RIETI Discussion Paper Series 15-E-097

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http://www.rieti.go.jp/en/

RIETI Discussion Paper Series 15-E-097
August 2015

The Effectiveness of Pre-Disaster Planning and Post-Disaster Aid: Examining the impact on plants of the Great East Japan Earthquake

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Abstract:

We examine the extent to which pre-disaster planning and post-disaster aid can help firms to recover from a natural disaster event. Using detailed plant-level data covering the areas affected by the March 2011 Great East Japan Earthquake and tsunami, we find that neither pre-disaster planning nor post-disaster aid has a significant effect on the short term impact of the disaster in terms of the number of days that plants ceased operations. However, we do find evidence to suggest that post-disaster sales growth can be influenced by pre- and post-disaster policy. More specifically, we find that pre-disaster policies such as planning production substitution with other plants and making alternative transport arrangements affect sales post-disaster. We also discover that post-disaster aid from banks and from trading partners influences post-disaster sales but that government aid has no statistically significant effect.

Keywords: Natural disaster, Firms, Japan, Earthquake

JEL codes: Q54, R10, R12, D22, L10, L25, M13, C01

Acknowledgements: We would like to thank RIETI for their continued support and access to the micro data. This study uses the micro-data of Questionnaire Survey on Damages to Companies Caused by the Great East Japan Earthquake, which conducted by Research Institute of Economy, Trade and Industry (RIETI) and also uses Tokyo Shoko Research (TSR) data. The usual disclaimer applies. This study is conducted as a part of the Project "Restoration from Earthquake Damage and Growth Strategies of the Japanese Regional Economy" undertaken at RIETI.

1. **Introduction**

As the world economy continues to grow and an increasing proportion of the population lives in cities and urban areas it is important to understand how economic resilience to natural disasters can be influenced by the actions of firms and governments. Many of the great challenges of the future that will be faced by countries and cities will be closely connected to the risks associated with a changing climate and a range of geo-hazards from earthquakes and volcanoes to extreme weather events such as typhoons, floods, and rising sea levels. It is important, therefore, to design mitigation strategies and policies to cope with current and future geo-hazards some of which are predicted to increase in frequency and magnitude. With continued agglomeration of economic activity in cities, obtaining a clear understanding of how countries, firms and people are able to adapt to current and future environmental and geo-hazard risk is of importance to policymakers and academics.

In this paper we use detailed plant-level surveys to examine the impact of the Great East Japan earthquake of 2011 on the performance of manufacturing plants. The Great East Japan earthquake struck off the Pacific coast of Tohoku at 14.46 on Friday 11 March 2011 with a magnitude of 9.0 on the Richter scale. It was the most powerful earthquake recorded to hit Japan and triggered tsunami waves that reached a height of over 40 metres and travelled up to 10 km inland.[1] The short term economic impact of the earthquake was significant with manufacturing production falling approximately 40% in Tohoku region following the earthquake before slowly recovering to pre-earthquake levels over the following 12-18 months.[2] While at an aggregate level the economy appeared to recover, at the plant-level the situation was mixed with post-earthquake performance depending on a number of factors, not least the degree of earthquake damage incurred. The focus of this paper is on two specific factors that may have influenced the post-earthquake performance of

[1] According to a Japanese National Police Report the numbers of people killed, injured or missing was 15,891, 6,152 and 2,584 respectively (National Police Report 2015). The same report states that 127,290 building totally collapsed, 272,788 builds half collapsed and another 747,989 buildings were partially damaged. There was also extensive damage to roads, railways and infrastructure. For example, fifteen ports were located in the disaster zone and suffered some damage alongside an estimated 10% of Japans fishing ports (Fukada 2011). The tsunami also caused meltdowns at three nuclear reactors at the Fukushima Daiichi Nuclear Power Plant. Residents within a 20km radius were subsequently evacuated. Total insured losses from the earthquake alone were estimated to be between US$14.5 and US$34.6 billion (Hennessy-Fiske 2011) whilst the Word Bank estimated total damages to be in the region of US$235 billion. In the immediate aftermath of the disaster the Bank of Japan offered US183 billion to help stabilise the banking system and restore normal market conditions (Uranaka and Kwon 2011).

[2] Source Japanese Ministry for Economy, Trade and Industry http://www.meti.go.jp/statistics/tyo/iip/index.html

plants; these are the level of pre-disaster planning undertaken by each plant and whether or not each plant received post-earthquake aid. Such an analysis allows us to obtain a greater understanding of the dynamics of economic resilience to natural disasters.

An important attribute of earthquakes relevant to our study is that they are inherently local phenomena and as such, although the damage from an earthquake may be spatially extensive, there is considerable heterogeneity across affected areas. This arises both because the characteristics of the earthquake itself will physically differ across space, but also because exposure in terms of buildings and the distribution of the population is likely to be spatially heterogeneous. Thus, any sort of reliable assessment of the damage caused by an earthquake and hence the allocation of pre and post-quake aid needs ideally to take place at the most disaggregated level possible.[3]

