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Stock market reaction to supply chain disruptions from the 2011 Great East Japan Earthquake

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ABSTRACT

Problem definition: This paper provides empirical evidence on the effect of the 2011 Great East Japan Earthquake (GEJE) on the financial performance of firms.

***Academic/Practical Relevance*:** The GEJE was characterized as the most significant disruption ever for global supply chains. In its aftermath, there was a great deal of debate about the risks and vulnerabilities of global supply chains and there were calls to redesign and restructure supply chains.

***Methodology*:** We empirically estimate the effect of the GEJE on the stock prices of firms. Our analyses are based on a global sample of 470 firms collected from articles and announcements in the business press that identify affected firms, as well as 382 firms that are not mentioned in the business press but are in industries potentially subject to contagion or competitive effects.

Results: We estimate that firms experiencing supply chain disruptions due to the GEJE lost on average 5.21% of their shareholder value during the one-month period after the GEJE. For Japanese firms, the effect was much more severe with an average 9.32% loss in shareholder value. Non-Japanese firms averaged a 3.73% loss in shareholder value. We also find that upstream and downstream supply chain propagation effects from the GEJE are negative, and the contagion effect on firms related to the nuclear industry is very negative. For firms in the rebuilding industries or competitors to firms affected by the GEJE, the competitive effect from the GEJE is positive.

Managerial Implications: The loss suffered by both Japanese firms and non-Japanese firms experiencing supply chain disruptions due to the GEJE is economically significant. Although the loss is more severe for firms whose operations were directly affected by the GEJE, it is also significant for firms who experienced indirect effects from their upstream and downstream supply chain partners, further confirming the importance of supply chain risk mitigation strategies.

Keywords: *risk management; supply chain management; empirical research; global operations management*

1. Introduction

The March 11, 2011 Great East Japan Earthquake (hereafter referred to as the GEJE) that hit the Pacific coast of Japan is considered as one of the most severe earthquakes on record. The earthquake, tsunami, aftershocks, and the subsequent meltdown at the Fukushima nuclear plant brought devastating human, social, and economic damages. It also severely disrupted global supply chains. The business press characterized the GEJE as “the most significant supply chain disruption ever” (Tibken 2011) and a “black swan” catastrophic event for global supply chains. Six Japanese prefectures were primarily impacted, home to over 6,000 factories (Todo et al. 2015). Both domestic and global supply chains in automotive, electronics, and semiconductor industries were especially disrupted (Park et al. 2013).

This paper provides empirical evidence on the effect of the GEJE on the financial performance of firms. The financial performance is measured by changes in stock prices (or shareholder value). The analyses are based on a primary sample of 470 publicly traded firms collected from articles and announcements in the business press that identify firms affected by the GEJE. The sample is global and consists of firms from 24 different countries, with 48% of the firms headquartered in the US, 19% in Japan, and 13% in Europe. The sample includes firms from both manufacturing and service industries. In addition, we create a sample of 382 firms that are not mentioned in the business press but are in industries potentially subject to contagion effects (negative spillover) and competitive effects (positive spillover) from the GEJE. We use evidence from the financial effects of the GEJE to develop insights and implications into various issues including: the direct effects; upstream and downstream effects of supply chain disruptions; and the contagion and competitive effects in varied industries.

In the immediate aftermath of the GEJE, there was a great deal of debate about the risks and vulnerabilities of global supply chains. Articles in the business press questioned whether supply chains were more susceptible to disruptions because of popular strategies such as: concentration of plants, suppliers, and inventories in a single region; limited redundancies and lack of slack in supply chains; single sourcing; etc. Some articles also questioned the risks implicit in the popular just-in-time system approach to managing supply chains. For example, *The New York Times* reported that “Japan's vaunted just in time approach to business has become wait and see” (Jolly 2011). This was perhaps driven by the perception that negative financial impacts from supply chain disruptions due to the GEJE were very severe. However, much of the evidence on the financial impact is anecdotal and qualitative. By estimating the shareholder value effects of GEJE, we provide objective evidence on the financial impact of a significant and catastrophic natural disaster.

A subset of our sample consists of firms whose operations in Japan were not directly affected by the GEJE but instead indirectly affected due to disruptions at either their suppliers or customers. We estimate the financial impact on these firms to provide evidence on the degree to which disruption effects propagate through supply chains. Since firms are dependent on their supply chain partners through exchange of material and information, their financial performance will depend on the performance of their supply chain partners. There is considerable interest in the literature to study the magnitude and persistence of financial performance dependencies in supply chains. Cohen and Frazzini (2008) and Menzly and Ozbas (2010) use firm level and industry level supplier-customer relationships and find that economically significant relationships can help predict each of the related firms' stock returns. Lanier et al. (2010) document accounting-based performance linkages in three-firm supply chains. By estimating the stock price effects of the GEJE across the supply chain, we add to this literature and provide evidence on the financial dependency of supply chain partners from a major supply chain shock.

We also provide evidence on the contagion and competitive effects of the GEJE. The idea behind a contagion effect is that negative events affecting a firm or set of firms in an industry can make investors, customers, and suppliers wary of other firms in the same and/or related industries, which can have a negative effect on those firms. In the case of the GEJE, several global industries were impacted including motor vehicle manufacturing, electronics manufacturing, nuclear, and insurance. Although a subset of our sample firms were not affected by the GEJE either directly on their own operations or indirectly via suppliers or customers, they were involved with these industries. We use these samples to study the contagion effects of the GEJE. The alternative to a contagion effect is a competitive effect where negative events such as a natural disaster can create business opportunities for certain firms and industries. A subset of our sample firms were in rebuilding industries or were competitors to firms affected by the GEJE. We use these samples to shed light on the competitive effects of the GEJE.

We also compare and contrast our results with Hendricks and Singhal (2003, 2005, 2014) who measure the financial performance impacts from endogenous, firm-specific supply chain disruptions from parts shortages, order changes, production problems, ramp-up issues, etc. They do not study supply chain disruptions that result from natural disasters. In contrast, the GEJE is an exogenous, systemic shock that disrupted global supply chains and affected many firms at the same time.

Much of the literature that examines the impact of natural disasters on firm performance, including shareholder value, focuses on the localized effects experienced by firms or industries that are directly involved in or impacted by the disaster. Examples include the effects of the 1989 San Francisco earthquake on real estate firms (Shelor et al. 1990), and the impact of the 1992 hurricane Andrew on insurance firms (Lamb 1995). There are also a few studies that consider the impact from the GEJE itself. For example, Todo et al. (2015) use both survey and secondary data to study the impact on sales growth and recovery time for firms physically located in the impacted prefectures of Japan (also see Carvalho et al. 2014). More recently, researchers consider indirect effects from natural disasters as well. For example, Barrot and Sauvagnat (2016) study the impacts to sales growth and shareholder value of firms with suppliers headquartered in US counties hit by natural disasters.

Our paper adds to the extant literature in a number of ways. First, our sample comprises firms headquartered in a number of nations whose shares are traded on a variety of national markets, enabling us to consider impacts to complex and global supply chains. Second, we examine not only firms whose operations in Japan were directly affected; we also consider firms not necessarily located in the areas directly affected by the GEJE but whose upstream or downstream supply chain partners were impacted. Third, we consider negative and positive spillover effects that such major disasters have for firms in certain industries. Last, we estimate the impacts to shareholder value, a more encompassing measure than either revenue- or cost-based performance metrics.

Firms experiencing supply chain disruptions due to the GEJE lost on average 5.21% of their shareholder value during the one-month period after the GEJE. For the Japanese firms in our supply chain disruption subsample, the effect was much more severe with an average 9.32% loss, whereas the non-Japanese firms averaged a 3.73% loss. This percent loss is statistically and economically significant for both the Japanese and non-Japanese firms. For the non-Japanese firms, whose operations are generally not in the region directly affected by the GEJE, the magnitude is less than that for the Japanese subsample.

We find that upstream and downstream supply chain propagation effects from the GEJE are significantly negative for shareholder value. The average downstream effect from suppliers to customers is –3.06% over the one-month period after the GEJE, and the average upstream effect from customers to suppliers is –4.97% over the same period. The contagion effect of the GEJE on firms related to the nuclear industry is very negative and sustained; the average effect is –12.59% over the one-month period after the GEJE. We find that the motor vehicle manufacturing industry experiences a significant contagion effect but the electronics manufacturing industry does not. Insurance companies with exposure to the GEJE lost 2.09% of their shareholder value over the one-month period after the GEJE. For firms in the rebuilding industries or competitors to firms affected by the GEJE, the competitive effect of the GEJE is positive over the one-month period after the GEJE.

The remainder of the manuscript is structured as follows. Section 2 describes our sample collection procedure and the sample. Section 3 explains the methodology. Section 4 discusses our results and implications. The final section summarizes the paper.

2. Sample Selection and Description

2.1 General description of the sample

We build our primary sample from announcements and articles in business publications and newswires. We search the *Financial Times*, the Asian, European, and US editions of the *Wall Street Journal*, and the *Dow Jones News Service*. The search covers the period from March 11, 2011 through September 30, 2011 and identifies articles with at least one of the following keywords: quake, earthquake, tsunami, disaster, seismic, nuclear meltdown, or nuclear reactor. We read these articles to identify firms that were affected by the GEJE. We restrict our sample to those firms that are publicly traded and whose stock price and financial information are available in the databases of the Center for Research in Security prices (CRSP), North American Compustat, and/or Global Compustat.

The sample consists of 470 publicly traded firms headquartered in 24 different countries (see Panel A of Table 1). About 48% of the sample firms are headquartered in the US, 19% in Japan, 5% in the United Kingdom, and 4% in Germany. Australia, Canada, China, France, South Korea, and Taiwan each account for 2% to 3% of the sample firms.

To get an idea of the industry distribution of our sample, we segment our sample into eight industry groups using the grouping from Hendricks and Singhal (2003) (see Panel B of Table 1). Over 60% of the sample are firms whose primary SIC code is manufacturing (SIC codes 0001-3999) and nearly 40% are firms whose primary SIC code is services (4000-9999). Amongst the manufacturing firms, about 17% of the sample is from rubber, leather, stone, metals, machinery, and equipment; 15% from computers, electronics, communications, and defense; and 12% from food, textile, furniture, paper and chemicals. On the service side, services and financial services account for 90 firms (19% of the sample), half of which are insurance firms. Logistics and supply account for 67 firms (14% of the sample), one-third of which are airlines. The industry distribution suggests that the effect of the GEJE was broad and across most industry sectors.

Panel C of Table 1 reports sample firm statistics based on the most recent fiscal year completed preceding March 2011. The median observation in the sample represents a firm with $8.52 billion in market value of equity, $12.40 billion in total assets, and $9.34 billion in sales.

2.2 Detailed description of the sample

To analyze the effects of the GEJE in more detail, we break our sample into various subsamples (see Table 2). We read each article to determine the primary impact of the GEJE on the firm. There are a small number of sample firms that were impacted in multiple ways. In these few cases, we ascertain which source was more prominently highlighted in the press articles.

Negative impacts from the GEJE include damage and destruction of physical assets, production and service stoppages, supply shortages, decreased demand from business customers or consumers, insurance losses, and negative spillover effects. In considering supply chain disruptions, we take a holistic view of supply chains that includes internal operations as well as those of supply chain partners such as suppliers and customers (e.g., Hendricks and Singhal 2003). Thus, supply chain disruptions in our sample include firms whose operations in Japan were directly affected by the GEJE and also those firms indirectly impacted because of disruptions at their suppliers or customers. Based on the announcements from the business press, the GEJE had a potentially negative effect on 377 firms in our sample (80% of the sample). Negative events such as a natural disaster can also create positive business opportunities for certain firms and industries. Positive effects include increased demand for reconstruction and rebuilding services and materials, and for alternative products to replace or supplement goods that are in short supply. Based on the announcements from the business press, the GEJE had a potentially positive effect on 93 firms (20% of the sample). We split the 377 negatively affected firms into six subsamples, and the 93 positively affected firms into two subsamples. We discuss the details of these subsamples next.

