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Saileshsingh Gunessee[a], Nachiappan Subramanian[b,*], Kun Ning[a]
[a] *Nottingham University Business School China, 199 Taikang East Road, Ningbo 315100, China*
[b] *School of Business, Management and Economics, University of Sussex, Brighton BN1 9SL,UK*

Abstract

Purpose – This paper provides quantitative evidence of natural disasters' effect on corporate performance and studies the mechanisms through which the supply chain moderates and mediates the link.
Design/methodology/approach – Using two major natural disasters as quasi-experiment, namely the 2011 Japanese earthquake-tsunami (JET) and Thai flood (TF), and data over the period 2010Q1-2013Q4, effect of these events on end assemblers' performance is studied, with a focus on the personal computer (PC) supply chain. The moderating influence of delivery and sourcing – as supply chain flexibility and agility – are examined through end assemblers' and suppliers' inventory. The suppliers' mediating role is captured as disruption in obtaining PC components through their sales.
Findings – Only JET had any negative effect, further quantified as short-term and long-term. The TF instead portrays an insignificant but positive aftermath, which is construed as showing learning from experience and adaptability following JET. Inventory matters, but differently for the two events, and suppliers only exhibit a moderating influence on the assemblers' disaster-performance link.
Originality/value – Natural disasters, as catastrophic vulnerabilities, are distinct from other vulnerabilities in that they are hard to predict and have significant impact. Since little is known about the impact of natural disasters on firm performance and how supply chain mechanisms moderate or mediate their impact, they should be distinctly modelled and empirically studied from other vulnerabilities. This paper sheds light on supply chain resilience to such events with the role of dynamic capabilities.

Keywords: Natural disasters, Catastrophic vulnerability, Firm performance, Agility, Learning, Dynamic capabilities.
Paper type: Research paper

***** Corresponding author. Tel.: +44 1273872982.
E-mail: saileshsingh.gunessee@nottingham.edu.cn (S. Gunessee),
N.Subramanian@sussex.ac.uk (N. Subramanian), karen.ning@nottingham.edu.cn (K. Ning).

1. Introduction

Natural disasters (NDs) can have a significant impact on firms, made even worse with global supply chains that rely increasingly on outsourcing and leaner production. An enterprise's supply chain resilience – that is, its 'ability to survive, adapt, and grow in the face of turbulent change' (Pettit *et al.,* 2013) – is tested in the face of NDs. This is because, being highly unpredictable events, their impact on the supply chain can be huge if firms do not possess a resilient enough supply chain to cope with such events.

Indeed, major natural disasters have the potential to disrupt the supply chain of firms within an industry. For example, in 2011 the Japanese earthquake-tsunami (JET) and the Thai flood (TF) totally disrupted the global electronic supply chains and resulted in huge negative economic outcome for firms, exemplified by closure of their plants for several months and loss of their market share (World Bank, 2012, p.9; Manners-Bell, 2014, p.59). In particular, both events affected leading electronics firms such as Sony, Fujitsu, and Dell, because the electronics supply chain of semi-conductors and hard-disk drives were affected (Manners-Bell, 2014, pp.87-89). Hence, the electronics industry, and in particular the personal computer (PC) industry, is an interesting case to explore if one wishes to grasp the impact of such NDs.

This paper contributes to this endeavour by studying the direct and indirect impacts of NDs on the corporate performance of end assemblers. It first sets out a conceptual framework that grounds NDs as catastrophic vulnerability and links it with end assemblers' performance (including short-term and long-term effects). It then spells out the indirect link of supply chain flexibility and agility with performance, specifically end assemblers' delivery and sourcing from suppliers. A second indirect mediating link working through supplies disruption is likewise identified.

The study then provides quantitative estimates of the effect of these events on firm performance using a sample of ten leading PC end assemblers and using these two major natural disasters as a quasi-experiment over the period 2010Q1-2013Q4. The estimate is further split into short-term and long-term effects. The paper also studies the moderating role of delivery and sourcing respectively through end assemblers' and suppliers' inventories. This is alternatively compared to the mediating role of supplies disruption on the effect of NDs on corporate performance, through PC suppliers' sales.

Studies that have related NDs to the supply chain have done so conceptually, but such work is generic and fails to draw specifics to the uniqueness of NDs (see

Pettit *et al.* 2010; Pettit *et al.* 2013; Sheffi and Rice, 2005). For example, the two studies by Pettit *et al.* see NDs as one turbulent factor and vulnerability among other turbulent factors and vulnerabilities. Facing these broad vulnerabilities, firms need to possess various capabilities as, for example, attributes to anticipate and overcome disruptions, to balance the effects of vulnerabilities, and to achieve resilience. This also echoes Sheffi and Rice's (2005) depiction of a resilient enterprise and how to achieve this in general terms.

In this paper we argue that the unpredictability of these events and the likelihood of their significant impact make them distinct from other supply chain disruptions, risks, and vulnerabilities. First, they are difficult to anticipate and foresee. This is why a ND is seen as a highly disruptive event, catastrophic risk and turbulent vulnerability. Still, generic frameworks that lump such unique change or event with other vulnerabilities and disruptions are bound to prescribe generic mitigation strategies. Apart from being hard to anticipate, such unique disruptive catastrophic event and vulnerability would have different impact on the firm and its supply chain, as exemplified by JET and TF.

In terms of quantified evidence of NDs as they relate to firms and their supply chain, the evidence is scant. Indeed, a review of the literature reveals studies of the so-called 'economics of natural disasters', which mostly provide 'macroeconomic effects' of NDs (see Cavallo and Noy, 2010), with little in way of firm-level evidence. Looking at supply chain glitches, Hendricks and Singhal (2003, 2005a, 2005b) document the negative impact of these disruptions on shareholder value and corporate performance, but they consider all types of disruptions and thus nothing specific to NDs. Instead, Leiter *et al.* (2009) uses European firm-level data to study the effects of floods on capital accumulation, employment, and productivity, but without any supply chain context. MacKenzie *et al.* (2012) and Matsuo (2015) are rare examples of studies that consider the effect of the JET that works via production, though the latter is based on one company's supply chain, namely Toyota, and the former uses an aggregate input-output approach.

