contraction of output in the last quarter of 2011, forcing the GDP growth forecast to be revised downward from 2.6% to 1%, even though the flooded areas were limited to some provinces in the central and north-eastern locations (Bank of Thailand, 2012). As figure 6 shows, the floods hit several key central provinces, especially Ayutthaya, Pathum Thani, Nonthaburi, Samut Sakhon and, not least, parts of Bangkok. Although the overall impact on the economy appeared to be transitory, as the affected industries were expected to return to normal capacity in the first quarter of 2012, manufacturing sectors were the hardest hit by the disaster in terms of serious declines in production and sluggish recovery. Based on a business survey conducted by Bank of Thailand (2012), some 43% of businesses reported that the impacts of the inundation on their businesses were likely to be short-lived (figure 7) and usual operations could be restored within three months, while 46% are able to restore operations within four to six months. About 11% of respondents said that the adverse effects of the floods on their businesses would last more than six months.

**Figure 6. Areas affected by Thailand's 2011 flooding**

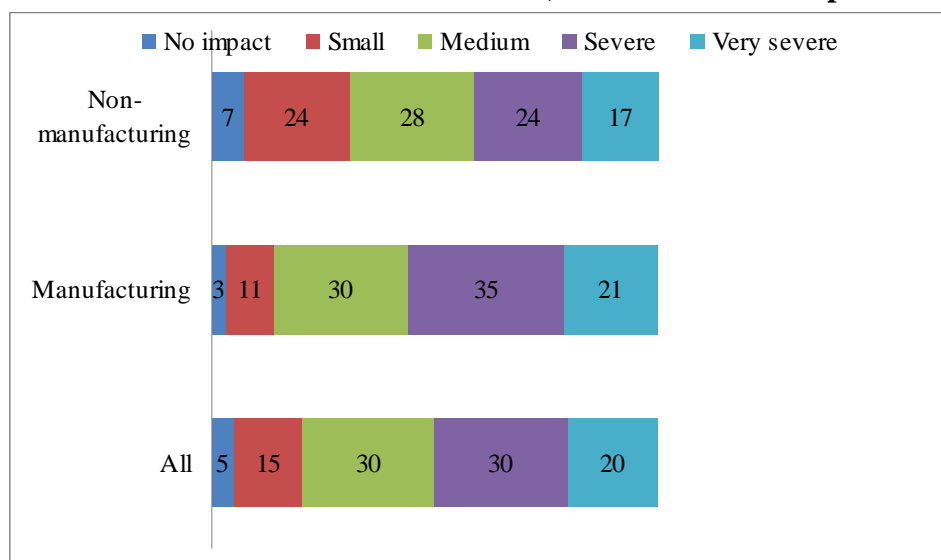


*Source: Financial Times, 3 November 2011.*

Figure 8 provides some preliminary evidence that the impacts of floods were more pronounced in the manufacturing sector than in the non-manufacturing sector, based on the survey by Bank of Thailand (2012). Now that just-in-time procurement, as discussed in the previous section, has become part and parcel of manufactures in Thailand, this indicates that supply chain disruptions result in the breakdown of parts and components delivery that lead to considerable cuts in the whole supply chain of manufacturing production. As figure 8 shows, approximately 56% and 41% of firms in the manufacturing and non-manufacturing sectors, respectively, reported that the impact of the flooding on their businesses was “severe” or “very severe”. In contrast, 14% of manufacturing firms reported that the flooding had “no impact” or “a small impact” on their businesses, whereas the proportion of non-manufacturing firms reporting limited impacts was 31%.

**Figure 7. Time of production recovery to normal level****(Unit: Per cent of respondents)**

Source: Business Survey (October-November 2011), Bank of Thailand, 2012.

**Figure 8. Impacts of flooding on business****(Unit: Per cent of respondents)**

Source: Business Survey (October-November 2011), Bank of Thailand, 2012.

The tremendous impact of the floods on Thailand's manufactures can be partly explained by supply chain disruptions. Table 3 reports the damage to the industrial estates in Ayutthaya, where the concentration of production blocks in the global supply chains is high. More than half of the plants located in the industrial estates in Ayutthaya were affected by the flooding, and the damage to production machinery and other equipment accounted for the largest proportion of total losses. Among the

most affected estates in this province was the Bangpa-in industrial estate, where nearly 80% of the plants were under water compared with approximately 50% of the plants in the province's other two industrial estates, Banwa and Saharattananakorn.