Firm (97 firms) – firms whose operations were directly affected by the GEJE, resulting in production or service stoppages. An example is the announcement by Renasas Electronics Corporation that seven of its facilities were shut down, with five suffering structural damage from the earthquake.

Downstream (72 firms) – firms whose operations were not directly affected by the GEJE but instead indirectly affected by downstream propagation from some of their suppliers affected by the GEJE. An example is the announcement by Honeywell International Inc. that faced supply chain disruptions as Japanese providers of electronic components attempted to recover from the GEJE.

Upstream (113 firms) – firms whose operations were not directly affected by the GEJE but instead indirectly affected by upstream propagation from some of their business customers or end consumers affected by the GEJE. An example is the announcement by Johnson Matthey PLC, the world's largest supplier of catalytic converters and headquartered in the United Kingdom, which indicated that it expected lower sales as the GEJE was likely to limit production at its automaker business customers. This subsample includes firms from the retail sector. There were a number of announcements that indicated the GEJE would curb buying from Japanese consumers for all non-essential products, especially luxury goods. This subsample also includes airlines as many airlines curtailed their operations for a number of reasons including reduced demand for air travel; disruptions in airport operations; and protecting airline crews from radiation and aftershocks.

Multiple Impacts (2 firms) – firms not directly affected by the GEJE but instead indirectly affected by both upstream and downstream propagation from some of their customers and suppliers.

We use the subsamples of *Firm*, *Downstream*, *Upstream*, and *Multiple Impacts* to provide insights into the magnitude of the supply chain disruption effects from the GEJE.

Insurance (45 firms) – primary insurers, reinsurance firms, and firms that underwrite life insurance. The GEJE obviously had a negative impact on the insurance industry as insurers had to pay for claims related to property damage, loss of life, and business interruption and discontinuity.

Nuclear (48 firms) – firms involved in activities such as mining uranium; designing, engineering and constructing nuclear projects; manufacturing equipment for nuclear plants; and operating nuclear power generation plants. The Fukushima nuclear plant meltdown raised significant concerns about the prospects and future of firms involved with the nuclear power generation industry. We use this subsample to provide insights into the magnitude of the contagion effects from the GEJE.

The final two subsamples consist of the 93 firms that were potentially positively affected by the GEJE. These subsamples include:

Rebuild (46 firms) – firms whose products and services would be required to rebuild homes, factories, offices, and infrastructure that were damaged or destroyed by the GEJE. This subsample includes a diverse set of industries such as cement, construction, lumber, mining, and steel.

Competitors (47 firms) – firms that benefited because their competitors were negatively affected from the GEJE. This includes firms involved in alternate sources of energy generation including renewable sources of energy such as wind, solar, and hydro, as well as fossil fuel based sources of energy. Such firms benefited from the rising concern and backlash against nuclear power that emerged after the meltdown at the Fukushima nuclear plant. Another example is an announcement by Thai Union Frozen Products PCL, the world's biggest canned-tuna producer, that it expected increased sales to Japan following damage to the Japanese seafood processing industry.

We use the subsamples of *Rebuild* and *Competitors* to provide insights into the magnitude of the competitive effects from the GEJE.

We categorize firms as Japanese if their corporate headquarters is located in Japan, and they have major stock issues traded on a Japanese stock market. Table 2 also provides a breakdown of the number of Japanese and non-Japanese firms in each subsample. Most of the Japanese firms are in the *Firm* subsample, which is expected as this subsample is firms with operations that were directly affected by the GEJE via production or service stoppages. 63 of the 88 Japanese firms are in the *Firm* subsample, and Japanese firms make up 65% of the *Firm* subsample. Note that the other seven subsamples are dominated by non-Japanese firms.

Since our sample is based on articles appearing in the business press, one can argue that our sample is more representative of larger multinational firms. However, in our research context that considers the impact of the GEJE on global supply chains, larger multinational firms are the ones we are most interested in. As mentioned earlier, compared to other natural disasters, the GEJE has received much more attention from the press, practitioners, and academicians because it disrupted global supply chains and had global impact. Given this, it is not surprising that the English-language business press would have more articles about larger multinational firms based in the US and Europe. However, we note that in 2010, only three of the 100 largest global firms were Japanese headquartered (DeCarlo 2010). Given that our sample has 19% Japanese firms, large Japanese firms appear to be well-represented. Nonetheless, we note that our sample is representative of the impact of the GEJE on large multinational firms, and not necessarily on small and Japan-only firms.

To address potential bias in our results from selecting our sample based on articles in the business press, as well as to estimate potential contagion and competitive effects, we create five additional subsamples of firms that did not appear in the articles that we reviewed. These subsamples include a total of 382 firms in the following industries: motor vehicle manufacturing (88 firms): electronics manufacturing (88 firms); nuclear (44 firms); insurance (83 firms); and renewable energy (79 firms).

3. Methodology

We use event study methodology to estimate the shareholder value effects of the GEJE. This methodology is used to estimate abnormal returns associated with specific events after controlling for market-wide factors that influence stock prices (Brown and Warner 1985). Abnormal returns reflect the stock price changes associated with an event; an abnormal return is:

Return with the event happening – Return if the event had not happened

The return with the event happening is the actual return and is observable and measureable. The return if the event had not happened is not observable and has to be estimated. The abnormal return is the portion of the actual return that can be attributed to the event. So by estimating abnormal returns we are trying to estimate the difference between the returns in the world where the GEJE happened and the world where it did not. Event study methodology is based on the Efficient Market Hypothesis (EMH) that the shareholder value effects of an event are quickly reflected in the stock price.

There are two important issues in designing an event study methodology to estimate abnormal returns. The first is choosing the event period over which abnormal returns are estimated. The second is the method used to estimate the abnormal returns and the statistical tests used to judge their significance. We discuss these two issues next.

3.1 Choosing the event period

The GEJE struck the east coast of Japan on March 11, 2011at 2:46 PM local time. Since most of the Asia-Pacific stock markets were open at that time, March 11, 2011 is the first trading day that these markets could react to the GEJE event. Although European, North American and many other stock markets were closed when the GEJE struck Japan, they could react to the GEJE when these markets opened later on March 11, 2011. Thus, March 11, 2011 is the first trading day when markets worldwide could react to the GEJE event. Following event study conventions, we convert calendar time into event time such that the day of the event (March 11, 2011) is Day 0, Day 1 is the trading day following the event, Day –1 is the trading day before the event, etc.

It is quite common in event studies to estimate abnormal returns on the day of the event and the day before or after, and attribute this to the event under study (e.g., Hendricks and Singhal 2003, Thirumalai and Sinha 2011). The one- or two-day event period is typically preferred because, according to the EMH, information is quickly incorporated into stock prices. However, in our case, information about the severity of the GEJE gradually unfolded over a number of days. For example, in the immediate aftermath of the GEJE, many firms indicated that they were affected by the GEJE, but were uncertain about the nature and severity of the disruptions. Subsequent announcements by these firms provided more details about the nature and severity of the effects. Thus, to capture the abnormal returns associated with the GEJE, we must consider a longer event period.

The literature does not provide much guidance on the appropriate length of the event period for events such as the GEJE. Jacobs and Singhal (2017) use an 11-day event period to study the stock market reaction to the collapse of the Rana Plaza building in Bangladesh, one of the worst industrial accidents in history. Tielmann and Schiereck (2017) and Ramiah et al. (2017) both examine the stock market reaction to Brexit, using a 15-day event period and an 11-day event, respectively. Carter and Simkins (2004) use a 6-day event period to examine the stock market reaction to airlines from the September 11, 2001 terrorist attack in the US. Given the significance of the GEJE, and the ongoing information release about the GEJE, we estimate the abnormal returns on the day of the GEJE as well as the subsequent 20 trading days. Thus, we use a 21-

day event period (Day 0 to Day 20) as our main focus, but we also report results for alternate event periods. Since a calendar week comprises five trading days, our 21-day event period covers approximately one month in calendar time. A number of factors influence our choice of using a 21-day event period.

First, analysis of the business press indicates that press coverage mentioning our sample firms peaks in the first month after the GEJE, and then declines substantially. For example, the first month after the GEJE accounts for nearly 78% of the articles about our sample firms from our search from March 11, 2011 through September 30, 2011. The second and third months account for 13% and 4% of the articles, respectively. Nearly all sample firms are first mentioned in the press within 20 trading days after Day 0.

Second, we examine the overall stock market volatility before and after the GEJE for the three most represented countries in our sample (US, Japan, and United Kingdom). Increases in stock market volatility could indicate that new information is being released in the market and/or there is uncertainty about the financial implications of an event. Figure 1 plots the daily stock returns from 20 trading days before the GEJE (Day –20) through 60 trading days after the GEJE (Day 60). As seen in Figure 1, there is not much change in the volatility of the US and United Kingdom stock markets before and after the GEJE. Our analyses indicate that post- and pre-GEJE stock market volatilities (measured by the standard deviation of daily stock returns) are not significantly different for the US or United Kingdom stock markets. On the other hand, the volatility in the Japanese market appears to increase for the first several days following the GEJE, and seems to return to the pre-GEJE levels after Day 20. The Japanese stock market volatility during the first 20 trading days after the GEJE (Day 0 to Day 20) is three times higher than the volatility during the 20 trading days before the GEJE (Day –20 to Day –1), statistically significant at the 1% level. Figure 1 and our statistical tests indicate that increases in stock market volatilities are observed generally in the first month (20 trading days) after the GEJE, and only in the Japanese stock market.

Finally, there is some evidence on the recovery of Japanese manufacturing firms from the GEJE. Todo et al. (2015) report the median recovery (defined as restart of production) was five days, and less than 30 days for 90% of the firms that they surveyed. Carvalho et al. (2014) report that although the industrial production in areas directly affected by GEJE fell to 67% in March 2011, it recovered to 91% in June 2011.

Given the pattern of press reporting of the GEJE, changes in stock market volatility, evidence on the recovery of Japanese manufacturing firms, and the fact that the stock market is forward looking, a 21-day event period (a month in calendar time) seems reasonable. Thus, our primary focus will be on interpreting the abnormal returns over the 21-day event period. For robustness, we will also report results over both shorter (3-day and 11-day) and longer (61-day) event periods. Note that the 61-day event period spans about three calendar months.

3.2 Estimating abnormal returns and statistical testing

Consistent with many event studies (e.g., Hendricks and Singhal 2003, Thirumalai and Sinha 2011), we use the market model to estimate abnormal returns. The market model assumes that the stock return and the market return are related over a given time period as:

$$R_{it} = \alpha_i + \beta_i R_{mt} + \varepsilon_{it.} \quad (1)$$

where R_{it} is the Day t return of stock i; R_{mt} is the Day t market return; α_i is the intercept of the relationship for stock i; β_i is the systematic risk (or beta) of stock i, which measures the sensitivity of stock i's return to the market return; and ε_{it} is the error term for stock i on Day t. The stock market movement accounts for a portion of stock i's return, and is represented by the term $\beta_i R_{mt}$ (the systematic component of stock i return). The portion of the return that is unexplained by market movements is ε_{it} (the idiosyncratic component of stock i return). Since our sample firm stocks are traded in a wide variety of markets, we generate R_{mt} for stock i by using the market index that is dominant in firm i's country. For example, the CRSP Value Weighted index is used for US firms, the Nikkei 225 index is used for Japanese firms, and the FTSE 100 index is used for UK firms.