As such, with the supply chain literature not having adequately grounded NDs in theory and with little direct evidence on NDs, there is a lack of insight on such catastrophic events and their effects. Thus, the main contribution of this study is to model and evidence this.

A second contribution of the study is to offer an understanding of the supply chain mechanisms at work. First, it sheds light on how flexibility and agility work as moderating influences, with specific insight as to which of lean or excess inventory works and how. We learn whether sourcing from suppliers by end assemblers enabled the latter's continued performance in the context of these disruptive events. Furthermore, the moderating and mediating influence of the supply chain is informative about the resilience of the PC supply chain during such events and how to build resilience (see Christopher and Peck, 2004; Fiksel, 2015, pp. 103-104).

The rest of the paper is organised as follows. Section 2 provides background to the two natural disasters. Section 3 provides a sketch of the conceptual framework and hypotheses development, while Section 4 describes the data collection and quasi-experimental methodology. Section 5 outlines the empirical results and Section 6 offers theoretical and managerial implications of this work, while the final section summarises the findings.

2. Background on the Natural Disasters

Among recent NDs two events, the Japanese earthquake-tsunami (JET) and the Thai flood (TF) in 2011 affected both people and business, as they resulted in casualties and created huge loss.

On March 11, 2011, the Tohoku earthquake off the coast of Japan triggered a tsunami which also resulted in nuclear power plant damage. The JET severely affected a large geographical area and caused devastating disruptions to the industrial supply chain in Japan on an unprecedented scale (Fujita and Hamaguchi, 2012). What made this event even more striking was that its effects were both to the national and global supply chains (MacKenzie *et al.*, 2012; World Bank, 2012, p. 11). As the Japanese electronics industry accounts for a large market share in the global market for electronic products, this disaster affected many companies (Manners-Bell, 2014, p.59). In the coastal areas, petrochemical complexes were significantly damaged. As a consequence, hydrogen peroxide, used in semiconductor manufacturing, became short in supply. In in-land areas along the Tohoku bullet-train line and the highways, many high-tech plants were damaged. In particular, electronic components, such as semiconductors and hard disk drives, were affected (Manners-Bell, 2014, p.86; Matsuo, 2015).

The Thai economy was affected due to prolonged flooding in 2011. Though Thailand has often suffered from flooding, the 2011 flood had the most severe impact when compared to past floods. Heavy, continuous rain coupled with the monsoon period saw the average accumulated rainfall amount by October 2011 35% higher compared to the normal annual rainfall, according to the Thai based Hydro and Agro Informatics Institute. The end result was the most devastating flash floods that Thailand had ever witnessed. That year the Thai economy grew by only 0.5-0.8%, compared to 7.3-7.5% the previous year, according to the World Development Indicators.

The electronics industry was significantly affected during the Thai flood. Before the event, Thailand produced approximately 43% of the world's hard disk drives (HDD) and many companies with plants in Thailand were affected (Manners-Bell, 2014, p.80). As an example, Western Digital Corporation, which produced one-third of the world's hard disks prior to the flood, lost 45% of its shipments because its factory in Bang Pa-in Industrial Estate in Ayutthaya province was flooded. In a similar vein, the Toshiba factory, one of the four major HDD makers, was also flooded. In fact, Toshiba was forced to shift production to its alternate facilities in the Philippines. Interestingly, two other major HDD manufacturers, namely Samsung and Seagate Technology, though not directly affected, were forced to reduce production as they lacked supplier parts (see Haraguchi and Lall, 2015). As a consequence, the PC makers with no forthcoming supplies of HDD were, in turn, themselves affected. The anecdotal lessons learnt here are that an efficient supply chain that relies on outsourcing and lean practices with little safety inventory suffers badly from such events.

3. Conceptual framework and hypotheses development

The conceptual framework postulated is depicted in Figure 1. As outlined in the introduction, this piece studies the direct and indirect effects of NDs on corporate performance. Thus, the 'Natural Disasters – Flexibility, Agility & Disruption – Performance' framework highlights the direct impact of NDs and its interplay with flexibility, agility and supplies disruption, as related to end assemblers' performance. We draw from the supply chain literature to conceptualise the various links under study.

** FIGURE 1 HERE **

3.1. Natural disasters and end assemblers' performance

Natural disasters have been referred to as highly disruptive events, catastrophic risks, and turbulent vulnerabilities. A supply chain disruption is an unintended situation which leads to supply chain risk, and which would be exceptional if highly disruptive. A catastrophic risk is seen as a type of disruptive risk that can have a severe impact on a firm and its supply chain (Kleindorfer and Saad, 2005; Wagner and Bode, 2006). Vulnerability is defined as the 'existence of random disturbances that lead to deviations in the supply chain from normal, expected or planned activities, all of which cause negative effects' (Svensson, 2000). Thus, turbulent vulnerability is a change in the business environment beyond the enterprise's control that makes the enterprise susceptible to a disruption and deviation (Fiksel, 2015, p.95).

In this paper we define a natural disaster as a *catastrophic vulnerability*. Catastrophic vulnerabilities are events or changes which are hard to predict and, when they occur, have a severe impact in that they can be highly disruptive to the business functions of an enterprise, including its supply chain, and can have negative consequences. Apart from NDs, they can include pandemics, terrorist attacks, civil unrest, and geopolitical conflicts.

The key feature of this definition of catastrophic vulnerability is, first, the *high unpredictability* of such events or changes. Second is the *catastrophic* nature of such random disruptive events. It is impactful. These are important to draw out as 'mitigating strategies' that work for normal supply chain disruption or demand uncertainty might be inadequate for such low probability high impact vulnerable change (Simchi-Levi *et al.*, 2014). Indeed, traditional risk management tools are inadequate as catastrophic disruptions which happen due to gradual change and sudden shocks are difficult to anticipate with any confidence (Fiksel, 2015, pp. 4-5).