**Table 3. Damage to industrial estates in Ayutthaya (as of 10 February 2012)**

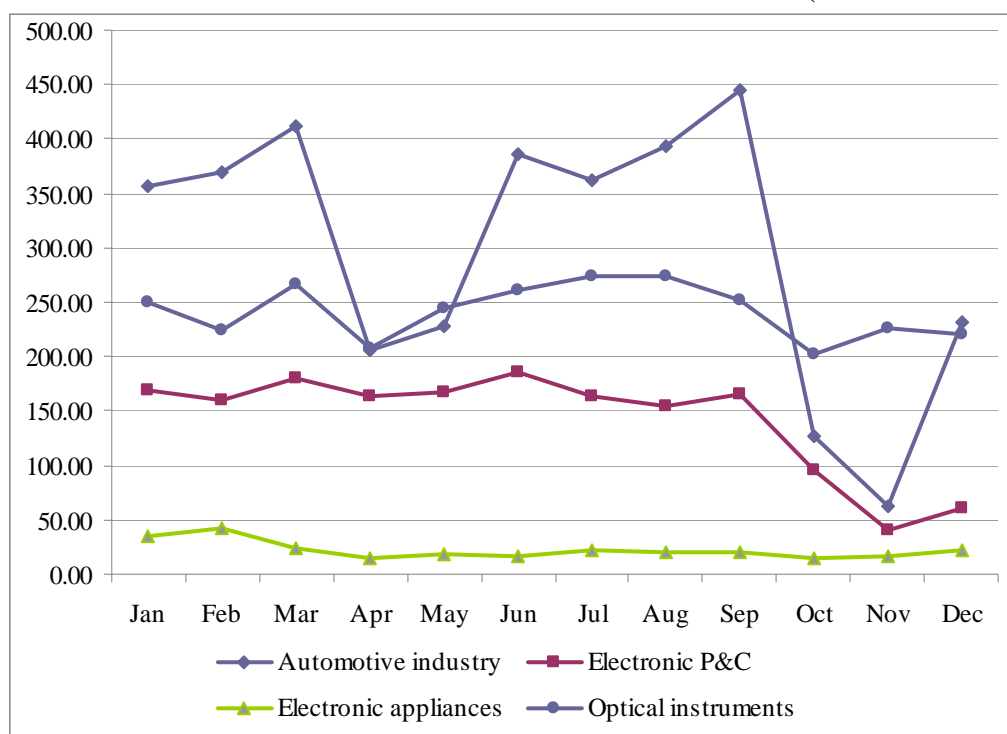
Industrial estates	No. of plants	Investment (billion baht)	No. of affected plants	Damage (million baht)			
				Building	Machine	Others	Total
Banwa	143	57.03	67	1 648.2	4 036.6	1 587.9	7 272.7
Bangpa-in	90	67.20	71	534.5	3 089.1	1 660.7	5 284.3
Saharattananakorn	46	10.26	25	26.0	836.6	3 838.2	4 700.8
<b>Total</b>	<b>279</b>	<b>134.49</b>	<b>163</b>	<b>2 208.7</b>	<b>7 962.3</b>	<b>7 086.8</b>	<b>17 257.8</b>

*Source:* Industrial Estate Authority of Thailand, Department of Industrial Works, Ministry of Industry, Thailand.

Although the factories clustered in the affected industrial estates (e.g., Bangkok, Ayutthaya and Samut Sakhon) amount to just 29.3% of all production plants in industrial estates and less than 0.5% of all production plants in Thailand (see table 2), the slump in the production of key manufactures related to production networks in the flooded areas appear to be remarkable. The reason is that the industrial estates in these areas have been a major source of intermediate input procurement through which parts and components are delivered just-in-time to final assembly plants. Therefore, the disruptions of parts and components deliveries in these areas inevitably compelled other stages of production in the non-flooded areas, in both Thailand and other countries, to cease their operations. For example, due to the shutdown of its plant in Ayutthaya, Honda experienced immediate shortages of auto parts which “forced Honda to cut production around the world, from the Philippines to Swindon in the United Kingdom”.<sup>1</sup> Failures of intermediate material deliveries from the flood-affected areas, by and large, prevailed in various manufacturing sectors including cars, computers, electronics, electrical appliances and optical instruments.

Figure 9 portrays the monthly production indices of key manufactures with the production bases in the flood-affected areas, including automotive and electronic parts and components, electrical appliances and optical instrument industries. The figure provides a clearer picture of the flooding on production networks in Thailand, as it shows production by each industry responded differently. The automotive industry appears to have experienced the most noticeable contraction (approximately 87.5%) in the production index, falling from nearly 444.5 in September 2011 to a low of 62.5 in November 2011. However, car production rebounded quickly and strongly in December 2011 when the index started to move up again, an upward trend that was expected to continue in the first quarter of 2012.

<sup>1</sup> See “Supply chain disruption: Sunken ambitions”, *Financial Times*, 3 November 2011.

**Figure 9. Monthly Production Index in 2011 for selected industries****(Unit: Per cent)**

Source: Office of Industrial Economics, Ministry of Industry, Thailand.