We use ordinary least squares regression over an estimation period of 200 trading days to estimate $\hat{\alpha}_i$ and $\hat{\beta}_i$. We begin the estimation period 202 trading days prior to the GEJE on March 11, 2011, and end it three trading days prior. To estimate equation (1), firms must have a minimum of 40 stock returns during the 200-day estimation period. A_{it}, the abnormal return for firm i on Day t, is calculated as the difference between the actual and the expected return, where the expected return for firm i on Day t is estimated as $(\hat{\alpha}_i + \hat{\beta}_i R_{mt})$. Thus,

$$A_{it} = R_{it} - (\hat{\alpha}_i + \hat{\beta}_i R_{mt}) \quad (2)$$

The mean abnormal return for Day t is computed by:

$$A_t = \sum_{i=1}^{N} \frac{A_{it}}{N} \quad (3)$$

where N is the number of firms in the sample on Day t.

To calculate the abnormal return on Day *t* for stock *i* (see equation 2), we estimate $\hat{\beta}RR_{mmmm}$. Note that $\hat{\beta}RR_{mmmm}$ depends on the estimated beta of the stock and the market return on Day *t*. In the days after the earthquake, the Japanese stock market experienced extreme movements when compared to the movements before the earthquake and other stock markets (see Figure 1). Clearly, the Japanese market returns during the period of interest [Days (0, 20)] do not represent the Japanese market returns in the world where the GEJE did not happen. Thus, using the Japanese market returns from the period of interest underestimates the abnormal return that can be attributed to the GEJE. To correct for this, we assume that the Japanese market returns during the pre-event period represent what would have happened to the Japanese market returns in the world where the GEJE did not happen. To reflect this, we use the distribution of the Japanese returns during the pre-event period to simulate the Japanese market returns in the period of interest. For each of the 61 days in our event period (Day 0 to Day 60), we randomly draw with replacement one return from the 200 daily returns of the Nikkei 225 Index over Days −202 through −3. Each random draw corresponds to a single day return. We then use the market model with alphas and betas estimated from the pre-event period and these randomly drawn market returns to estimate the abnormal returns for each of the 88 Japanese firms in our sample. We repeat this process 1000 times to get 1000 abnormal returns for each event day for each Japanese firm in our sample. We average the abnormal returns from the 1000 trials for each Japanese firm, and use this average as our estimate of daily abnormal returns in reporting the results.

As a robustness check, we compare our estimates for the Japanese firms obtained from the market model using simulated Japanese market returns, with the actual returns as well as those obtained from the mean-adjusted model that does not require or use market returns. The results from the two methods are very similar to results from the market model using simulated Japanese market returns. We also test the robustness of our results using four different estimation periods (100-day, 150-day, 350-day, and 300-day); again, the results are substantively similar. See the online appendix for details of these comparisons.

We are estimating the abnormal returns for multiple firms with an event on the same calendar day. This can cause cross-sectional dependence in abnormal returns across the sample firms. If such cross-sectional dependence is not adjusted for, then the standard deviation can be underestimated, and the magnitude of the test statistics can be overestimated. To account for this, we use the test advocated by Brown and Warner

(1985) that adjusts for cross-sectional dependence. We compute the mean abnormal return $\bar{\bar{A}}$, for the 200-day estimation period as:

$$\bar{A} = \frac{\sum_{t=-202}^{t=-3} A_t}{200} \tag{4}$$

We then estimate the standard deviation from the mean daily abnormal returns for the 200-day estimation period as:

$$\hat{S}(\bar{A}_t) = \sqrt{\sum_{t=-202}^{t=-3} \left(\bar{A}_t - \bar{A}\right)^2 / 199} \tag{5}$$

We calculate the Day *t* test statistic TS_t as:

$$TS_t = \bar{A}_t / \hat{S}(\bar{A}_t) \tag{6}$$

To determine the statistical significance of the mean abnormal returns, we use *t*-tests. The cumulative abnormal return (CAR) for a given period (t_1, t_2), is:

$$CAR(t_1, t_2) = \sum_{t=t_1}^{t_2} A_t \tag{7}$$

Similar to the test statistic for a single day, TS_j for a *j*-day event period is derived as:

$$TS_j = \frac{\sum_{t=t_1}^{t_2} A_t}{\hat{S}(\bar{A}_t)\sqrt{j}} \tag{8}$$

Since some of our subsample sizes are somewhat small, mean results can be unduly influenced by outliers. Accordingly, we also report median and percent negative (positive) abnormal returns in our discussion. We test for the statistical significance of the median abnormal return using the Wilcoxon signed-rank test. We use the binomial sign test to determine if the percent negative (positive) abnormal returns are significantly different than the null of 50%. For all tests, we report two-tailed *p*-values.

Note that we are estimating abnormal returns and CARs at the firm level. Thus, the CARs that we report are the percent impact to shareholder value for the average firm in our sample, and they do not represent the total impact to all firms, industries, or portfolios.

4. Results

This section presents the results of the abnormal returns for the sample of firms affected by the GEJE. Panel A of Table 3 presents the results for the full sample. The results indicate that the GEJE had an immediate negative effect on the sample firms. The mean and median CARs for Days (0, 2) are –4.33% and –1.40%, respectively, both significant at the 1% level. Over 63% of the firms experience negative abnormal returns during this three-day period, significantly greater than 50% at the 1% level. The CAR for Days (0, 10) is similar to the CAR for Days (0, 2). The mean and median CARs for the 21-day period [Days (0, 20)] are –3.74% and –2.62%, respectively, both significant at the 1% level. Over 66% of the firms experience negative abnormal returns during this period, significantly greater than 50% at the 1% level. The mean (median) CAR for Days (0, 60) is –6.58% (–4.48%), significant at the 1% (1%) level. Nearly 65% of the sample firms experience negative abnormal returns over this period, significantly greater than 50% at the 1% level.

The full sample results of Table 3 Panel A includes firms that were either negatively or positively affected. We first analyze the abnormal returns for the subsample of negatively affected firms and then for the positively affected firms.

4.1 Abnormal returns for the subsample of negatively affected firms

Panel B of Table 3 presents the abnormal returns for the subsample of negatively affected firms. The GEJE had an immediate negative effect on the sample firms. The mean and median CARs for Days (0, 2) are –6.88% and –2.53%, respectively, both significant at the 1% level. The mean (median) CAR for Days (0, 20) is –5.77% (–4.63%), significantly less than zero at the 1% (1%) level. Almost 77% of the sample firms experience negative abnormal returns during this period, significantly greater than 50% at the 1% level. The CAR for Days (0, 60) is not substantively different from the CAR for Days (0, 20).

The subsample of negatively affected firms includes two subsamples that one would not consider as experiencing supply chain disruptions in the conventional sense. These subsamples are *Insurance* and *Nuclear*. The negative effect on insurers is expected as insurers must pay claims for business interruptions, damages, and loss of life. The negative impact for firms in the *Nuclear* subsample results from the contagion effect of the Fukushima nuclear plant meltdown, which raised significant concerns about the prospects and future of firms involved with the nuclear power generation industry. To evaluate the negative effects specifically due to supply chain disruptions from the GEJE, we estimate the performance effects of the subsample of negatively affected firms excluding the *Insurance* and *Nuclear* subsamples. Panel C of Table 3 presents these results.

The immediate market reaction for the firms that reported supply chain disruptions is negative. The mean and median CARs for Days (0, 2) are –6.49% and –1.55%, respectively, both significant at the 1%

level. The mean and median CARs for Days (0, 20) are –5.21% and –4.47%, respectively, both significant at the 1% level. Over 77% of the firms experience negative abnormal returns during this period, significantly greater than 50% at the 1% level. The CAR for Days (0, 60) is not substantively different from the CAR for Days (0, 20).

To further examine the effect of supply chain disruptions, we segment the supply chain disruptions subsample in Panel C into Japanese and non-Japanese firms. Panel D presents the results for the Japanese firms. Most of the Japanese firms experienced disruptions because their operations were directly affected by the GEJE via production or service stoppages. The mean and median CARs for Days (0, 20) are −9.32% and −7.34%, respectively, both significant at the 1% level. Over 93% of the Japanese firms experience negative returns, also significant at the 1% level.

Panel E presents the results for the non-Japanese firms. Most of the non-Japanese firms experienced disruptions because of disruptions at their suppliers or customers. The mean and median CARs for Days (0, 20) are −3.73% and −2.93%, respectively, both significant at the 1% level. Over 71% of non-Japanese firms experience negative returns, also significant at the 1% level. Although the percent loss in shareholder value due to supply chain disruptions are statistically and economically significant for both the Japanese and the non-Japanese firms, the magnitude of the abnormal returns for the Japanese firms is significantly greater than that for the non-Japanese firms. We also note that the effects of the GEJE persist through Day 60 for Japanese firms, but they appear to subside for non-Japanese firms after Day 20.

The supply chain disruption results in Table 3 are based on a sample of firms mentioned in the business press such as the *Financial Times*, the Asian, European, and US editions of the *Wall Street Journal*, and the *Dow Jones News Service.* As discussed earlier, one can argue that results based on firms mentioned in the business press may not be representative of the industry. To address this issue as well as to consider the potential contagion effect of the GEJE, we collect an additional sample of firms that are not mentioned in the business press sources that we searched. We focus our analyses on the two largest industry groups in our sample of firms that experienced supply chain disruptions due to the GEJE. These industries are motor vehicle manufacturing (SIC code 371) and electronics manufacturing (SIC code 367). See the online appendix for details of how we collect additional sample firms for these two industries.

For the motor vehicle manufacturing industry subsample from the business press, the mean (median) CAR for Days (0, 20) is −6.46% (−6.98%), and it is −7.22% (−7.27%) for the subsample not from the business press. Although the CARs for these two subsamples are significant at the 1% level, the differences in means and medians between the two subsamples are not statistically significant. The results suggest that in the motor vehicle manufacturing industry, either a contagion effect might exist, or some firms affected by the GEJE in this industry were not mentioned in the business press that we searched. Detailed results of this comparison are in the online appendix.

For the electronics manufacturing industry subsample from the business press, the mean and median CARs for Days (0, 20) are −3.74% and −5.19%, respectively, with the median significant at the 1% level. For the subsample not from the business press, the mean and median CARs for Days (0, 20) are 0.12% and −1.89%, respectively, both insignificantly different from zero. The differences in means and medians between the two subsamples are both statistically significant at the 5% level. The results suggest that either there is no contagion effect, or that most of the electronics manufacturing firms affected by the GEJE were likely covered in the business press that we searched. Detailed results of this comparison are in the online appendix.

4.2 Propagation effects of supply chain disruptions

To estimate the propagation effects of supply chain disruptions, we split the supply chain disruptions sample reported in Table 3 Panel C into the following three subsamples described in section 2.2 above – *Firm*, *Downstream*, and *Upstream*.

Panel A of Table 4 presents the results for the subsample of firms whose operations were directly affected by the GEJE. The immediate abnormal returns are quite negative. The mean and median CARs for Days (0, 2) are –14.67% and –15.16%, respectively, both significant at the 1% level. The mean (median) market reaction over the 21-day period from Day 0 through Day 20 is –7.19% (–5.49%), significant at the 1% (1%) level. Over 81% of the sample firms experience negative abnormal returns over this period, significantly greater than 50% at the 1% level. The mean and median CARs for Days (0, 60) are −9.43% and −7.44%, respectively, both significant at the 1% level.