Catastrophic vulnerability can have a direct impact on corporate performance, especially if this means incapacitated production and sales. This is because unexpected disruptions of operations and business functions would potentially leave the enterprise unable to function properly. For instance, unanticipated disruptions as a result of a natural disaster would lead to disruption in delivery of products to final customers and, in turn, reduced customer satisfaction as delivery targets fail and continuing to serve these customers comes at higher costs (Fiksel, 2015, p.102).

Therefore, conceptually we expect catastrophic vulnerability, such as a natural disaster, to have negative consequences for firms and their supply chain (see Figure 1). Indeed, there is a general consensus that natural disasters entail negative economic outcomes and usually affect the global supply chain of any industry and thus firm performance (Cavallo and Noy, 2010; Sheffi and Rice, 2005; Wagner and Neshat, 2010). The scant evidence bears this out. Using European firm-level data, Leiter *et al.* (2009) in their study of the effects of floods, find significant negative effects on capital accumulation, employment, and productivity. In the specific case of JET and TF, Fujita and Hamaguchi (2012) and Haraguchi and Lall (2015) document the adverse consequences of JET and TF respectively. In addition, Manners-Bell (2014) descriptively outlines how these events negatively impacted on computer parts in the PC industry.

Thus, the two NDs under study are expected to have had a negative impact on corporate performance. The following is posited:

H1: JET and TF, as catastrophic vulnerabilities, had a direct negative effect on end assemblers' performance in the PC industry.

As a corollary to hypothesis 1, we can also posit whether these NDs had a profound impact on corporate performance. As such, of interest to this study is *quantifying* the economic significance of the hypothesised negative evidence. From a theoretical standpoint catastrophic vulnerabilities, such as NDs, are expected to have huge and significant impact (Simchi-Levi *et al.*, 2014; Wagner and Bode, 2006; Wagner and Neshat, 2010). This emanates from the fact they can disrupt whole operations and supply chain networks, made more difficult by firms' inability to anticipate such catastrophic events.

Specific to JET and TF, the above studies provide some descriptive information on what happened to some firms' industrial production and earnings pre- and post-catastrophic events. For instance, Haraguchi and Lall (2015) highlight how the Thai flood reduced the world's industrial production by 2.5%. They also estimate the number of days it took electronics firms to recover and report how Western Digital, the world's largest HDD maker at that time, suffered a 35% reduction in earnings. In the case of JET, Fujita and Hamaguchi (2012) report how, within a year, industrial production fell by 21.5%, 29.6%, and 30.5% respectively for integrated circuits, communications equipment, and information & electronics equipment.

However, the issue with these 'estimates' is they do not provide for 'controlled' effects. That is, they do not control for extraneous factors such as firm-specific, industry-specific, and economy-related factors. This issue is recognised by Hendricks and Singhal (2005b), when they use a controlled matched pairing of firms to study the effect of supply chain glitches. Henceforth, this study uses secondary panel data of firms and a regression approach which allows *control* for both time (in-) variant specific factors. As such, the estimates obtained could be termed as 'controlled' effects as they control for any confounding factors that could affect end assemblers' performance.

Thus,

Corollary to H1: As catastrophic vulnerable events, JET and TF are expected to have had an economically significant effect on end assemblers' performance.

Short-term and long-term effects. While the general effect of NDs is undisputed, less clear are their short-term and long-term effects. Sheffi and Rice (2005) and Munoz and Dunbar (2015) have conceptually discussed the performance profile of an enterprise following a disruption.

Figure 2 graphically shows how performance varies over time, moving from an original to a new equilibrium in the long term following a disruption such as a natural disaster. Such an event as that illustrated reveals declining performance in the short-term due to revenue loss. As the firm starts to respond, it may take two paths to recovery: a smooth path (i.e. solid curvature); or a more disruptive one (i.e. dashed part), facing additional losses and costs despite a brief recuperation. The effect of a ND could have a prolonged effect, where the new equilibrium is lower than the old one. This is because a disruption can have a negative long-term effect on performance. This is confirmed by Hendricks and Singhal (2012, pp. 57-58) who show that the loss in shareholder value associated with a disruption is not just short-term as it can last for two to three years. They also reveal that short-term loss is larger than the long-term one.

** FIGURE 2 HERE **

This evidence, and the above conceptualisation of the short-term and long-term effects, suggests two things: there is a long-term effect; and, the short-term effect may be at least equal to, or larger than, that long-term impact. The rationale behind this is that catastrophic events can lead to interruptions and capacity reduction which severely impede a firm's ability to maintain its pre-event equilibrium, as depicted in Figure 2. There is an immediate effect in the aftermath of such an event. On the one hand, this immediate effect we hypothesise could be smooth, with a revenue drop due to interruption in production and delivery of final products. On the other hand, if operations are agile and resilient, the firm recuperates at first, but then performance plunges again. This is related to the nature of such a unique event, as the firm faces further operational costs and adjustments. Thus, it represents an alternate short-term effect (Munoz and Dunbar, 2015).

As a firm tries to regain stability after such disruption it takes time to become fully functional before it reaches a new stable state. This new equilibrium can be lower or higher than the old equilibrium. This means there is a long-term effect of such catastrophic vulnerability, which includes a longer time to recuperate operational activities (Sheffi and Rice, 2005). While firms could reach a steady state, where they are fully operational to the pre-disaster level, yet they could lose market share and never regain this level. This is because some firms may be affected differently by such catastrophic events. With this, we hypothesise that:

H2: The short-term effect on performance of a natural disaster is equal or higher than the long-term effect, with a prolonged negative effect.