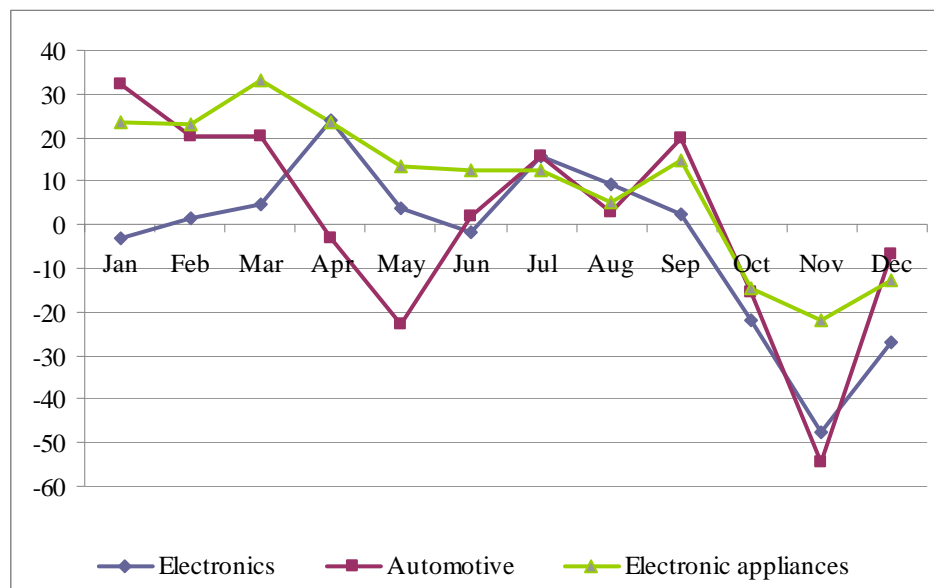
Similarly to the automotive industry, the production of electronic parts and components exhibited a sharp drop in the production index of more than 65%, from 165.1 in September 2011 to 40.2 in November 2011; the recovery appears to have been relatively patchy as production nodes for key electronic parts and components – such as hard disk drives and semiconductors – by major companies such as Seagate Technology, Toshiba, Western Digital and Hutchinson Technology, among many others, are highly clustered in the affected areas. Such supplies cannot be easily replaced, at least in the short term, by production from other parts of the world. The production of electronic appliances and optical instruments was less affected, with an approximate decline of 12.5% in production. The production index of electronic appliances, despite a slight decline in August-October 2011, remained quite robust at between 200 and 250. Likewise, the decline in production of optical instruments was negligible. The resilience against the production shocks in these sectors is attributable largely to sufficient inventory stockpiles of parts and components, which allowed other non-affected plants to carry on their operations despite the suspended production and shipment of parts and components.

Likewise, Thailand's floods pushed its key industrial exports, which depend on global production networks involving industrialized economies, into a sharp contraction. Exports by the electronics, automotive and electrical appliances industries started to exhibit a downward trend in April-May 2011 after Japan's earthquakes, followed by another dip in July 2011 when heavy rainfall inundated several provinces in Thailand. As figure 10 shows, the most affected sector in terms of exports was the automotive industry in which the year-on-year export contraction reached more than

50% in November 2011. Drastic falls of 47.4% and 21.9% also occurred in the electronics and electrical appliances industries, respectively. The considerable impact of Thailand's flooding, which resulted in severely disrupted production and contraction of direct exports, can be explained by the linkages with global production networks.

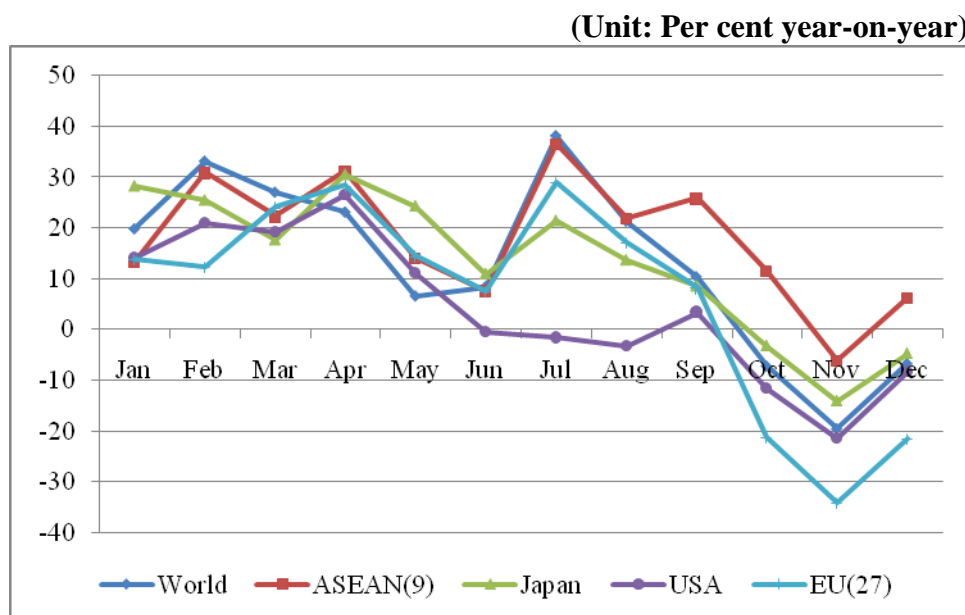
**Figure 10. Monthly growth rates in 2011 of Thailand's key industrial exports**

(Unit: Per cent, year-on-year)



Source: Office of Industrial Economics, Ministry of Industry, Thailand.