Panel B of Table 4 gives the results of firms whose suppliers were affected by the GEJE. This measures the downstream effect from suppliers on business customers. The immediate abnormal returns, as measured by the CAR for Days (0, 2), are slightly negative but insignificant. This suggests that customer firms were perhaps not able to assess the disruptions to their suppliers in the immediate aftermath of the GEJE and, hence, the market did not have information on which customer firms were affected due to disruptions at their suppliers. However, the CAR over the 21-day period from Day 0 through Day 20 is negative and statistically significant. The mean (median) CAR for Days (0, 20) is –3.06% (–2.59%), significant at the 5% (1%) level. Over 73% of the firms experience negative abnormal returns, significantly greater than 50% at the 1% level.

To provide a perspective on the magnitude of the downstream propagation effects of the GEJE, we compare the results of Panel B of Table 4 with other studies that document downstream propagation effects. Barrot and Sauvagnat (2016) study the stock market reaction to customers of suppliers headquartered in US counties hit by natural disasters. They find that the mean CAR for customers over Days (–10, 40) is –1.13%. Hertzel et al. (2008) find that the mean stock market reaction to customers of firms filing for bankruptcy is –0.19%. Fee and Thomas (2004) report that horizontal mergers have a negative market reaction of –0.12% for customers of merged firms. In our case, mean downstream propagation effects of −3.06% from the GEJE are greater in magnitude than the downstream propagation effects documented by other researchers for natural disasters, bankruptcies, and horizontal mergers.

Panel C of Table 4 gives the results of firms whose customers were affected by the GEJE. This measures the upstream effect from customers and consumers on sample firms. The immediate abnormal returns are negative. The mean and median CARs for Days (0, 2) are –2.85% and –1.27%, respectively, both significant at the 1% level. The mean and median CARs for Days (0, 20) are –4.97% and –4.44%, respectively, with over 76% of the firms experiencing negative abnormal returns. The mean and median CARs for Days (0, 60) are marginally negative. This suggests that at least some customers may have recovered from the effect of the GEJE after Day 20.

To assess the magnitude of the upstream propagation effects of the GEJE, we compare the results of Table 4 Panel C relative to other studies that document upstream propagation effects. Hertzel et al. (2008) find that the mean stock market reaction to suppliers of firms filing for bankruptcy is –1.96%. Fee and Thomas (2004) report that horizontal mergers have a negative market reaction of –0.30% for suppliers of merged firms. Pandit et al. (2011) find that customer earnings announcements cause a mean stock market reaction for suppliers of 4.48% (–4.05%) if the earnings is good news (bad news). In our case, the mean upstream propagation effects of −4.97% from the GEJE are greater in magnitude than the upstream propagation effects found by other researchers for bankruptcy and horizontal mergers, and are similar in magnitude to the effects of customer earnings announcements.

We also test whether the market reaction for the three subsamples are significantly different from one another. For Days (0, 20), the mean and median CARs for the *Firm* subsample are significantly more negative than either the *Upstream* or *Downstream* subsamples, indicating that the direct effects of the GEJE were more severe than the indirect effects of disruption through supply chain propagation. Although the mean and median CARs for the *Upstream* subsample are more negative than those for the *Downstream* subsample, they are not significantly different from one another.

Given that our sample is generated from business press articles, it is possible that some direct effects to firms went unreported, and instead indirect effects from customers or suppliers were reported. If this occurred, the *Upstream* and *Downstream* subsamples might over-estimate the magnitude of supply chain propagation effects. If our subsample composition is affected in this manner, the relative difference between the direct effects and indirect effects of the GEJE might be even greater.

4.3 Comparison with Hendricks and Singhal (2003, 2005, 2014)

Although not a perfect comparison, it is useful to benchmark the results of the supply chain disruptions in our sample with the supply chain disruptions results in Hendricks and Singhal (2003, 2005, 2014), henceforth referred to as H&S. As mentioned earlier, H&S do not study supply chain disruptions that result from natural disasters. Instead, they focus on endogenous, firm-specific disruptions. Given the differences between our sample and H&S, comparisons must be made with caution, but they can provide some perspective on the magnitude of the GEJE impact relative to the impact of supply chain disruptions examined by H&S.

Hendricks and Singhal (2003) attribute supply chain disruptions to either internal operations, suppliers, and/or customers, which are analogous to our subsamples of *Firm*, *Downstream*, and *Upstream*, respectively. We update the disruption sample in Hendricks and Singhal (2014) to include announcements from 2004 to 2014. We note that for the H&S sample, the abnormal returns are measured beginning with Day –1, the day before the announcement, rather than Day 0 as in this paper. This is conventional practice in most event studies to account for the possibility that information about the event could have been publicly released the day before the publication. For an unpredictable event like the GEJE, there are no chances of anticipation or early release of information. Accordingly, we adjust the end-date in the H&S event periods to ensure we compare an equal number of days in each event period across the two studies.

Table 5 presents the differences in the 21-day CARs for the supply chain disruptions in our sample and the H&S sample. For comparison, we repeat our CAR results over Days (0, 20) from Panels C, D, and E of Table 3 as well as Panels A, B, and C of Table 4. These results are presented in columns 1 through 4. The H&S results are presented in columns 5 thorough 8. As seen in columns 9 and 10, the CARs for the supply chain disruptions subsample from the GEJE are significantly less negative than those in H&S. The CARs for supply chain disruptions from the GEJE for the Japanese firms are more negative than those in H&S, but the differences are statistically insignificant. For the non-Japanese firms, the CARs are significantly less negative than those in H&S.

For the direct effects of supply chain disruptions (represented by our *Firm* subsample and the Internal sample in H&S), the results are very similar between the two studies; the differences are statistically insignificant. However, in comparing the indirect effects of supply chain disruptions, the mean and median CARs for both the *Downstream* and *Upstream* firms in our sample are significantly less than those for the corresponding Suppliers and Customers samples in H&S.

4.4 Abnormal returns for the *Nuclear* and *Insurance* subsamples

Panel A of Table 6 presents the abnormal returns for the *Nuclear* subsample from the business press. In the case of the GEJE, the meltdown at the Fukushima nuclear plant raised significant concerns about the prospects and future of firms involved with the nuclear industry. Although firms in the *Nuclear* subsample were not directly affected by the GEJE, they were involved with the nuclear industry. We use this sample to shed light on the contagion effects of the GEJE on firms that are involved with the nuclear industry.

The effect of the GEJE on firms involved with the nuclear industry is immediate and significantly negative (Panel A of Table 6). The mean and median CARs for Days (0, 2) are –11.19% and –6.29%, respectively. The mean and median CARs for Days (0, 20) are –12.59% and –10.12%, respectively, both significant at the 1% level. 89% of the firms experience negative abnormal returns over this period, significantly greater than 50% at the 1% level. The mean and median CARs for Days (0, 60) are –21.60%

and –10.47%, respectively. The results indicate that the contagion effect on firms related to the nuclear industry is very negative and sustained.

To shed further light on the contagion effect in the nuclear industry, we compare the results from the *Nuclear* subsample in Panel A with the results from a sample of nuclear firms not based on the business press. See the online appendix for details on how we generate this comparison sample.

For the *Nuclear* subsample from the business press, the mean (median) CAR for Days (0, 20) is −12.59% (−10.12%) and it is −14.84% (−3.58%) for the subsample not from the business press. The CARs for these two subsamples are significant at the 1% level, but the differences in means and medians between the two subsamples are not statistically significant. The results indicate that the abnormal returns for the *Nuclea*r subsample based on the business press are representative of the nuclear industry, and they suggest a significant industry-wide contagion effect. Detailed results of this comparison are in the online appendix.

In the case of the GEJE, the contagion (negative) effects for firms involved with the nuclear industry are especially strong and persistent. This is not surprising as the nuclear industry is particularly susceptible to contagion, as observed in the Three Mile Island incident of 1979 (Bowen et al. 1983) and the Chernobyl incident of 1986 (Kalra et al. 1993). Bowen et al. (1983) find that the Three Mile Island incident resulted in a 21-day stock market reaction of –5.39% for US utilities with at least 20% of their capacity from nuclear energy. Kalra et al. (1993) find that the Chernobyl incident resulted in a 21-day stock market reaction of –2.30% for US utilities with at least 20% of their capacity from nuclear energy.

The contagion effect in our *Nuclear* subsample is particularly strong when compared to studies in other fields that have examined contagion. Lang and Stulz (1992) find that on average, bankruptcy announcements have a negative stock market reaction of 1% on a portfolio of competitors. Laux et al. (1998) find that dividend increases (decreases) have a stock market reaction of 0.05% (–0.32%) on a portfolio of rivals. Erwin and Miller (1998) report that announcements of open-market share repurchases have a negative stock market reaction of –0.25% on a portfolio of industry rivals.

Table 6 Panel B presents the results for the *Insurance* subsample from the business press. The immediate abnormal returns are negative. The mean and median CARs for Days (0, 2) are –4.79% and –4.11%. The mean (median) CAR for Days (0, 20) is –2.09% (–2.14%), with the median significant at the 5% level. Over 62% of the sample firms experience negative abnormal returns over this period, insignificantly greater than 50%. The mean (median) CAR for Days (0, 60) is –4.83% (–5.47%), significant at the 10% (1%) level. Over 64% of the sample firms experience negative abnormal returns over this period, significantly greater than 50% at the 10% level.

We compare our results with other studies on the impact of natural disasters on the insurance industry. Shelor et al. (1992) discuss two opposing hypotheses regarding the impact of natural disasters on insurers: loss claims can deplete insurer resources, leading to loss in shareholder value ("loss as loss"); or, disasters might lead to increased demand for policies as well as premium increases, leading to gain in shareholder value ("loss as gain"). They study the impact of the 1989 California earthquake on US insurers, and find a 2-day CAR of 1.72%, supporting the "loss as gain" hypothesis. Conversely, other researchers (e.g., Angbazo and Narayanan 1996, Lamb 1995, Ewing et al. 2006, Yamori and Kobayashi 2002) find that insurers suffer negative CARs from hurricanes and earthquakes, in the range of −2% to −5%. The average 21-day CAR of −2.09% that we find for insurers affected by the GEJE is in line with these latter findings, and lends support to the "loss as loss" hypothesis.

We also estimate the market reaction for a sample of insurance firms that are not mentioned in the business press. See the online appendix for details on how we generate this sample.

For the *Insurance* subsample from the business press, the mean and median CAR for Days (0, 20) is −2.09% and −2.14%, respectively, with the median significant at the 5% level. The mean and median CAR for Days (0, 20) for the subsample not from the business press is −0.34% and −0.54%, respectively, both insignificantly different from zero. The difference in the means between the two subsamples is statistically significant at the 10% level. The results suggest no evidence of a contagion effect and/or that most of the insurers affected by the GEJE were likely covered in the business press that we searched. Detailed results of this comparison are in the online appendix.

4.5 Competitive effects of the GEJE

Negative events such as a natural disaster can create business opportunities for some firms and industries. In describing the sample in Section 2, we discuss that firms in the *Rebuild* and *Competitors* subsamples are likely to experience competitive (positive) effects from the GEJE. Table 7 presents the abnormal returns for these subsamples.

Panel A of Table 7 presents the combined results for the *Rebuild* and *Competitors* subsamples. The immediate abnormal returns are positive. The mean and median CARs for Days (0, 20) are 4.79% and 3.86%, respectively, significant at the 1% level. Over 76% of the firms experience positive abnormal returns during this period, significantly greater than 50% at the 1% level. However, over the next 40 trading days, this positive reaction is reversed. The mean CAR for Days (0, 60) is −3.87% (insignificantly different from zero) and the median CAR is −2.65%, significant at the 5% level. Only about 40% of the firms experience a positive reaction over Days (0, 60), significantly less than 50% at the 10% level.