3.2. Supply chain flexibility and agility

Figure 1 depicts the mitigating role of supply chain flexibility and agility to moderate the catastrophic vulnerability-corporate performance link. Supply chain flexibility can be defined as the capability of supply chains to respond to changes and the ability to adjust without much effort, cost, or performance (Singh and Sharma, 2014). The related concept of supply chain agility can instead be defined as the adaptability and quickness (i.e. speed of response) to change, especially to uncertain changes and events (Prater *et al.*, 2001; Fayezi *et al.*, 2015). Speed of response, or timeliness, is a key aspect of agility in that an agile enterprise is one that can react and adapt quickly. Quick lead-time in producing customised products is an example (Fayezi *et al.*, 2015).

There is an inherent connection between flexibility and agility. Following Prater *et al.* (2001), a firm's supply chain agility can be seen to be determined by how physical components, such as sourcing, manufacturing and delivery, are adapted to incorporate speed and flexibility. As timeliness and flexibility increases, so does supply chain agility. In turn, supply chain agility can reduce the stress and external vulnerability an organisation faces due to catastrophic changes and events. It can mitigate the negative effects of catastrophic vulnerability on corporate performance. When facing catastrophic vulnerability, enterprises that have little agility and flexibility expose themselves to the disastrous consequences of such changes and events. Still, too much flexibility and agility in the context of low vulnerability can lead to an erosion of profits (Pettit *et al.*, 2013).

Of the three physical components, this piece is interested in two: agility and flexibility in delivery; agility and flexibility in sourcing.

Delivery and order fulfilment. Agility and flexibility in delivery is the ability of the firm in terms of order fulfilment, such as the ability to change the method of delivering final products to customers in a timely manner (Pettit *et al.*, 2010; Prater *et al.*, 2001). With a catastrophic disruption an enterprise loses the capacity to fulfil orders and loses potential business as a consequence. Therefore, the enterprise can use various means to ensure catastrophic vulnerability mitigation: inventory management; demand pooling; alternate distribution modes; multiple service centres; expedited shipping and transportation (Fiksel, 2015, p.98). We focus on the first of these.

Inventory management is a safety approach to build flexibility in supply chains to overcome uncertainty and as a mitigating influence during disasters. To mitigate the effect of uncertainty, it is often advised that firms maintain operational buffers along their supply chain in terms of safety stocks or productive capacity (Colicchia *et al.*, 2010; Pettit *et al.*, 2010). This helps end assemblers deliver finished products to customers.

However, this needs to be balanced against the advantage of lean production and just-in-time delivery where inventory is kept to a minimum. Such practices espouse efficiency and enhance profitability of the firm and thus reduce internal vulnerability – the downside of excess inventory. Nevertheless, lean inventory trades off lower internal vulnerability for higher external vulnerability, as it becomes susceptible to disruptions being less agile and flexible (Dabhilkar *et al.*, 2016; Fiksel *et al.*, 2015).

Thus, keeping excess inventory is expensive and often considered against the spirit of lean and efficient manufacturing, but still it needs to be balanced against the negative consequences of disasters, where keeping inventory is a buffer to mitigate the uncertain effects of a ND (Pettit *et al.*, 2013). As such, finding the right balance is salient to building the agility that will sustain corporate performance. When it comes to JET, MacKenzie *et al.* (2012) find that consumer sales were fulfilled by having inventory in the production pipeline, supporting the notion of having excess inventory as being important in the face of NDs.

Therefore, from the above, a positive outcome from the interplay of JET and TF with inventory on corporate performance is expected, as excess inventory acts to mitigate disruption related to catastrophic vulnerability.

Sourcing. Flexibility and agility in sourcing from suppliers can also act as a mitigating strategy to reduce any disruptive catastrophic effect on corporate performance (see Fig. 1). It is the ability to quickly receive inputs and to change them if necessary, including the mode of getting inputs (Pettit *et al.*, 2013). During a catastrophic vulnerable change or event, an enterprise can compensate for any sudden and negative impact if its inbound logistics, that is sourcing, can enable it to continue its operations (Prater *et al.*, 2001). For example, suppliers with enough capacity and expedited shipping of inputs could respond quickly to end assemblers' needs.

Consequently, suppliers, through the management of their own inventory, can help mitigate any negative effect on end assemblers. In the same vein as end assemblers, if suppliers use lean practices with regard to inventory, then they are less likely to mitigate the negative ND-performance link. Instead, suppliers that have slack (i.e. excess inventory) can cope better in terms of the delivery of supplies to end assemblers.

Thus, it is hypothesised that:

H3: After JET and TF, excess inventory held by end assemblers for delivery and order fulfilment was positively related to end assemblers' performance, as they mitigated any disruption.

H4: After JET and TF, excess inventory sourced from suppliers was positively related to end assemblers' performance, as they mitigated any disruption.

3.3. Supplies disruption

Eschewing mitigating strategies and the direct impact, catastrophic vulnerability can have an indirect effect on firm performance. It can disrupt the supply chain of an enterprise by affecting its suppliers directly first and, in turn, the enterprise. Indeed, for end assemblers at the downstream stage of production, a disruption to any of its supplies can have a knock-on effect creating bottlenecks in its supply chain (Manners-Bell, 2014, p.10). With catastrophic events and changes, such as NDs, this disruption can be very acute given its high unpredictability. This could permeate the whole supply chain and eventually affect corporate performance of end assemblers. Starved of its supplies the enterprise would suffer severe losses, depending on the severity of such catastrophic vulnerability (Sheffi and Rice, 2005; Wagner Bode, 2006).

Thus, natural disasters could also affect PC end assemblers by affecting suppliers through a disruption of input supplies first. In contrast to the discussion in sub-section 3.2 above, suppliers can be viewed as having not only a moderating influence, but also a mediating one. As outlined in section 2, as a result of the NDs electronic components, such as HDD and semiconductors, were affected and, in turn, the effect trickled down to end assemblers, as reported in the year-end annual reports of major firms such as Dell and Fujitsu (Haraguchi and Lall, 2015; Fujita and Hamaguchi, 2012; Manners-Bell, 2014). Such mediating link, disaster → suppliers' sales → end assemblers' corporate performance, is corroborated in studies documenting other disasters (see Sheffi and Rice, 2005). Thus, we hypothesise that:

H5: JET and TF had a negative indirect effect on PC end assemblers' performance, through a disruption of supplies and suppliers' sales.