Manufacturers in Thailand, both local and MNCs, serve as low-cost assembly lines, and the finished products are exported, especially to markets in the European Union, Japan and the United States (see figure 5). Therefore, the disruptions in Thailand's manufactures would adversely affect the delivery of those products to international markets. Figure 11 substantiates this point by underlining the fact that the contraction of industrial exports to advanced economies, particularly the European Union, Japan and the United States, are more pronounced than in exports to other ASEAN countries that are emerging as low-cost production bases similar to Thailand. The sharpest contraction in Thailand's industrial export markets was in the European Union where the industrial export growth dropped by 34.2% in November 2011, followed by declines of 21.4% for the United States and 14.1% in Japan. However, industrial exports to other ASEAN countries remained relatively robust with only a slight dip of 6.1% in November 2011.

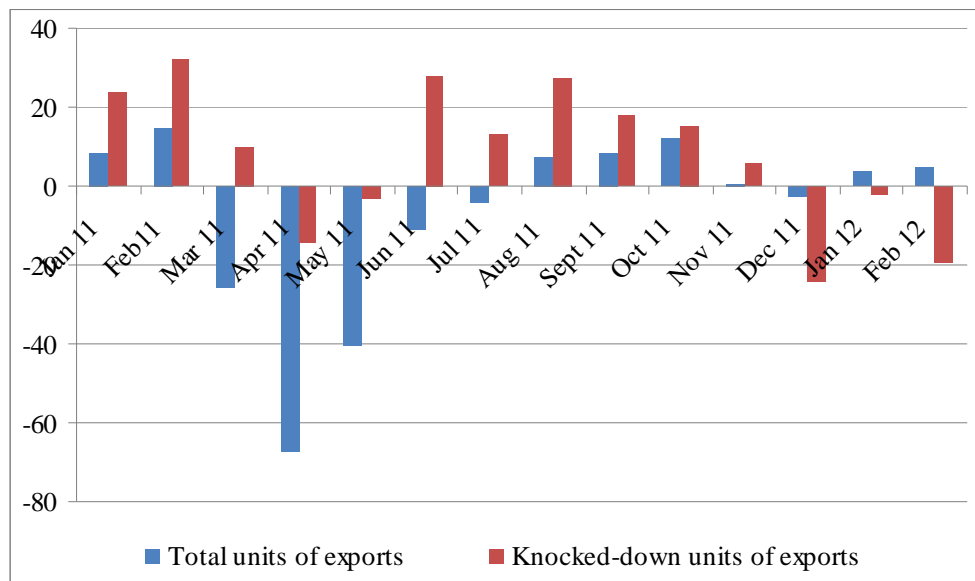
**Figure 11. Monthly export growth in 2011 by key markets**

Source: Office of Industrial Economics, Ministry of Industry, Thailand.

A contraction in manufacture exports as a result of the flooding was not limited to Thailand. The fact that manufacturers in Thailand are directly connected with global production networks implies that the ripple effect of flooding can be transmitted to its trading partners. In the automotive industry, for example, the shutdown of the Japanese car assembly lines in Thailand can obstruct the exports of knocked-down units – vehicle parts and components that are produced in one country and then exported to another country for final assembly – from Japan. Figure 12 illustrates the impacts of Thailand's flooding on Japan's automotive exports through the global production networks by providing a comparison between the year-on-year growth rates of total exports and those of knocked-down unit exports. It can be seen that although the growth of total automotive exports remained rather robust and stable, with slightly positive growth in the last quarter of 2011, the exports of knocked-down vehicles experienced a noticeable decline of 24.1% in December 2011, a trend that persisted during January-February 2012. This demonstrates the significance of the global production chains in automotive production and serves as a warning that supply chain disruptions in one country can bring about the knock-on effects on exports of the other countries.



**Figure 12. Growth rates of automobile exports from Japan, January 2011-February 2012**



Source: Japan Automobile Manufacturers Association.

Notes: The numbers are year-on-year growth rates. A knocked-down unit refers to a semi-finished vehicle with a unit-value less than 60 per cent of the unit-value of a finished vehicle.

#### 4. Managing supply chain disruptions

Given the growing concern that the global production networks have become increasingly vulnerable to disruptions triggered by natural disasters, this section attempts to explore the available options and strategies for businesses to manage and mitigate such risks through building up the supply chains that are resilient to such uncertainties. The following discussion draws largely on the findings, insights and recommendations from a wide array of the existing studies of supply chains, operations management and Business Continuity Planning, with emphasis on the disruptions associated with high-impact, low-probability events.