Panel B of Table 7 presents the results for the *Rebuild* subsample, and Panel C of Table 7 presents the results for the *Competitors* subsample. The pattern of results for both these subsamples is quite similar to that reported in Panel A.

The results for the competitive effects indicate that if the focus is on the market reaction over Days (0, 20), then the competitive effect is positive as predicted. However, if one extends the time period to 60 days after the GEJE, the market reaction is not persistent for either the *Rebuild* or *Competitors* subsamples. We conjecture that lack of persistence could be due to either quicker-than-anticipated recovery from the disaster, or initial over-exuberance by the stock market in estimating either the potential windfall from reconstruction or stumbles from competitors, or a combination of both.

Of the 47 firms in the *Competitors* subsample, 15 are in the renewable energy industries (wind, hydro, and solar). As mentioned earlier, these industries benefited from the backlash against the nuclear industry that emerged subsequent to the meltdown at the Fukushima nuclear plant. To analyze the competitive effect on renewable energy industries in more depth, we generate a subsample of firms in the renewable energy industries that are not from the business press and compare it with our subsample of firms from the business press. See the online appendix for details of our sample generation process.

For the renewable energy industry subsample from the business press, the mean (median) CAR for Days (0, 20) is 7.15% (6.58%), and it is 5.17% (2.63%) for the subsample not from the business press. The CARs for these two subsamples are significant at the 5% level, but the differences in means and medians between the two subsamples are not statistically significant. The results suggest that either a competitive effect might exist in the renewable energy industry, or that some firms affected by the GEJE in this industry were not mentioned in the business press that we searched. Detailed results of this comparison are in the online appendix.

5. Summary

This paper provides empirical evidence on the effect of the GEJE on the stock prices (or shareholder value) of firms. The analyses are based on a global sample of 470 publicly traded firms collected from articles and announcements in the business press that identify firms affected by the GEJE. Firms experiencing supply chain disruptions due to the GEJE lost on average 5.21% of their shareholder value during the one-month period after the GEJE. For the Japanese firms, the effect was much more severe with an average 9.32% loss in shareholder value. Non-Japanese firms averaged a 3.73% loss in shareholder value. For both Japanese and non-Japanese firms, this level of loss is statistically and economically significant.

The upstream and downstream supply chain propagation effects from the GEJE on shareholder value are negative. Over a one-month period after the GEJE, the average downstream effect from suppliers to customers is –3.06%, and the average upstream effect from customers to suppliers is –4.97%.

The contagion effect of the GEJE on firms in the motor vehicle manufacturing industry is significantly negative but not for the electronics manufacturing industry. For the nuclear industry, the contagion effect is very negative and sustained; the average effect is –12.59% over the one-month period after the GEJE for firms mentioned in the business press, and –14.84% for firms not mentioned in the business press. Insurance companies with exposure to the GEJE lose 2.09% of their shareholder value over the one-month period after the GEJE, but insurance firms not mentioned in the business press did not suffer significant losses, indicating no contagion effect. Thus, contagion effects seem to depend on specific industry characteristics. Determining the characteristics that make certain industries more susceptible to contagion effects could be fruitful future research.

For the competitive effect (positive spillover), both of the affected subsamples experience significantly positive abnormal returns over the first month after the GEJE but the positive effect dissipates over the next two months. This competitive effect is very similar between firms mentioned or not mentioned in the business press.

A limitation of our analyses is that we study only the GEJE. Although a major disrupter of global supply chains, the GEJE is still only a single event. Generalizing our results to other natural disasters or supply chain shocks must be done with caution. However, given the severity of the event in a highly industrialized region and its global impact on supply chains, it should serve as an upper bound for the effects of natural disasters. Future studies of similar events would aid in generalizability.

Our analyses provide some preliminary explanation of the heterogeneity in abnormal returns across affected firms by comparing and contrasting the results for the various subsamples, as well as those for the Japanese and non-Japanese firms. However, consideration of the effect of firm level characteristics (e.g., firm size, geographic and business diversification, operational slack) on abnormal returns would be interesting. Developing and testing appropriate hypotheses regarding the moderating effects of firm level characteristics on abnormal returns could extend our research.

Although our use of percent changes to shareholder value as a measure of firm performance is well-established, it would be interesting to employ other measures such as stock price volatility, sales growth, or profitability, as well as various non-financial measures of performance. It would also be interesting to study how such supply chain operations, structures, and strategies changed subsequent to the GEJE.

References

Angbazo, L.A., R. Narayanan. 1996. Catastrophic shocks in the property-liability insurance industry: Evidence on regulatory and contagion effects. *Journal of Risk and Insurance* 63(4), 619-637.

Barrot, J.N., J. Sauvagnat. 2016. Input specificity and the propagation of idiosyncratic shocks in production networks. *Quarterly Journal of Economics* 131(3), 1543-1592.

Bowen, R.M., R.P. Castanias, L.A. Daley. 1983. Intra-industry effects of the accident at Three Mile Island. *Journal of Financial and Quantitative Analysis* 18(1), 87-111.

Brown, S.J., J.B. Warner. 1985. Using daily stock returns: The case of event studies. *Journal of Financial Economics* 14(1), 3-31.

Carvalho, V.M., N. Makoto, S.Y. Umeno. 2014. *Supply Chain Disruptions: Evidence from the Great East Japan Earthquake*. Discussion paper 14-E-035, Research Institute of Economy, Trade, and Industry.

Carter, D.A, B.J. Simkins. 2004. The market's reaction to unexpected, catastrophic events: The case of airline stock returns and the September 11th attacks. *The Quarterly Review of Economics and Finance* 44(4), 539-558.

Cohen. L., A. Frazzini. 2008. Economic links and predictable returns. *The Journal of Finance* 63(4), 1977-2011.

DeCarlo, S. 2010. The world's leading companies. Forbes. Available at https://www.forbes.com/2010/04/21/, accessed 15 Jul 2017.

Erwin, G.R., J.M. Miller. 1998. The intra-industry effects of open market share repurchases: Contagion or competitive? *Journal of Financial Research* 21(4), 389-406.

Ewing, B.T., S.E. Hein, J.B. Kruse. 2006. Insurer stock price responses to Hurricane Floyd: An event study analysis using storm characteristics. *Weather and Forecasting* 21(3), 395-407.

Fee, C.E., S. Thomas. 2004. Sources of gains in horizontal mergers: Evidence from customer, supplier and rival firms. *Journal of Financial Economics* 74(3), 423-460.

Hendricks, K B., V.R. Singhal. 2003. The effect of supply chain glitches on shareholder wealth. *Journal of Operations Management* 21(5), 501-522.

Hendricks, K B., V.R. Singhal. 2005. An empirical analysis of the effect of supply chain disruptions on long-run stock performance and equity risk of the firm. *Production and Operations Management* 14(1), 35-52.

Hendricks, K B., V.R. Singhal. 2014. The effect of demand-supply mismatches on firm risk. *Production and Operations Management* 23(12), 2137-2151.

Hertzel, M., Z. Li, M.S. Officer, K. Rodgers. 2008. Inter-firm linkages and the wealth effects of financial distress along the supply chain. *Journal of Financial Economics* 87(2), 374-387.

Jacobs, B.W., V.R. Singhal. 2017. The Effect of the Rana Plaza disaster on shareholder wealth of retailers: Implications for sourcing strategies and supply chain governance. *Journal of Operations Management* 49-51, 52-66.

Jolly, D. 2011. Long pause for Japanese industry raises concerns about supply chain. *The New York Times*, 17 Mar 2011, 1.

Kalra, R., G.V. Henderson, Jr., A.R. Gary. 1993. Effects of the Chernobyl nuclear accident on utility share prices. *Quarterly Journal of Business and Economics* 32(2), 52-77.

Lamb, R.P. 1995. An exposure-based analysis of property-liability insurer stock values around Hurricane Andrew. *Journal of Risk and Insurance* 62(1), 111-123.

Lang, L.H.P., R.M. Stulz. 1992. Contagion and competitive intra-industry effects of bankruptcy announcements. *Journal of Financial Economics* 32(1), 45-60.

Lanier, D. Jr., W.F. Wempe, Z.G. Zacharia. 2010. Concentrated supply chain membership and financial performance: Chain- and firm-level perspectives. *Journal of Operations Management* 28(1), 1-16.

Laux, P., L.T. Starks, P.S. Yoon. 1998. The relative importance of competition and contagion in intra-industry information transfers: An investigation of dividend announcements. *Financial Management* 27(3), 5-16.

Menzly, L., O. Ozbas. 2010. Market segmentation and cross-predictability of returns. *The Journal of Finance* 65(4), 1555-1580.

Pandit, S., C.E. Wasley, T. Zach. 2011. Information externalities along the supply chain: The economic determinants of suppliers' stock price reaction to their customers' earnings announcements. *Contemporary Accounting Research* 28(4), 1304–1343.

Park, Y.W., P. Hong, J.J. Roh. 2013. Supply chain lessons from the catastrophic natural disaster in Japan. *Business Horizons* 56, 75-85.

Ramiah, V., H.N. Pham, I. Moosa. 2017. The sectoral effects of Brexit on the British economy: Early evidence from the reaction of the stock market. *Applied Economics* 49(26), 2508-2514.

Shelor, R.M., D.C. Anderson, M.L. Cross. 1990. The impact of the California earthquake on real estate firms' stock value. *Journal of Real Estate Research* 5(3), 335-340.

Shelor, R.M., D.C. Anderson, M.L. Cross. 1992. Gaining from loss: Property-liability insurer stock values in the aftermath of the 1989 California earthquake. *Journal of Risk and Insurance* 59(3), 476-488.

Tibken, S. 2011. Japan quake 'most significant' supply chain disruption ever. *Dow Jones Newswires*, 1 Apr 2011.

Tielmann, A., D. Schiereck. 2017. Arising borders and the value of logistic companies: Evidence from the Brexit referendum in Great Britain. *Finance Research Letters* 20, 22-28.

Thirumalai, S., K.K. Sinha. 2011. Product recalls in the medical device industry: An empirical exploration of the sources and financial consequences. *Management Science* 57(2), 376-392.

Todo, Y., K. Nakajima, P. Matous. 2015. How do supply chain networks affect the resilience of firms to natural disasters? Evidence from the great East Japan earthquake. *Journal of Regional Science* 55(2), 209-220.

Yamori, N., T. Kobayashi. 2002. Do Japanese insurers benefit from a catastrophic event?: Market reactions to the 1995 Hanshin–Awaji earthquake. *Journal of the Japanese and International Economies* 16(1), 92-108.

Table 1. Descriptive statistics for the sample of 470 publicly-traded firms affected by the March 2011 Great East Japan Earthquake (GEJE).

Panel A. Corporate headquarters countries among sample firms

Country	Occurrences (%)	Country	Occurrences (%)
United States	225 (47.9%)	Taiwan	12 (2.6%)
Japan	88 (18.7%)	South Korea	10 (2.1%)
United Kingdom	25 (5.3%)	Australia	10 (2.1%)
Germany	18 (3.8%)	Hong Kong	9 (1.9%)
Canada	14 (3.0%)	India	5 (1.1%)
France	14 (3.0%)	Switzerland	4 (0.8%)
China	13 (2.8%)	Other countries (11)	22 (4.7%)

Panel B. Industry distribution of sample firms

SICs	Industry Description	Occurrences (%)
0001-1999	Agriculture and natural resources	35 (7.5%)
2000-2999	Food, textiles, furniture, paper, chemicals	58 (12.3%)
3000-3569, 3580-3659, 3800-3999	Rubber, leather, stone, metals, machinery, equipment	79 (16.8%)
3570-3579, 3660-3699, 3760-3789	Computers, electronics, communications, defense	73 (15.5%)
3700-3759, 3790-3799	Automobile, aircraft, transportation	40 (8.5%)
4000-4999	Logistics and supply	67 (14.3%)
5000-5999	Wholesaling and retailing	28 (6.0%)
6000-9999	Services and financial services	90 (19.1%)

Panel C. Sample firm statistics at the end of the fiscal year preceding March 2011

	Market Value (million USD)	Total Assets (million USD)	Sales (million USD)	Net Income (million USD)	Employees (000s)
Mean	21,656	50,546	22,944	1,471	56.4
Median	8,521	12,397	9,339	403	20.0
Std Dev	38,138	144,803	46,940	3,333	127.3

Table 2. Subsample categories for the sample of 470 publicly-traded firms affected by the March 2011 Great East Japan Earthquake (GEJE).