4. Data and Methodology

Empirical specification. The empirical strategy to examine the direct effect of these natural disasters on corporate performance is to deploy a before-and-after regression design in the spirit of a quasi-experiment. The regression equation considered is:

$$Y_{it} = \alpha + \lambda_1 JET + \lambda_2 TF + \beta X_{it} + \eta_i + \phi_{it} + \varepsilon_{it} \quad (1)$$

where, *JET* is a dummy variable to indicate discontinuity due to the Japanese earthquake-tsunami, taking a value of 1 for observations after the event and 0 before. Similarly, *TF* represents an event dummy defined as 1 for observations after the Thai flood and 0 before it happened. Y_{it} denotes the dependent variable(s) for firm *i* and at time *t*, with the latter being a *quarterly* time period. The explanatory variables X_{it} are to be only included when addressing the questions of moderation and mediation.

Key to the strategy to obtain ‘controlled’ estimates is the inclusion of the terms ϕ_{it} and η_i. The first represents *time varying* firm-specific effects, which is to control for any time-variant factors related to firm performance, other than those included in the regression. This allows not only the capture of time-specific shocks, but controls for time varying variables which, due to usage of quarterly data, would limit the use of ‘observable’ time varying explanatory factors. The second term, η_i, is added to control for unobserved heterogeneity; it should capture time-invariant factors that affect the dependent variable. As various dummies are used in the estimation, unobserved heterogeneity is modelled and the above specification (1) is estimated using a random effects model. This means the panel data is estimated using a feasible generalised least squares technique, such that unobserved heterogeneity η_i are treated as random effects. With random effects and time varying firm-specific effects, one can, in turn, choose to use few key regressors and, what is more, use them one at a time. The above approach is, of course, another way of dealing with the omission of important variables and, in turn, of dealing with endogeneity driven by omitted variables.

Interest is on the parameters λ to see if there are any changes post-disaster in a ‘general’ sense, without any specific context of a *Y-X* relationship. This is expected to be negative.

Data and variables. The selection of firms to form the sample of end assemblers and suppliers has the following logic. Based on information about which industries were most affected by these disasters, the PC industry is chosen. Then, companies which had not only annual reports, but also had quarterly reports that could be traced back in time preceding these events by at least one year (i.e. four quarters before JET) were selected. The starting list of companies was retrieved from the *Morning Star* filings and the companies own websites. A company is classified as an end assembler if its final products are mostly meant for consumers. In addition, to confirm this and to further demarcate between end assemblers and suppliers, the industrial grouping on the *CreditRiskMonitor* website was consulted. Finally, based on available data, the leading PC makers by sales were picked which eventually led to the following companies being treated as end assemblers: *Acer, Asus, Clevo, Dell, Fujitsu, HP, Lenovo, Samsung, Sony* and *Toshiba*. A stress test using a smaller sample of *predominantly* PC makers (i.e. without Fujitsu, Samsung, Sony, and Toshiba), does not alter the findings of the study.

To construct the suppliers' sample the study considered whether the company is involved in the upstream stage of the production process. Based on section 2, the components chosen are: HDD, Motherboard (mthbd), Chip & CPU (ccpu). The suppliers used then are: *Western Digital, Seagate, Scandisk, Transcend* (hdd); *Gigabyte Technology, MSI, Biostar, ASRock* (mthbd); *Intel, Qualcomm, AMD, NVIDIA* (ccpu). These are leading suppliers for the respective component. The suppliers' information was then used to construct indicators *averaged* for each quarter to connect it to the end assemblers' data as described below. Given the nested structure the data takes, we report clustered robust standard errors.

The final sample consists of 160 observations made up of ten PC makers over the period 2010Q1-2013Q4 (i.e. 10 x 16). To capture the pre-event period, information one year prior to the 2011 events is used, while information two years after the events is used in light of hypothesis *H2* related to short- and long-term effects.

Table A.1 describes the variables and data sources. The dependent variable Y_{it}, sales ratio, is constructed as sales to total assets; where sales were obtained from quarterly reports of the firms over the period 2010Q1-2013Q4. The choice of sales as a proxy for performance is dictated by the fact that the most directly measurable impact on firms would be felt on sales, as highlighted by Manners-Bell (2014, p.89). Still, gross profit as an alternative measure was used and the results, not reported here, are fairly robust.

JET and *TF* are the first regressors of interest. The natural disasters, as outlined above, are described as event dummies representing a before and after scenario. The timing of these disasters for the Japanese earthquake-tsunami (JET) and the Thai flood (TF) are respectively dated at 2011Q1 and 2011Q4 in this study. The timing of the JET is considered as March 11, 2011 and, due to the nature of the disaster as a singular event, this is beyond question. However, for the Thai flood this is less so due to its cumulative effect over time. Still, Haraguchi and Lall (2015) report the worsening of the flood in the fourth quarter of 2011. This is also borne out by the Centre for Research on the Epidemiology of Disasters EM-DAT dataset.

The other explanatory variables were lagged by one period and, as such, used 2009Q4 as the starting period for these regressors. This is done to guard against endogeneity of the reverse causality type. As such a firm's current dependent variable is expected to react to past values of the independent variables.

The end assemblers' inventory is used to construct excess inventory. To do so in the spirit of the theoretical arguments outlined in the theoretical section, it is constructed as an *above average* measure using inventory turnover. Average here is defined as the ten PC makers average for each quarter. The latter is taken as the industry standard to demarcate lean vs. excess inventory. Thus, *above average inventory turnover* is used to capture a flexible supply chain because a low inventory turn is often indicative of the presence of safety stocks and operational buffers. This also means that, the way the variables are constructed, the relationship of inventory turnover with sales ratio post-event is expected to be negative. Though not reported here, several other regressions were run using different measures of inventory, such as inventory-to-assets and inventory turnover based on quartiles instead of averages. Results are robust to these alterations.