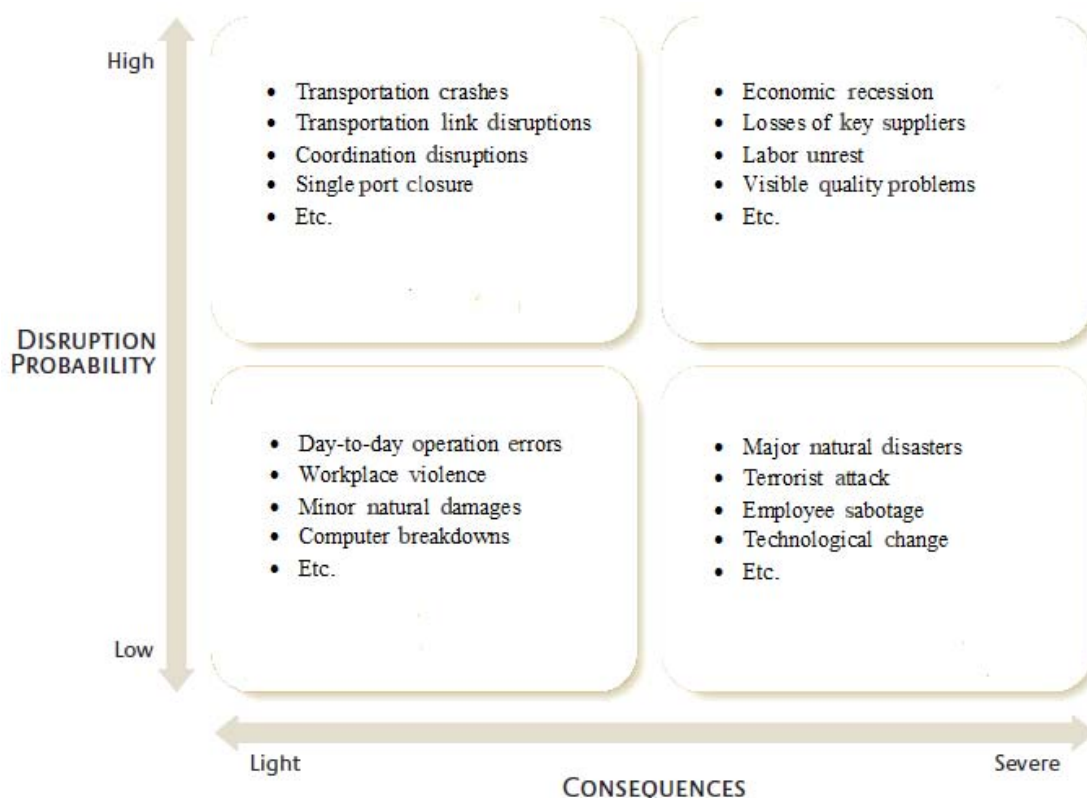
##### (a) Vulnerability assessment and awareness

In order to manage supply chain disruptions, one has to specify risk sources and vulnerabilities. However, the existing literature defines supply chain risks in many different ways and from many different dimensions. For example, Mason-Jones and Towill (1998) broadly classified supply chain risks into three categories: (a) internal to the firm; (b) external to the firm but internal to the supply chain network; and (c) external to the network. In contrast, Kleindorfer and Saad (2005), and Wagner and Bode (2008) posited that there were two broad sources of supply chain risks. One arises from the problems of supply and demand coordination, and the other is pertinent to disruptions affecting normal activities such as regulatory, legal and bureaucratic risks, infrastructure risks and catastrophic risks. The simplest way to distinguish the supply chain risks associated with natural disasters from other types of

risks perhaps rests with that of Sheffi and Rice (2005), in which supply chain vulnerabilities can be categorized by their probability and consequences.

Figure 13 presents a vulnerability map of a single company, where the potential threats to normal operations are categorized by disruption probability and severity of consequences. This vulnerability map essentially helps management identify the sources of vulnerabilities and prioritize measures that need to be taken to restore normal operations and minimize losses. As shown in the figure, natural disasters fall into the bottom-right area of the map as events that disrupt normal operations with high impacts and low probability. It should be mentioned that there is no one-size-fits-all approach to mitigating supply chain risks, as different sources of risks and vulnerabilities necessitate different strategies. More importantly, an attempt to reduce or circumvent one source of risks tends to exacerbate the others, as individual risks are often interconnected (Chopra and Sodhi, 2004). For example, a firm can reduce the risk of production delays by running at higher capacity; however, this in turn aggravates the risks of production breakdowns.

**Figure 13. Vulnerability map for a single company**



Source: Adapted from Sheffi and Rice, 2005.