Category	Description of sample firms	All firms		Japanese firms		Non-Japanese firms	
		Frequency	% of subsample	Frequency	% of subsample	Frequency	% of subsample
Potential negative effects:							
Supply chain disruptions							
Firm	Operations directly affected	97	34.2%	63	22.2%	34	12.0%
Downstream	Effects from suppliers	72	25.4%	4	1.4%	68	23.9%
Upstream	Effects from customers	113	39.8%	8	2.8%	105	37.0%
Multiple impacts	Effects from suppliers and customers	2	0.7%	0	0.0%	2	0.7%
	Supply chain disruptions subtotals	284	100.0%	75	26.4%	209	73.6%
Other negative effects							
Insurance	Insurance industry	45	48.4%	5	5.4%	40	43.0%
Nuclear	Nuclear industry	48	51.6%	3	3.2%	45	48.4%
	Other negative effects subtotals	93	100.0%	8	8.6%	85	91.4%
	Negative effect subtotals	377	100.0%	83	22.0%	294	78.0%
Potential positive effects:							
Rebuild	Involved with rebuilding/reconstruction	46	49.5%	5	5.4%	41	44.1%
Competitors	Direct competitors affected	47	50.5%	0	0.0%	47	50.5%
	Positive effects subtotals	93	100.0%	5	5.4%	88	94.6%
Total sample		470	100.0%	88	18.7%	382	81.3%

Table 3. Cumulative abnormal returns for the sample of firms affected by the Great East Japan Earthquake (GEJE). Event Day 0 is the date of the GEJE on March 11, 2011.

Panel A . Total sample (all subsamples)							
Event Day(s)	*N*	Mean	*t*	Median	*Z* [a]	% Negative	*Z* [b]
(0, 2)	469	-4.33%	(-16.39) ***	-1.40%	(-7.40) ***	63.75%	(5.96) ***
(0, 10)	468	-2.66%	(-5.25) ***	-2.08%	(-7.05) ***	63.25%	(5.73) ***
(0, 20)	467	-3.74%	(-5.35) ***	-2.62%	(-8.01) ***	66.60%	(7.17) ***
(0, 60)	467	-6.58%	(-5.53) ***	-4.48%	(-7.62) ***	64.88%	(6.43) ***
Panel B . Negatively affected subsamples (excludes *Rebuild*, *Substitute*, *Competitors* from Panel A)							
Event Day(s)	*N*	Mean	*t*	Median	*Z* [a]	% Negative	*Z* [b]
(0, 2)	377	-6.88%	(-24.13) ***	-2.53%	(-12.06) ***	75.60%	(9.94) ***
(0, 10)	377	-4.78%	(-8.75) ***	-3.54%	(-11.68) ***	75.60%	(9.94) ***
(0, 20)	377	-5.77%	(-7.65) ***	-4.63%	(-11.25) ***	76.92%	(10.46) ***
(0, 60)	376	-7.24%	(-5.63) ***	-4.59%	(-7.54) ***	66.22%	(6.29) ***
Panel C . Supply chain disruption subsample (excludes *Insurance* and *Nuclear* from Panel B)							
Event Day(s)	*N*	Mean	*t*	Median	*Z* [a]	% Negative	*Z* [b]
(0, 2)	284	-6.49%	(-18.73) ***	-1.55%	(-9.58) ***	72.54%	(7.60) ***
(0, 10)	284	-4.15%	(-6.26) ***	-3.25%	(-9.20) ***	72.54%	(7.60) ***
(0, 20)	284	-5.21%	(-5.68) ***	-4.47%	(-9.78) ***	77.11%	(9.14) ***
(0, 60)	284	-5.24%	(-3.36) ***	-4.00%	(-5.41) ***	63.73%	(4.63) ***
Panel D . Supply chain disruption subsample with Japanese firms only							
Event Day(s)	*N*	Mean	*t*	Median	*Z* [a]	% Negative	*Z* [b]
(0, 2)	75	-21.75%	(-42.88) ***	-20.34%	(-7.53) ***	100.00%	(8.66) ***
(0, 10)	75	-10.05%	(-10.34) ***	-8.57%	(-6.88) ***	90.67%	(7.04) ***
(0, 20)	75	-9.32%	(-6.95) ***	-7.34%	(-6.68) ***	93.33%	(7.51) ***
(0, 60)	75	-14.37%	(-6.28) ***	-11.39%	(-6.87) ***	86.67%	(6.35) ***
Panel E . Supply chain disruption subsample with non-Japanese firms only							
Event Day(s)	*N*	Mean	*t*	Median	*Z* [a]	% Negative	*Z* [b]
(0, 2)	209	-1.01%	(-2.33) **	-0.84%	(-4.59) ***	62.68%	(3.67) ***
(0, 10)	209	-2.04%	(-2.44) **	-1.75%	(-5.90) ***	66.03%	(4.63) ***
(0, 20)	209	-3.73%	(-3.23) ***	-2.93%	(-7.05) ***	71.29%	(6.16) ***
(0, 60)	209	-1.97%	(-1.00)	-1.29%	(-1.65) *	55.50%	(1.59)

Notes: [a] *Z* -statistics for medians are obtained using Wilcoxon signed-rank tests (in parentheses)
[b] *Z* -statistics for % negatives are obtained using binomial sign tests (in parentheses)
All tests are two-tailed: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

Table 4. Cumulative abnormal returns for the sample of firms either directly affected by the GEJE, or indirectly affected from downstream and upstream or downstream supply chain issues; Event Day 0 is the date of the GEJE on March 11, 2011.

Event Days	*N*	Mean	*t*	Median	*Z* [a]	% Negative	*Z* [b]
Panel A . Firm (directly affected)							
(0, 2)	97	-14.67%	(-36.68) ***	-15.16%	(-7.90) ***	88.66%	(7.62) ***
(0, 10)	97	-7.14%	(-9.32) ***	-4.68%	(-7.11) ***	84.54%	(6.80) ***
(0, 20)	97	-7.19%	(-6.79) ***	-5.49%	(-6.76) ***	81.44%	(6.19) ***
(0, 60)	97	-9.43%	(-5.23) ***	-7.44%	(-5.36) ***	69.07%	(3.76) ***
Panel B . Downstream (from affected suppliers)							
Event Days	*N*	Mean	*t*	Median	*Z* [a]	% Negative	*Z* [b]
(0, 2)	72	-1.38%	(-2.50) **	-0.28%	(-1.33)	54.17%	(0.71)
(0, 10)	72	-1.56%	(-1.49)	-0.79%	(-2.52) **	55.56%	(0.94)
(0, 20)	72	-3.06%	(-2.10) **	-2.59%	(-4.27) ***	73.61%	(4.01) ***
(0, 60)	72	-4.20%	(-1.69) *	-3.13%	(-2.57) **	63.89%	(2.36) **
Panel C . Upstream (from affected customers)							
Event Days	*N*	Mean	*t*	Median	*Z* [a]	% Negative	*Z* [b]
(0, 2)	113	-2.85%	(-5.42) ***	-1.27%	(-5.67) ***	71.68%	(4.61) ***
(0, 10)	113	-3.31%	(-3.29) ***	-2.99%	(-5.42) ***	74.34%	(5.17) ***
(0, 20)	113	-4.97%	(-3.57) ***	-4.44%	(-5.77) ***	76.11%	(5.55) ***
(0, 60)	113	-2.58%	(-1.09)	-2.06%	(-1.65) *	60.18%	(2.16) **

Notes: [a] *Z* -statistics for medians are obtained using Wilcoxon signed-rank tests
[b] *Z* -statistics for % negatives are obtained using binomial sign tests
All tests are two-tailed: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

Table 5. Comparison of 21-day cumulative abnormal returns for the supply chain subsamples from the GEJE versus supply chain disruptions as defined by Hendricks and Singhal (2003, 2005, 2014) but with sample expanded so that it includes years 1989-2014.

Column	*(1)*	*(2)*	*(3)*	*(4)*		*(5)*	*(6)*	*(7)*	*(8)*	*(9)*	*(10)*
GEJE Supply Chain disruption sample					Supply Chain disruption sample as defined by H&S					Differences (GEJE − H&S)	
Subsample	*N*	Mean	Median	% Neg.	Subsample	*N*	Mean	Median	% Neg.	Mean	Median
All disruptions	284	-5.21%	-4.47%	77.11%	Total	1,867	-7.20%	-6.28%	66.36%	1.99%	1.81%
		(-5.68) ***	(-9.78) ***	(9.14) ***			(-21.11) ***	(-15.96) ***	(14.14) ***	(2.53) **	(1.97) **
Japanese firms	75	-9.32%	-7.34%	93.33%	Total	1,867	-7.20%	-6.28%	66.36%	-2.12%	-1.06%
		(-6.95) ***	(-6.68) ***	(7.51) ***			(-21.11) ***	(-15.96) ***	(14.14) ***	(-1.21)	(-1.16)
Non-Japanese firms	209	-3.73%	-2.93%	71.29%	Total	1,867	-7.20%	-6.28%	66.36%	3.47%	3.35%
		(-3.23) ***	(-7.05) ***	(6.16) ***			(-21.11) ***	(-15.96) ***	(14.14) ***	(4.76) ***	(3.01) ***
Firm	97	-7.19%	-5.49%	81.44%	Internal	686	-6.43%	-5.41%	65.16%	-0.76%	-0.09%
		(-6.79) ***	(-6.76) ***	(6.19) ***			(-12.59) ***	(-8.73) ***	(7.94) ***	(-0.47)	(-0.39)
Downstream	72	-3.06%	-2.59%	73.61%	Suppliers	262	-8.27%	-6.24%	68.32%	5.21%	3.65%
		(-2.10) **	(-4.27) ***	(4.01) ***			(-8.42) ***	(-6.82) ***	(5.93) ***	(3.79) ***	(2.29) **
Upstream	113	-4.97%	-4.44%	76.11%	Customers	289	-10.13%	-8.73%	69.90%	5.17%	4.29%
		(-3.57) ***	(-5.77) ***	(5.55) ***			(-10.52) ***	(-8.18) ***	(6.76) ***	(3.56) ***	(2.92) ***

Notes: Z -statistics for medians are obtained using Wilcoxon signed-rank tests (reported in parentheses)
Z -statistics for % negatives are obtained using binomial sign tests (reported in parentheses)
t -statistics for differences in means are obtained using two-sample *t* -tests (reported in parentheses)
Z -statistics for differences in medians are obtained using Mann-Whitney U-tests (reported in parentheses)
All tests are two-tailed: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

Table 6. Cumulative abnormal returns for the sample of firms in the global nuclear industry and the global insurance industry (SIC codes 6311 and 6331); Event Day 0 is the date of the GEJE on March 11, 2011.