Finally, to study the moderating and mediating role of suppliers, variables (i.e. inventory turnover and sales ratio) were 'averaged' for each quarter. This includes the two variables for suppliers as a whole and based on the three individual components considered. The overall measures were further weighted to reflect an additional element of suppliers' flexibility; that of alternative facilities. As such, if suppliers had alternate facilities in Asia, neighbouring both Japan and Thailand, they could switch production to those facilities and continue operations. So, before summing and averaging (as a non-weighted measure would be), each supplier's sales ratio and inventory turnover were weighted, where the weight could take any value from 0, ¼, ½, ¾, or 1. These values depict presence from low to high, such that if all suppliers had a facility in other Asian countries then the weight is 1. At the extreme, if none have another facility, the weight is 0. For example, of the four motherboard suppliers only three had facilities neighbouring Japan and only one neighbouring Thailand, meaning with four alternate facilities out of a maximum of eight, the weight is ½.

Mediation in the normal way would be inferred using a mediating variable from the *same* set of firms (i.e. same dataset). To study mediation in the traditional sense here is unfeasible because two datasets are utilised, one for suppliers and one for end assemblers. Instead, two regressions are ran with differences surrounding the explanatory variable *suppliers' sales ratio* (SSR) as follows:

$$Y_{it} = \alpha + \lambda_1 JET + \lambda_2 TF + \beta_1 SSR_{it} + \eta_i + \phi_{it} + \varepsilon_{it} \quad (2)$$

$$Y_{it} = \alpha + \lambda_1 JET + \lambda_2 TF + \beta_1 SSR_{it} + \beta_2 SSR\_\text{Residuals}_{it} + \eta_i + \phi_{it} + \varepsilon_{it} \quad (3)$$

Specification (2) uses suppliers' sales ratio in its original form, where the variable is dubbed as the 'uncontrolled' suppliers' influence as it still captures *both* direct and indirect effects. Specification (3) instead shows what happens if one controls for the influence of *JET* and *TF* on suppliers' sales ratio. This is achieved by adding another variable, s*uppliers' sales ratio residuals* (SSR_Residuals). This variable is obtained by first running a regression, using the individual suppliers' data, of suppliers' sales ratio on *JET* and *TF* and then extracting the *residuals* from this regression. Then it is *averaged* for each quarter to connect it with the end assemblers' data as *SSR_Residuals*. The residuals are factors that affect suppliers' sales ratio *other* than the natural disasters, as they have been controlled for in a first step estimation. That is, this new variable (i.e. *SSR_Residuals*) has been purged of the influence of the NDs and their mediating influence, in comparison to the original variable (i.e. *SSR*) which still captures their influence.

The question then is to compare the estimated coefficients of these two variables, *suppliers' sales ratio* and *suppliers' sales ratio residuals*, in the two regressions and to observe what happens to them. The following protocol is used to draw inferences about mediation versus moderation:

- First check specification (2),
  - if the 'uncontrolled' explanatory variable, *suppliers' sales ratio*, is significant or not. Proceed only if significant; otherwise do not proceed as insignificance means the variable has no effect in the first place. It *rules out the mediating effect* at the outset (as well as moderating or direct effect).
- If one proceeds from the previous step, then focus on specification (3),
  - if original variable, *suppliers' sales ratio*, is still significant but newly added variable *suppliers' sales ratio residuals* is insignificant then there is *mediation*;
  - if original variable, *suppliers' sales ratio*, is insignificant but newly added variable *suppliers' sales ratio residuals* is significant then there is *moderation* [this can be confirmed further by a proper examination of interactive influences in a third regression of *SSR* interacted with *JET* and *TF*];
  - if both *suppliers' sales ratio* and *suppliers' sales ratio residuals* are significant then both *mediation and moderation* are prevalent.

5. Empirical Results

5.1. Summary statistics

** TABLE 1 HERE **

Table 1 shows the summary statistics for the end assemblers in panel A and suppliers in panel B. The end assemblers' mean sales ratio (i.e. sales-to-assets) for the whole period is 0.324. When looking at sales ratio before and after *JET* and *TF*, they are both lower after both events. However, an independent sample *t*-test reveals no statistically significant difference in means (*p*-value = 0.189). The inventory turn is smaller after both events, but again an independence sample *t*-test shows no statistically significant difference in means (*p*-value = 0.438). In the case of suppliers, the sales ratio and inventory turn are also lower after both events, but again no statistically significant differences are to be noted.

Overall, the lower figures for the end assemblers' sales performance fail to tell us much and can only be *indicative* of the influence of these NDs. In essence, they show the 'uncontrolled' influence (or lack of such) of a ND, where one has not accounted for other factors that can affect sales. Thus, the task is to examine this more thoroughly using regression analysis which should provide 'controlled' point estimates of these events.

5.2. Regression results

** TABLE 2 HERE **

Natural disasters and end assemblers' corporate performance (H1 and H2). Table 2 reports the results of the effects of NDs on end assemblers' performance. This can be inferred by looking at the estimates on the dummies *JET* and *TF*. Specification (1) reports results on both events, while specifications (2) and (3) report the influence of *JET* only by looking at one and two periods after the *JET*. As such, the first reveals the average long-term effect, while the latter two show the short-term effect. In addition, this helps to disentangle any confounding effects of the two events being lumped together.

The results are partially supportive of the first hypothesis. *H1* finds some support, especially related to the *JET*. Most coefficients on *JET* are negatively signed and statistically significant. In contrast, there is little support for the influence of *TF*. In fact, the coefficient is insignificant but positively signed.

It is also clear from specifications (2) and (3) that the *JET* effect is still robust when one focuses solely on *JET*, in the immediate aftermath of that ND. Surprisingly, there is not overwhelming support for *H2*. While regression (1) does show a prolonged effect after the event, the short-term effect does not completely outweigh the long-term effect. Indeed, while the coefficient in (2) is slightly higher than in (1), regression (3) shows a *lower* effect two periods after. It seems the short-term effect is mirroring the second more disruptive path depicted in Figure 2, but with a more pronounced spike upwards. Not reported, *TF* was also found insignificant in the short-term.