While most companies develop contingencies to shield against high-probability, low-impact risks that are typically recurrent and transitory, such as machinery disruptions and failed coordination, high-impact, low-probability risks such as natural disasters are often ignored. There is abundant evidence that many

organizations are not fully aware of the heavy costs imposed by such unpredicted events, in terms of the deterioration of long-term performance, competitiveness and, ultimately, survival ability (Christopher and Peck, 2004). The supply chain management, in practice, continues to focus on efficiency improvements through a “lean” operating platform while downplaying, if not neglecting, the strategies that usher in resilience of operations to such potential threats (see, for example, Milner and Kouvelis, 2002; and Corbett and DeCroix, 2002). In discussing this point, Radjou (2002) stated that an individual firm was barely capable of taking any actions to manage the risks and mitigate losses of supply chain disruptions, for two main reasons. On the one hand, investment in improvements of supply chain efficiency is naturally easier to justify as it is part and parcel of day-to-day production and requires efforts and resources for developing specific skills and techniques. Most supply chain disruptions such as earthquakes and floods, on the other hand, rarely happen, thereby making pre-emptive measures difficult to justify and implement, at least from the perspectives of firms.

The tremendous damage to global production networks caused by Thailand’s flooding highlights this shortcoming in existing supply chain management in which manufacturers who count on just-in-time procurement and vertical intra-industry specialization have, by far, placed undue emphasis on cost-saving, efficiency-enhancing motives through industrial clustering that yields low transportation and labour costs, economies of scale and availability of necessary infrastructure. The fact that businesses have not sufficiently envisaged the rising supply chain disruption risks associated with natural disasters essentially complicates the situation, especially when the parts are highly customized and cannot be duplicated easily elsewhere.<sup>2</sup>

(b) *Building up redundancy*

The most fundamental principle of managing supply chain disruptions is building up redundancy in just-in-time procurement, whereby spare resources are set aside to serve as a “buffer” against undesirable effects of supply chain disturbances on inter-firm relationships (Bode et al., 2011). To help firms weather the ripple consequences of disruptions, various strategies can be used to bolster redundancy in supply chains, such as larger inventory stockpiles, multiple-sourcing strategies, backup production sites and product designs that advocate compatibility with supplies from various sources, among many others (see, for example, Tang, 2006). Since procurement decisions, with redundancy, are now being made on a just-in-case basis, firms can be less concerned over timely delivery and the efficient functioning of its contractual partners and suppliers, thus ultimately reducing the problem of ensuring effective communications and coordination.

Thailand’s flooding crisis witnessed redundancy at work. Several companies utilized their inventory stockpiles and backup production sites to ease their production losses when their plants in the flooded areas were shut down. For example, Hutchinson Technology, one of the major suppliers of hard disk drive suspensions for Western Digital, had to suspend its operations in Rojana Industrial Park in Ayutthaya province due to cuts in power supply and an evacuation order by the Government.

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<sup>2</sup> See “The Downside of just-in-time inventory”, *Bloomberg Businessweek*, 24 March 2011.

Yet, despite the disruptions, Hutchinson Technology managed to meet its delivery demands by running at higher capacity at its United States assembly plants and by tapping on its inventory stockpiles.<sup>3</sup> Emcore Corporation, a provider of compound semi-conductor-based components and fibre optics, attempted to make up for the shortfall in production at its bases in Thailand by moving some manufacturing to its own facilities in China and the United States.<sup>4</sup>

In contrast, some other firms bore the brunt of lean supply chains, with little room for delivery errors. Toyota, Japan's biggest car manufacturer, estimated it had a loss of 37,500 units in October 2011 due to the closures of its three assembly plants in Thailand. Honda Motor Corporation ceased production at its Thai and Malaysian bases due to shortages of auto parts from its plants in Rojana Industrial Park. Mazda Motor Corporation and Mitsubishi Motors Corporation were also significantly affected when vehicle production sites in Thailand halted operations. The production losses and damage among Japanese automakers prompted them to discard the single-sourcing strategy and consider the multiple-sourcing approach for parts procurement for just-in-time operations.<sup>5</sup> The need for greater redundancy has given rise to the fear that the use of multiple suppliers and diversification of production blocks across the region will undermine Thailand's attractiveness as a regional host of FDI, with foreign investment being diverted to neighboring countries such as Indonesia and Viet Nam.<sup>6</sup>

It should be noted that the relatively high level of redundancy that helped the electronics companies weather the production disruptions can be partly explained by the strategies for sourcing from overseas suppliers among manufacturers in Thailand's electronics industries (Hiratsuka, 2011). First, in contrast to automotive and other manufactures, intensive procurement of parts and components was carried out by electronics producers in Thailand from overseas suppliers, rather than domestic partners; these foreign suppliers were spread through a number of countries/areas in various regions, including Indonesia, China, Japan, Malaysia, Mexico, the Philippines, Singapore, the United States, Hong Kong, China and Taiwan Province of China. Having suppliers located in various locations ensures good risk diversification. Second, most arm's length procurement pertains to suppliers in neighboring countries such as Indonesia, Malaysia, the Philippines and Singapore. The proximity of arm's length suppliers enhances inter-firm communications, control and the ability of companies to respond rapidly to the problems in supply chains. Last, most electronics firms in Thailand employ the multiple-sourcing strategy – sourcing the same parts and components from multiple suppliers located in different countries. In contrast to the single-sourcing strategy, the multiple-sourcing strategy not only encourages competition among suppliers, but also mitigates the risks of parts and components shortages.