Panel A. Nuclear							
Event Days	*N*	Mean	*t*	Median	Z^{a}	% Negative	Z^{b}
(0, 2)	48	-11.19%	(-13.38) ***	-6.29%	(-5.57) ***	89.58%	(5.48) ***
(0, 10)	48	-8.72%	(-5.45) ***	-6.12%	(-5.41) ***	87.50%	(5.20) ***
(0, 20)	48	-12.59%	(-5.69) ***	-10.12%	(-5.38) ***	89.58%	(5.48) ***
(0, 60)	48	-21.60%	(-5.73) ***	-10.47%	(-4.76) ***	82.98%	(4.52) ***
Panel B. Insurance							
Event Days	*N*	Mean	*t*	Median	Z^{a}	% Negative	Z^{b}
(0, 2)	45	-4.79%	(-8.29) ***	-4.11%	(-4.60) ***	80.00%	(4.02) ***
(0, 10)	45	-4.52%	(-4.08) ***	-4.62%	(-4.70) ***	82.22%	(4.32) ***
(0, 20)	45	-2.09%	(-1.37)	-2.14%	(-2.05) **	62.22%	(1.64)
(0, 60)	45	-4.83%	(-1.85) *	-5.47%	(-2.81) ***	64.44%	(1.94) *

Notes: [a] *Z*-statistics for medians are obtained using Wilcoxon signed-rank tests
[b] *Z*-statistics for % negatives are obtained using binomial sign tests
All tests are two-tailed: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

Table 7. Cumulative abnormal returns for the sample of firms with positive business opportunities resulting from the Great East Japan Earthquake (GEJE); Event Day 0 is the date of the GEJE on March 11, 2011.

Panel A. Combined sample of Rebuild and Competitors							
Event Days	*N*	Mean	*t*	Median	Z^{a}	% Positive	Z^{b}
(0, 2)	92	6.13%	(10.04) ***	5.40%	(7.09) ***	84.78%	(6.67) ***
(0, 10)	91	6.13%	(5.24) ***	5.05%	(6.80) ***	87.91%	(7.23) ***
(0, 20)	90	4.79%	(2.96) ***	3.86%	(5.68) ***	76.67%	(5.06) ***
(0, 60)	91	-3.87%	(-1.41)	-2.65%	(-1.97) **	40.66%	(-1.78) *
Panel B. Rebuild							
Event Days	*N*	Mean	*t*	Median	Z^{a}	% Positive	Z^{b}
(0, 2)	45	5.17%	(8.06) ***	5.05%	(4.65) ***	86.67%	(4.92) ***
(0, 10)	44	5.83%	(4.75) ***	4.83%	(4.69) ***	88.64%	(5.13) ***
(0, 20)	43	5.46%	(3.22) ***	4.32%	(4.39) ***	83.72%	(4.42) ***
(0, 60)	44	-2.68%	(-0.93)	-2.87%	(-1.36)	40.91%	(-1.21)
Panel C. Competitors							
Event Days	*N*	Mean	*t*	Median	Z^{a}	% Positive	Z^{b}
(0, 2)	47	7.05%	(7.41) ***	6.21%	(5.38) ***	82.98%	(4.52) ***
(0, 10)	47	6.40%	(3.51) ***	5.31%	(4.94) ***	87.23%	(5.11) ***
(0, 20)	47	4.17%	(1.66)	3.49%	(3.57) ***	70.21%	(2.77) ***
(0, 60)	47	-4.98%	(-1.16)	-2.57%	(-1.49)	40.43%	(-1.31)

Notes: [a] *Z*-statistics for medians are obtained using Wilcoxon signed-rank tests (in parentheses)
[b] *Z*-statistics for % negatives are obtained using binomial sign tests (in parentheses)
All tests are two-tailed: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

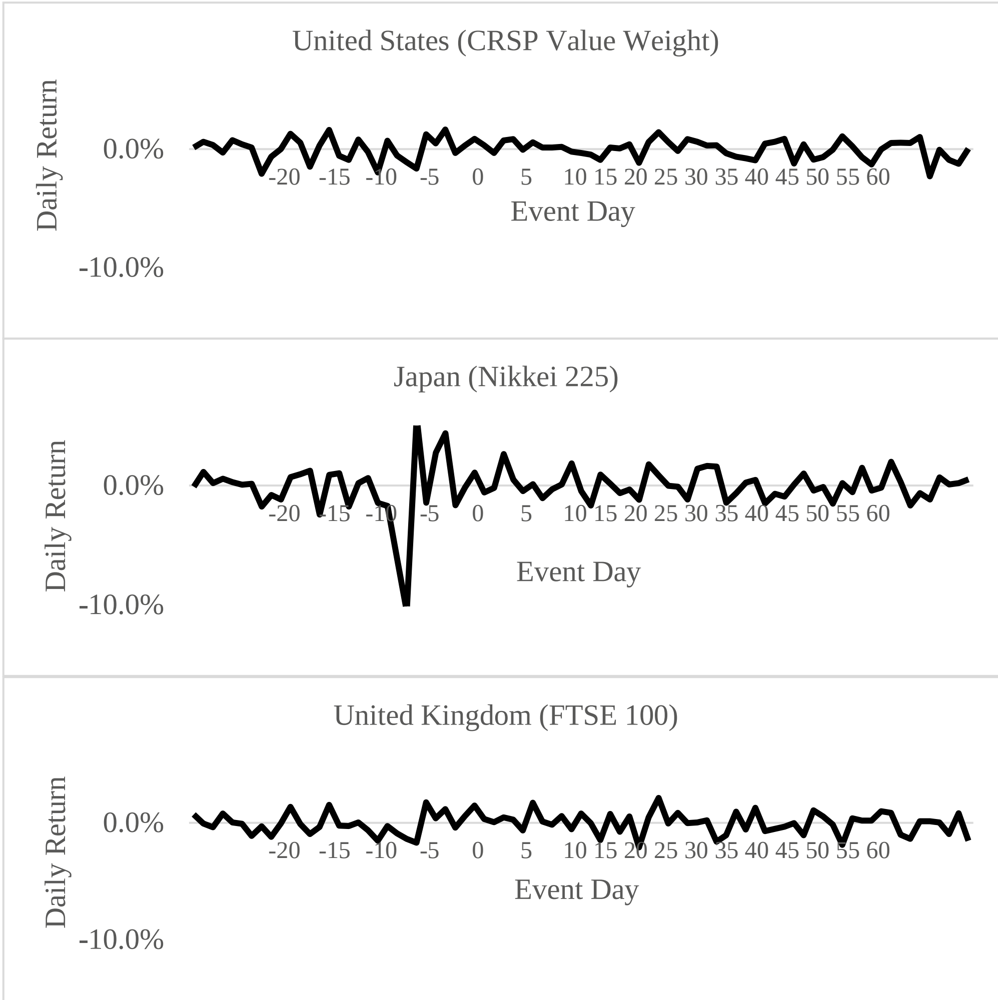

Figure 1. Stock market volatility before and after the Great East Japan Earthquake (GEJE), as demonstrated by the daily returns from Day −20 to Day 60 for the indices of the three most-represented markets in the sample (United States, Japan, United Kingdom); Event Day 0 is the date of the GEJE on March 11, 2011.

Online Appendix A.

To assess the robustness of our abnormal return estimation method that employs the market model together with simulated market returns for the Japanese sample firms, we compare abnormal returns using two other methods that do not rely on market returns: 1) the mean-adjusted model; and 2) actual returns. We also assess the robustness of our method to the length of the estimation window by comparing the results obtained using 100-day, 200-day, 250-day, and 300-day estimation periods versus our reported method that employs a 200-day estimation period.

Mean-adjusted model

The mean-adjusted model (also known as the comparison period model) makes no assumptions regarding the market returns, and instead assumes that the return of a sample firm without the event is the average return that the sample firm experienced during an estimation period before the event. Thus, abnormal return from the mean-adjusted model is:

$$\textit{Abnormal return on Day t for Firm i} = \textit{Actual return on Day t for Firm i} - \hat{\mu}_{i}$$

where $\hat{\mu}_{i}$ is the average daily return of Firm *i* from the estimation period. For each sample firm traded in the Japanese market, we estimate $\hat{\mu}_{i}$ using pre-event returns from Days –202 to Day –3 (a 200-day estimation period).

We note that the mean-adjusted model is commonly used in the literature (e.g., Thirumalai and Sinha 2011, Hendricks and Singhal 2003) and is also discussed in methodology papers dealing with event studies (e.g., Brown and Warner 1985, MacKinlay 1997). Although the mean-adjusted model does not require estimation of betas, the results are generally very similar to the models that estimate betas to compute abnormal returns.

Actual returns

While actual returns do not adjust for betas or other factors, and they are not a CAR in the traditional sense, they help provide some perspective on the reasonableness of the choice of model used to estimate CAR. It is well accepted in the literature that the choice of the model to estimate abnormal returns is less serious in event studies that focus on short windows (ranging from a few days to a few months) since daily expected returns are very small (e.g., Fama 1998). Note that:

$$\textit{Abnormal return} = \textit{Actual returns} - \textit{Expected returns.}$$

Thus, given that the expected daily returns are very small, abnormal returns should not differ much from actual returns if the windows are short.

Table A.1 reports the comparative results for the 88 Japanese sample firms using the three approaches for Days (0, 20), our main event period of interest. The mean CAR is −8.13% using the market model with simulated Japanese market returns, and it is –8.09% using the mean-adjusted model that does use any market returns. The mean cumulative actual return is −7.59%, which is very similar to both of the estimated CARs. This is what one would expect given that the daily actual return for the 88 Japanese firms based on a 200-day period before the GEJE (Days −202 to Day −3) is about 0.02%, which is quite small.

None of the differences in estimation from the three methods are statistically significant. This suggests that our primary estimation method, the market model with simulated Japanese market returns during the event period, is robust.

Table A.1. Comparison of cumulative returns for Days (0, 20) for the sample of Japanese firms (*N*=88) using three estimation methods: market model with simulated Japanese market returns; mean-adjusted model; actual returns. Event Day 0 is the date of the GEJE on March 11, 2011.

Column	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*
Estimation method	Japanese sample firms (*N* =88)			Differences to Market Model	
	Mean	Median	% Neg.	Mean	Median
Market Model with simulated Japanese market returns	-8.13% (-6.20) ***	-7.34% (-6.31) ***	89.66% (7.40) ***	– –	– –
Mean-adjusted Model	-8.09% (-5.13) ***	-7.29% (-6.29) ***	88.51% (7.18) ***	0.05% (0.13)	0.06% (0.40)
Actual returns	-7.59% (-10.82) ***	-7.61% (-5.96) ***	83.91% (6.33) ***	0.54% (0.25)	-0.27% (-0.43)

Notes: *Z* -statistics for medians are obtained using Wilcoxon signed-rank tests (reported in parentheses)
Z -statistics for % negatives are obtained using binomial sign tests (reported in parentheses)
t -statistics for differences in means are obtained using two-sample *t* -tests (reported in parentheses)
Z -statistics for differences in medians are obtained using Mann-Whitney U-tests (reported in parentheses)
All tests are two-tailed: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

Estimation Periods

In our manuscript, we estimate abnormal returns for the Japanese firms using the market model together with simulated market returns. The parameters of the market model and the pool of Japanese market returns used for the simulation are both obtained using a 200-day estimation period (Day –202 to Day –3). For robustness, we also estimate results using four different estimation windows (100-day, 150-day, 250-day, 300-day). We use the same procedure as described in the manuscript. For each estimation window, we run the regressions for each firm to estimate unique market model parameters. Next, for each of the 61 days in our event period (Day 0 to Day 60), we randomly draw with replacement one return from the daily returns of the Nikkei 225 Index over the corresponding estimation window [either Days (–102, –3), Days (–152, –3), Days (–252, –3), or Days (–302, –3)]. We repeat this process 1000 times to get 1000 abnormal returns for each event day for each Japanese firm in our sample. We average the abnormal returns from the 1000 trials for each Japanese firm, and use this average as our estimate of daily abnormal returns. Table A.2 presents the results obtained from using the four different estimation windows, and compares them with the results obtained from using the 200-day estimation window. The results indicate that abnormal returns of the Japanese firms using the simulation method are robust with respect to different estimation periods.