One could give some ‘economic’ interpretation to these figures, in light of corollary to *H1*. Given the dependent variable is sales normalised by total assets, one could multiply this sales ratio by ‘average total assets’, which should allow interpretation of the point estimates in terms of sales (in millions of $). The average total assets for PC makers in the sample are 60269.75. Thus, $1408.82m, $1519.88m, and $852.30m are the numbers obtained (using the full coefficients). This can be interpreted as suggesting on average sales is, after the JET, in the longer term around $1408.82m *less* and in the short term $1519.88m and $852.30m *less* after one and two quarters respectively. *It is clear there are non-negligible long-term consequences and effects of such catastrophic events* (see Hendricks and Singhal, 2012, p. 57). This prolonged effect could be due to losing market share, the cost of rebuilding or of ignoring such unanticipated disruption in the first place (Chopra and Sodhi, 2014).

One explanation why the Thai Flood is insignificant but positively signed is that after the sudden occurrence of the *JET*, which had a negative impact on industrial activity in general, including the sample of PC firms under study, there was some ‘degree of preparedness’ and ‘learning from experience’. This fits with Fiksel *et al’s* (2015) point that ‘every disruption represents a learning opportunity that may suggest shifting to a different state of operations’ (p. 79). As such JET acted as an opportunity to learn for PC makers and they adapted their operations allowing for some flexibility. In fact, consulting some of the annual reports for the year 2011, reveals this to be the case. For instance, Fujitsu’s 2011 Annual Report reveals that after the Great East Japan Earthquake the company ‘increased its inventory holdings of parts and materials to prepare for unforeseen circumstances’. This helped during the TF.

Supply chain agility and flexibility in moderating ND-performance (H3 and H4). Table 3 reports findings related to hypotheses *H3* and *H4*. Start with flexibility and agility in delivery through the use of safety stocks (i.e. *H3*). With *above average inventory turnover* on its own being negatively signed and significant seems to suggest that firms which keep excess inventory appear to enjoy higher sales. Still, this has to be interpreted together with the interactive terms. The post-JET influence in the inventory management context is positively signed, while the post-TF influence is negative and significant. The former is contrary to prediction as *higher* above-average inventory signifies lean inventory management, rather than excess inventory, and is positively influential post-disaster.

One could interpret this as suggesting safety stocks that are kept as part of supply chain risk management seem to matter under normal circumstances, but in the case of an extreme disruption they fail to play a role. Thus, companies that had safety stocks could have been over-reliant on them to work even for catastrophic events and they possibly lacked flexibility and agility elsewhere within their supply chain. For instance, they could have been reluctant to invest in flexibility (see Fujita and Hamaguchi, 2012).

Instead, firms with lean inventory management are more likely to possess flexibility and agility in other parts of the supply chain (see Pettit *et al.*, 2013), thus it is possible they made better use of this elsewhere to cope with such an event. One example is they could have alternate facilities which they put to better use than those firms reliant on excess inventory for flexibility (see Fujita and Hamaguchi).

However, the fact the results are reversed when looking at the Thai flood where the interactive term is negative and significant for PC makers suggests they learnt to make better use of those buffer stocks eventually, but only after JET's consequences. This again fits with the above explanation of 'learning from experience' after *JET* leading into the Thai Flood, as borne out by the Fujitsu case. Thus, there is partial support for *H3*, which is suggestive that inventory management works only if it is properly channelled as part of a holistic approach, such as a Business Continuity Plan which takes on board all flexible factors and not just one.

When it comes to hypothesis *H4*, the results are shown in columns (2)-(5) of Table 3. This examines the moderating role of inputs from suppliers (i.e. sourcing in agility and flexibility), with the question being whether suppliers maintaining excess inventory had a mitigating influence post-disaster. There are four reported regressions with the first capturing how suppliers' overall weighted average inventory turnover relates to end assemblers' sales performance. The next three specifications show average inventory turnover of suppliers' individual components.

The results could mean two things. First, looking at regression (1) in table 3 reveals one explanation for the *net* negative effect of the *JET* highlighted before. Here the suppliers' inventory turnover, while normally positively related to end assemblers' performance, clearly has a negative impact on the PC makers' own sales post-JET. Though this does not rule out a mediating influence, the moderating effect of suppliers' lack of flexibility and agility could be at work. However, in the case of *TF* the positively signed interactive terms, balanced against the negatively signed *TF*, again bears the same story of learning and readiness due to experience. As such suppliers were more prepared post-JET than they were pre-JET, similar to end assemblers. Thus, *H4* finds partial support.

Secondly, looking at the individual components, as reported in specifications (3)-(5), it can be seen that PC makers were mostly affected by what happened to the disk drive manufacturers, and to a lesser extent the Motherboard and Chip-CPU manufacturers, that too with a degree of variability in effects. Overall, this can be seen to fit with descriptive evidence that highlights how disruption in obtaining electronic components, such as semiconductors and hard disk drives, affected the PC industry (Haraguchi and Lall, 2015; Manners-Bell, 2014, pp. 86-89).

** TABLE 3 HERE **

** TABLE 4 HERE **

Results of the mediating role of suppliers' performance (H5). The results of the mediating influence of supplies disruption working through suppliers are shown in Table 4. While suppliers can be seen to have moderating influence as Table 3 shows, it is also possible the two NDs could have affected suppliers and, in turn, end assemblers' performance. Therefore, disaster → suppliers' sales → end assemblers' corporate performance. The first two columns show the mediating results, while the third column shows the moderating influence for comparative purposes.

It is clear that there is moderation as the *suppliers' sales ratio* becomes insignificant, while *suppliers' sales ratio residuals* is significant. This is further confirmed by results in regression 3. As such, disruption in getting parts from suppliers' does not seem to have impinged on PC makers, finding no support for *H5*.