However, deviating from just-in-time to just-in-case operations through larger inventory stockpiles and redundancy in suppliers is constrained by cost-benefit tradeoffs in two ways (Shavell, 1984; Hendricks and Singhal, 2003; and Chopra and Sodhi, 2004). First, stockpiling extra inventory incurs higher holding costs and the danger of product obsolescence, while the use of multiple-sourcing strategies hampers efficiency arising

<sup>3</sup> See "Thai floods will impact hard disk drive components", *Forbes*, 17 October 2011.

<sup>4</sup> Available at: [http://emcore.com/news\\_events/release?y=2011&news=305](http://emcore.com/news_events/release?y=2011&news=305).

<sup>5</sup> See "Thai flooding disrupts Japanese auto production, prompts scrutiny of supply networks", *The Associated Press*, 26 October 2011.

<sup>6</sup> See "Thai floods may shift Japan investment to Indonesia, Viet Nam", *Bloomberg*, 15 November 2011.

from economies of scale and forces a firm to divest its redundancy arrangements and transactions. If the management costs associated with additional redundancy are prohibitively high, utilizing redundancy as a hedge against supply chain disruptions is not an option. Furthermore, redundancy has proved unfavorable to a firm's response capacity, product quality and, ultimately, its entire supply chain. If the gains from buffering production chains cannot sufficiently compensate the higher management costs, building up redundancy in an inter-firm relationship is not feasible.

(c) *Building up Flexibility*

The other avenue for managing supply chain disruptions is concerns boosting flexibility, i.e., the capability to forestall uncertainties and respond to them quickly through reliable and timely information about the potential disruptions and their consequences in an exchange relationship (Johnson et al., 2004). In principle, flexibility enriches a company's dependence on, and influence with its exchange partners and production networks as a result of better information exchange, in contrast to creating redundancy that, as discussed above, essentially reduces inter-firm linkages in the supply chains. Whether one approach is better than the other is inconclusive, as it depends on various factors such as inter- and intra-firm dependence, the nature of the products and corporate culture (Bode et al., 2011). More importantly, flexibility and redundancy are not mutually exclusive, in that a company can gain greater resilience to supply chain disruptions through redundancy and, at the same time, building up cohesion and communications with its partners.

Sheffi and Rice (2005) suggested that the flexibility of supply chains comprised three main elements: (a) supply procurement; (b) conversion and (c) distribution. The first element, flexibility of supply procurement, refers to developing and aligning the corporate-supplier relationship, both in single- and multiple-sourcing policies. Expanding the vertical specialization relationship requires investment in monitoring suppliers, better exchange of information and, not least, mutually agreed Business Continuity Planning (Harrald, 2002). The second element is concerned with conversion flexibility – a company's ability to quickly respond to disruptions. Several business strategies help boost conversion flexibility. For example, the use of standardized processes and identical machinery allows the operating teams to carry out activities in various locations, so that a breakdown in one plant enables them to quickly resume their operations in the other plants. The third element, distribution flexibility, refers to the extent to which a company can continue to service and maintain good relationships with its key customers in the aftermath of any supply chain disruption. A business model that advocates distribution flexibility is, for example, the build-to-order, as opposed to the fixed configuration operating strategy, whereby a firm faced with parts shortages, banks on pricing strategies and services to sell what it can make, rather than disappointing and foregoing customers.

The detrimental impact of Thailand's flooding on manufacturing production points to inadequate flexibility of supply chains, as most companies failed to foresee potentially disastrous disruptions and to cope rapidly and positively with such a high-impact, low-probability event. For example, Western Digital was unable to quickly determine the extent of the impact and the time required to restore full operations,

thus reflecting inadequate exchanges of information with its suppliers and partners.<sup>7</sup> The lack of procurement flexibility appears to have been highly costly, as Western Digital is on the verge of losing its position as the world's largest supplier of hard disk drives. Sony Corporation experienced the downside of distribution rigidity, as the shortages of specific parts for its new high-end camera configuration, NEX-7, forced it to defer the product launch, which has caused tremendous losses in its high-end camera market share. Likewise, Apple Inc. suffered from a decline in production and sales of its Mac computers, as production was not feasible without specific parts from affected suppliers in Thailand, thereby putting downward pressure on its stock price.