Table A.2. Comparison of cumulative abnormal returns for Days (0, 20) for the sample of 88 Japanese firms using simulated Nikkei market returns based upon five different estimation periods; Event Day 0 is the date of the GEJE on March 11, 2011.

	Column	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*
Estimation period		Japanese sample firms (*N* =88)			Differences to 200-day Estimation Period	
# of Days	(Start, Finish)	Mean	Median	% Neg.	Mean	Median
100	(-102, -3)	-9.61%	-8.13%	91.95%	1.48%	0.79%
		(-7.31) ***	(-6.74) ***	(7.83) ***	(0.67)	(1.13)
150	(-152, -3)	-9.41%	-8.49%	89.66%	1.27%	1.14%
		(-7.16) ***	(-6.57) ***	(7.40) ***	(0.58)	(1.18)
200	(-202, -3)	-8.13%	-7.34%	89.66%	– –	– –
		(-6.20) ***	(-6.31) ***	(7.40) ***		
250	(-252, -3)	-8.31%	-7.73%	89.66%	0.18%	0.39%
		(-6.33) ***	(-6.32) ***	(7.40) ***	(0.08)	(0.18)
300	(-302, -3)	-8.94%	-8.43%	89.66%	0.81%	1.09%
		(-6.81) ***	(-6.52) ***	(7.40) ***	(0.37)	(0.66)

Notes: *Z* -statistics for medians are obtained using Wilcoxon signed-rank tests (reported in parentheses)
Z -statistics for % negatives are obtained using binomial sign tests (reported in parentheses)
t -statistics for differences in means are obtained using two-sample *t* -tests (reported in parentheses)
Z -statistics for differences in medians are obtained using Mann-Whitney U-tests (reported in parentheses) All tests are two-tailed: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

As a further check on the robustness of our results to the length of the estimation window, we repeat this analysis for the non-Japanese firms in our sample (*N*=382). For each firm, we calculate abnormal returns using the market model for four different estimation windows (100-day, 150-day, 250-day, 300-day). For each estimation window, we run the regressions for each firm to estimate unique market model parameters. Next, we estimate the abnormal returns for each firm as the difference between the actual returns and the predicted returns from the market model. Table A.3 presents the results obtained from using the four different estimation windows, and compares them with the results obtained from using the 200-

day estimation window. The results indicate that abnormal returns of the non-Japanese firms estimated by using the market model are also robust with respect to different estimation periods.

Table A.3. Comparison of cumulative abnormal returns for Days (0, 20) for the sample of 382 non-Japanese firms using market model returns based upon five different estimation periods; Event Day 0 is the date of the GEJE on March 11, 2011.

	Column	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*
Estimation period		non-Japanese sample firms (*N* =382)			Differences to 200-day Estimation Period	
# of Days	(Start, Finish)	Mean	Median	% Neg.	Mean	Median
100	(-102, -3)	-2.61%	-1.69%	60.53%	-0.12%	-0.17%
		(-3.18) ***	(-4.77) ***	(4.10) ***	(-0.16)	(-0.32)
150	(-152, -3)	-2.67%	-1.82%	60.53%	-0.06%	-0.04%
		(-3.25) **	(-5.08) ***	(4.10) ***	(-0.08)	(-0.21)
200	(-202, -3)	-2.73%	-1.86%	61.32%	– –	– –
		(-3.33) ***	(-5.36) ***	(4.41) ***		
250	(-252, -3)	-2.78%	-1.88%	61.84%	0.05%	0.03%
		(-3.39) ***	(-3.40) ***	(4.62) ***	(0.07)	(0.17)
300	(-302, -3)	-2.71%	-1.74%	62.11%	-0.02%	-0.11%
		(-3.30) ***	(-5.33) ***	(4.72) ***	(-0.03)	(-0.01)

Notes: *Z* -statistics for medians are obtained using Wilcoxon signed-rank tests (reported in parentheses)
Z -statistics for % negatives are obtained using binomial sign tests (reported in parentheses)
t -statistics for differences in means are obtained using two-sample *t* -tests (reported in parentheses)
Z -statistics for differences in medians are obtained using Mann-Whitney U-tests (reported in parentheses)
All tests are two-tailed: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

Online Appendix B.

To generate comparison samples of firms not reported in the business press, we took the following approach per industry:

Motor Vehicle Manufacturing: In our sample from the business press, there are 34 firms in the motor vehicle manufacturing industry. For these 34 firms, the two SIC codes are 3711 (motor vehicles; 26 firms) and 3714 (motor vehicle parts; 8 firms). We use the Compustat Global and Compustat North America databases to identify all firms in SIC codes 3711 and 3714 with revenues in 2010. We select the 100 largest firms (by revenue) that are not in our business press sample. The median revenue of these 100 firms is $2.6 billion compared to the median revenue of $24.8 billion for our 34 sample firms. 28 of these 100 firms are headquartered in Japan. Out of these 100 firms, 88 have sufficient stock price data to estimate abnormal returns during the event period.

Electronics Manufacturing: For the electronics manufacturing industry, our sample from the business press includes 30 firms. For these 30 firms, the dominant SIC codes are 3674 (semiconductors; 14 firms) and 3670 (electronic components; 10 firms). We use the Compustat Global and Compustat North America databases to identify all firms in SIC codes 3670 and 3674 with revenues in 2010. We select the 100 largest firms (by revenue) that are not in our business press sample. We exclude firms that are in the renewable energy industry (photovoltaic components manufacturers) because we suspect a potentially positive competitive effect for these firms. The selected firms have median revenues of $1.5 billion compared to the median revenue of $2.7 billion for our 30 sample firms. 17 of these 100 firms are headquartered in Japan. Out of these 100 firms, 88 have sufficient stock price data to estimate abnormal returns during the event period.

Nuclear Industry: To generate the comparison sample, we begin with a list of companies in the nuclear industry that are involved in activities such as mining, processing, and enrichment of uranium; operating nuclear power plants; and processing nuclear waste (https://en.wikipedia.org/wiki/List-of-companies-in-the-nuclear-sector, accessed 30 Jun 2017). This list includes 122 firms. We also obtain names of all global nuclear reactor owners and operators from the World Nuclear Association website (http://www.world-nuclear.org/information-library/facts-and-figures/reactor-database.aspx, accessed 11 Jul 2017). This yields an additional 109 firms. Further, we search the Compustat Global and Compustat North America databases to identify any firm in 2010 with the words “nuclear”, “atomic”, or “uranium” (or foreign variants) in the firm name. This generates another 25 firms. In total, we compile a list of 255 unique firms of which 48 are in the *Nuclear* subsample obtained from the business press. Of the remaining 207 firms not announced in the business press, 140 are not publicly traded as they are either privately held, state entities, or state owned firms. Of the remaining 67 firms, 44 have sufficient stock price data to estimate abnormal returns during the event period. Four of these firms are headquartered in Japan.

Insurance Industry: The process for generating this sample is as follows. For the 45 firms in the *Insurance* subsample from the business press, the dominant SIC codes are 6331 (Fire, Marine, & Casualty Insurance; 25 firms) and 6311 (Life Insurance; 11 firms). We use the Compustat Global and Compustat North America databases to identify all firms in SIC codes 6311 and 6331 with revenues in 2010. We select the 100 largest firms (by revenue) that are not in our business press sample. The median revenue of these 100 firms is $9.0 billion compared to the median revenue of $10.1 billion for our 45 sample firms. Out of these 100 firms, 83 have sufficient stock price data to estimate abnormal returns during the event period. Four of these firms are headquartered in Japan.

Renewable Energy Industry: We begin with a list of renewable energy industry firms (https://en.wikipedia.org/wiki/List-of-renewable-energy-companies-by-stock-exchange, accessed 7 Nov 2017). This source yields 89 firms, and includes all 15 firms we identified from our search of announcements in the business press, netting 74 firms that are not from the business press subsample. We also search the Compustat Global and Compustat North America databases for any firms in 2010 with the words “solar”, “wind”, or “renewable” in the company name. This generates another 127 firms not in our sample from the business press. We review the website for each of these 127 firms to determine if it is primarily involved in renewable energy. This eliminates 22 firms, leaving us with 179 firms not from the business press. From these 179 firms, we select the 100 largest firms by revenue. These 100 firms have median revenue of $0.21 billion compared to the median revenue of $0.76 billion for the 15 renewable energy industry sample firms identified from the business press. Out of these 100 firms, 79 have sufficient stock price data to estimate abnormal returns during the event period. Only one of these firms is headquartered in Japan.

Table B.1 Comparison of cumulative abnormal returns for Days (0, 20) for the industry subsamples in this manuscript obtained from the business press versus industry samples of firms not reported in the business press; Event Day 0 is the date of the GEJE on March 11, 2011.

Column	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*	*(10)*
Industry	GEJE subsamples from the business press				Samples not reported in the business press				Differences	
	N	Mean	Median	% Neg.	*N*	Mean	Median	% Neg.	Mean	Median
Motor vehicle manufacturing	34	-6.46% (-2.86) ***	-6.98% (-4.24) ***	82.35% (3.77) ***	88	-7.22% (-3.89) ***	-7.27% (-5.05) ***	69.32% (3.62) ***	0.75% (0.40)	0.28% (0.30)
Electronics manufacturing	31	-3.74% (-1.55)	-5.19% (-2.73) ***	77.42% (3.05) ***	88	0.12% (0.07)	-1.89% (-1.63)	63.64% (2.56) **	-3.86% (-2.09) **	-3.29% (-2.03) **
Nuclear	48	-12.59% (-5.69) ***	-10.12% (-5.38) ***	89.58% (5.48) ***	43	-14.84% (-3.39) ***	-3.58% (-4.16) ***	76.74% (3.51) ***	2.25% (0.56)	-6.54% (-1.10)
Insurance	45	-2.09% (-1.37)	-2.14% (-2.05) **	62.22% (1.64)	81	-0.34% (-0.12)	-0.54% (-0.92)	60.49% (1.89) *	-1.75% (-1.84) *	-1.59% (-1.62)
Renewable energy	15	7.15% (1.25)	6.58% (2.20) **	26.67% (-1.81) *	75	5.17% (2.37) **	2.63% (2.11) **	40.00% (-1.73) *	1.98% (0.51)	3.95% (1.07)

Notes: *Z* -statistics for medians are obtained using Wilcoxon signed-rank tests (reported in parentheses)
Z -statistics for % negatives are obtained using binomial sign tests (reported in parentheses)
t -statistics for differences in means are obtained using two-sample *t* -tests (reported in parentheses)
Z -statistics for differences in medians are obtained using Mann-Whitney U-tests (reported in parentheses)
All tests are two-tailed: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

References for online appendix

Brown, S.J., J.B. Warner. 1985. Using daily stock returns: The case of event studies. *Journal of Financial Economics* 14(1), 3-31.

Fama, E.F. 1998. Market efficiency, long-term returns, and behavioral finance. *Journal of Financial Economics* 49(3), 283-306.

Hendricks, K B., V.R. Singhal. 2003. The effect of supply chain glitches on shareholder wealth. *Journal of Operations Management* 21(5), 501-522.

MacKinlay, A.C. 1997. Event studies in economics and finance. *Journal of Economic Literature* 35(1), 13-39.

Thirumalai, S., K.K. Sinha. 2011. Product recalls in the medical device industry: An empirical exploration of the sources and financial consequences. *Management Science* 57(2), 376-392.