6. Discussion and Implications

Natural disasters, as catastrophic vulnerabilities, are hard to predict, but their impact is profound on both society and business alike, as the two disasters discussed show. Given this characteristic, it is clear catastrophic vulnerabilities are quite distinct from other types of supply chain disruptions and risks. Thus, catastrophic vulnerability could be modelled distinctly as *ambiguity* instead of risk. Risk can be broadly defined as situations or events whose consequences or likely occurrence are possible, but subject to uncertainties (Aven, 2014, p. 31), and specifically defined as events or situations that can happen with assigned probabilities (Manners-Bell, 2014). Instead, ambiguity can be defined as situations or events whose outcomes and likely occurrence are unclear and cannot be assigned probabilities with precision (Aven, 2014, pp. 162-163; March, 1994, p. 178).

Ambiguous changes and events can have a profound impact on managerial decisions and corporate performance. The real world is replete with ambiguous events such as natural disasters, industrial actions, product defects and recalls, that tend to affect enterprises and their supply chain. A key characteristic of such events is their improbable nature with potential to be impactful, i.e., unpredictability with high impact. Yet the supply chain literature shows a surprising neglect of such events or change, with instead a focus on risk (Chopra and Sodhi, 2004; Simchi-Levi *et al.*, 2014). Add to this is that some enterprises are often unprepared for these events and instead focus on those for which they can prepare using traditional supply chain risk methods (Simchi-Levi *et al.*, 2014). The problem of ignoring, and then of using the wrong methods for such unanticipated events, can be costly (Chopra and Sodhi, 2014). The two major NDs were proof of this and so the consequences for ignoring ambiguous events and changes can be catastrophic.

With our findings that there are short and long term effects from catastrophic vulnerability, the fact that enterprises could learn from previous disruptions and that agility (i.e. speed and flexibility) could partially mitigate disruptive events, it is essential for a resilient enterprise to recognise the role of *dynamic capabilities* in building *supply chain resilience*. Supply chain resilience is seen as the capability of an enterprise to recover, adapt, and prosper in the face of vulnerability (Dabhilkar *et al.*, 2016; Pettit *et al.*, 2013), while dynamic capabilities enable an enterprise to build, integrate, and reconfigure resources to address rapidly changing business environments (Teece and Leih, 2016).

Though for normal disruptions ordinary capabilities would suffice, catastrophic vulnerability requires dynamic capabilities. This is because ordinary capabilities are just attributes to anticipate and overcome disruptions broadly defined (Fiksel, 2015, p. 96). With the difficulty to *anticipate* catastrophic vulnerability and its *distinctive* disruptive effect, we need to espouse dynamic capabilities to improve organisational resilience.

A key component of dynamic capabilities to improve resilience is organisational learning. Enterprises should be proactive to learn from the experience of previous disruptions (Dabhilkar *et al.*, 2016). Once such learning takes place it should be integrated as a capability which, in turn, acts as a dynamic mitigating strategy against similar disruptions in the future. However, enterprises must rely even more on learning and adaptation to cope with unexpected catastrophic disruptions (Fiksel, 2015, p.36).

The second component of dynamic capabilities is for enterprises to strive for agility, which in the view of catastrophic vulnerability would take a distinct form. Consider agility in both delivery and sourcing. Enterprises could adopt a hybrid inventory management policy instead of blindly following lean management in supply chains, as the latter could have negative consequences in the event of a catastrophic vulnerability. A hybrid inventory management policy would combine both leanness and agility, such as when required enterprises could respond with speed and flexibility. In fact, at times enterprises could even vary their inventory from minimum to maximum, depending on needs. Hence, enterprises should be nimble enough to change, adapt, and reconfigure their sourcing and delivery policies when needed.

The third component of dynamic capabilities for improving enterprises' resilience is recognising the dynamic effect of catastrophic vulnerability. There are both short-term and long-term effects. Therefore, a contingency plan which not only deals with short-term disruption, but also with long-term consequences, in adjusting operations is essential, in order to return to the pre-disruption equilibrium state or to move to a new equilibrium state in as short a span possible.

In a nutshell, whereas risk management deals with identifiable risks, we need to go beyond that and develop a strategic plan around ambiguities like catastrophic vulnerabilities. Under such a plan mitigating strategies should be constructed around dynamic capabilities so that the enterprise sustains resilience. This should ensure crucial business functions continue operating through unanticipated change.

7. Conclusion

With still little being known about the impact of natural disasters on corporate performance and underlying supply chain mechanisms that moderates or mediates their impact, this paper sets out to conceptualise ND as catastrophic vulnerability and empirically study it in the context of two events. Using the *JET* and *TF* as a quasi-experiment, in the spirit of a before-and-after design, this study first quantifies the effects of these NDs and decomposes them into short- and long-term effects. It also reports evidence of how PC supply chain works and reacts to these NDs using quarterly secondary data from 2010Q1-2013Q4.

Overall, *JET* is found to have a negative effect on corporate performance, but the Thai Flood is insignificant but positive. There is also evidence showing a prolonged effect of *JET*, suggesting NDs do not just have short-term effects. The Thai Flood after effect being insignificant and positive can be explained by the fact that firms learnt from JET and thus were ‘prepared’ in some ways for any subsequent NDs, as supported by anecdotal evidence. Supply chain flexibility and agility in terms of inventory management policy that keeps safety stocks (i.e. lower inventory turn) helped to mitigate the Thai Flood only. In the case of JET, the supply chain risk management was not adequate enough to deal with such catastrophic vulnerability. Both of these were interpreted as learning from experience and adaptability. Suppliers were also found to exert a moderating influence instead of mediating.

Two main implications are drawn. The first is the need for a conceptual rethink beyond risk. NDs and similar catastrophic vulnerabilities should be viewed from the lens of ambiguity. With ambiguous events and changes there is a need for dynamic capabilities to build supply chain resilience. This recognises short-term and long-term effects, organisation learning, and agile policies under catastrophic vulnerability.

Appendix

** TABLE A.1 HERE **

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