In contrast, the flexibility of supply chains helped ensure that several companies were unaffected by Thailand's floods. For example, American car manufacturer General Motors ceased its passenger-car assembly in Thailand but managed to promptly transfer its operations to other sites, thereby ensuring its production as well as sales were unaffected; in contrast, other car manufacturers, such as Toyota Corporation and Honda Motor Corporation, had to cut back car production substantially.<sup>8</sup> The resilience of GEM Thailand, a provider of semi-conductors and hard disk drives, offers another example of conversion flexibility as an insurance against natural disasters. As its plant in Ayutthaya was inundated, the management and employees took progressive action to quickly move critical inventory and support services to flood-free locations; some final assembly work was even finished at its customer sites.<sup>9</sup> The company's ability to speedily shift the workforce and keep up operations at other sites helped to ensure that its production capacity was virtually unaffected.

## 5. Conclusion: Implications for supply chains

The substantial impact of Thailand's floods on industrial production and direct exports has not only demonstrated how the country and, to a greater extent, developing Asia have become central to global production networks; it has also re-affirmed the fact that supply chain risk management serves as the other pivotal impetus for enhancing competitive advantage. In the face of increasingly drastic natural and man-made, disasters that likely lie ahead, in addition to the ever-expanding competitive pressure on industrial agglomeration and clustering, just-in-time production networks can be expected to incur increasingly heavy costs emanating from supply chain disruptions. Therefore, resilience to such shocks and breakdowns as well as the level of effectiveness in managing the risks and damage to supply chains are key elements that set a company apart from, and ahead of its competitors.

This paper provides some insights into strengthening the resilience of supply chains against high-impact, low-probability events such as terrorist attacks, disease outbreaks, earthquakes and floods, based on the supply chain management and operations literature plus some case studies arising from Thailand's worst inundation in 70 years in 2011. To sum up, this paper puts forward three important aspects of

<sup>7</sup> See "Thailand floods causing tech supply chain issues (updated)", *Forbes*, 10 December 2011.

<sup>8</sup> See "Worst Thai floods in 50 years hit Apple, Toyota supply chain", *Bloomberg*, 21 October 2011.

<sup>9</sup> Available at [www.gemcity.com/news-Thailand-Flood.aspx](http://www.gemcity.com/news-Thailand-Flood.aspx).

supply chain management that help to ensure immunity against supply chain disruptions and assist organizations in production networks to cope effectively with future catastrophes.

First and foremost, companies need to ensure that awareness of supply chain disruptions associated with high-impact, low-probability events is one of the fundamental aspects of corporate culture and management mindset. Although much evidence points to the deterioration of long-term performance in the aftermath of disruptions in terms of diminishing stock prices, loss of market shares and a lower likelihood of survival, realizing the risks of supply chain breakdowns is easier said than done. Most manufacturers and even governments are not fully aware of the escalating disruption risks associated with just-in-time procurement policy, and they continue to put excessive emphasis on enhancing efficiency improvement through lean operations, industrial clustering and economies of scale. Without appropriate identification of risk sources and the lack of a business continuity plan, a company is likely to fail in systematically and rapidly responding to disruptions, and it will ultimately incur much greater damage than what would otherwise have been inflicted.

Redundancy in just-in-time procurement policy is equally crucial. This paper clarifies two aspects of redundancy in supply chains – redundant inventories and redundant suppliers. The former offers a shock absorber for companies while the latter helps lessen the risk that a breakdown in delivery by one supplier will cause the stoppage of entire operations. In the aftermath of Thailand's flooding in 2011, there has been an increase in the quest for greater redundancy through reducing dependence on a single supplier as well as the spread of production sites throughout the region. This has created the fear among local businesses as well as the Government that Thailand will lose its long-standing position as a hub of global supply chains. However, this paper highlights the fact that dispersion forces, fortified by the escalating trend of procurement redundancy, are subject to trade-offs between lower disruption risks and higher costs in terms of holding outlays, transaction-specific investment and operational inefficiencies, and therefore implementation of the risk-mitigation strategies can only be limited. As industrial production rebounds to normality after the flooding turmoil, Thailand's industries will continue to flourish with regard to industrial agglomeration and economies of scale; therefore, a shift away from just-in-time to just-in-case operations is unlikely.

Last but not least, an area that allows vertical specialization and just-in-time procurement to proliferate but has yet been sufficiently emphasized is building up flexibility. Complementarity with redundancy and flexibility in fundamental supply chain elements (procurement, conversion and distribution) boosts a company's vertical relationship with its partners and suppliers, thereby helping companies to respond rapidly and effectively to disruptions through information exchange during in the flood crisis, firms with more flexibility in their supply chain operations tended to be more resilient in terms of buoyant production and service continuity. As supply chain disruptions caused by such catastrophes accentuate the downside risks of just-in-time production networks, it is vitally important for organizations to invest in incorporating flexibility into supply chains.

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