There are a small number of papers that are now beginning to use plant-level data in analyses of natural disasters. For example, Craioveanu and Terrell (2010) consider the impact of storms on firm survival following Hurricane Katrina while De Mel *et al.* (2011) conduct a post-disaster field study of surviving enterprises following the Sri Lanka tsunami. Dahlhamer and Tierney (1998) examined the 1994 Northridge earthquake and found damage and financial health affected the strength of business recovery. More recently for Japan, Hosono *et al.* (2012) study the effect of banks' lending capacity on firms' capital investment using the Kobe earthquake as an exogenous shock, while Cole *et al.* (2015) examine the impact of the Kobe earthquake on firm survival and performance using detailed building damage measures. In a third Kobe earthquake study Tanaka (2015) examines the short-term economic impact of the quake assuming that all plants within Kobe suffered the same damage and finds that the earthquake had a significant short term impact on employment and value added. Finally, Todo *et al.* (2015) examine the impact of the Great East Japan Earthquake on supply chain networks using similar data to ourselves. They find that extensive supply chains can negatively affect recovery through the higher probability of network disruption but positively through a great support network of partners both within Japan and overseas, resulting in an overall positive effect. Finally, also for the Great East Japan Earthquake,

[3] Existing studies in the natural disaster literature have tended to take a cross-country macroeconomic approach to examine the relationship between country level growth and natural disaster events (e.g. Loayza *et al.* 2009, Hallegatte and Dumas 2009, Noy 2009 and Strobl 2012, Kahn, 2005, McDermott et al. 2014). The lack of a consensus on the average effects of natural disasters can be seen in Cuaresma *et al.* (2008) and Cavallo and Noy (2010) who argue that on average natural disasters have a positive and negative impact, respectively. Felbermayr and Gröshel (2013) provide a review of the literature.

Wakasugi and Tanaka (2013) examine the determinants of plant stoppages, including descriptive evidence of how stoppages vary across plants.[4]

However, despite the increase in the number of plant-level studies to the best of our knowledge there has been almost no research that examines the impact of pre-disaster planning and post-disaster aid on plant recovery. The contribution of this paper is thus as follows. First, we complement the previous research of Todo *et al.* (2014) and Cole *et al.* (2015) to provide one of the first studies of the impact of a natural disaster on plant-level performance. Second, as far as we know we are the first to examine the extent to which pre-disaster planning by plants can affect post-disaster plant performance by using a unique plant-level survey that enables us to distinguish between earthquake damage and tsunami damage and to examine the extent to which a variety of pre-disaster policies benefit post-disaster economic performance. Policies include arranging alternative transportation methods in the event of an earthquake; arranging alternative production arrangements with other firms to enable current orders to be fulfilled; possessing a business continuity plan (BCP); and deliberately diversifying parts suppliers to minimise potential disruption to the supply chain. Third, we are again the first study to examine the effectiveness of post-disaster aid on post-disaster plant performance and to distinguish between different types of aid.[5]

Our results indicate that both earthquake and tsunami damage affected the duration for which operations were disrupted following the earthquake, but that only tsunami damage was a statistically significant and negative determinant of sales for the 6 months following the earthquake. In terms of pre-disaster planning, we find that developing a transport substitution policy, possessing a business continuity plan and arranging a production substitution policy that allows other firms to fulfil existing orders can prove beneficial post-disaster. Finally, we find that plants that received aid from banks and from trading partners experienced higher post-earthquake sales than those that did not. Other forms of aid have no statistically significant effect on post-earthquake sales. Our results

[4] Tokui *et al.* (2012) estimate that 90% of output losses was due to supply chain disruption and not as a direct effect of damage to individual plants. Carvalho *et al.* (2014) investigate the disruption of supply chain more in details, using firm transaction data (TSR data) while Henriet *et al.* (2011) examine firm-network characteristics and their relationship with resilience to nature disasters.

[5] Fukanuma *et al.* (2013) measures the economic impact of the special lending program for small and medium sized enterprises (SMEs) by Development Bank of Japan. As a result of questionnaire survey, they find that the special lending program for SME contributed to a reduction in the economic impact of the earthquake.

also support the Todo *et al*. (2015) finding that overseas affiliates can have a beneficial effect on post-quake performance.

The remainder of the paper is structured as follows. Section 2 discusses and examines the data used in this study and Section 3 outlines our methodology. Section 4 provides our econometric results and Section 5 Concludes.

2. **Data and Summary Statistics**

2.1 Data

To examine the impact on plants of the Great East Japan earthquake we utilise the plant-level survey "Questionnaire Survey on Damages to Companies Caused by the Great East Japan Earthquake" conducted by the Research Institute of Economy, Trade and Industry (RIETI).[6] The survey targeted a total of 6,033 manufacturing plants with five workers or more that were located in the prefectures formally defined as being impacted by the earthquake.[7] The prefectures were Aomori, Iwate, Miyagi, Fukushima, Tochigi and Ibaraki. The survey was mailed to plants during January 2012 and responses were requested by February 2012. Plants were also telephoned to encourage a response. The result of the data collection exercise was a total of 2,117 useable responses which represents a response rate of 35%.[8]

As part of the RIETI survey, plants were required to categorise the degree of earthquake and tsunami damage that they sustained as a result of the earthquake, to provide information on any pre-earthquake planning policies that were in place and to indicate whether they received post-earthquake aid and, if so, of what type. Plants were also asked to provide information on a number of plant characteristics such as total sales during the pre-earthquake period April to September 2010 and the post-earthquake period April to September 2011. We also utilise a dataset

[6] Hamaguchi (2013) provides an overview the survey data and includes a detailed analysis of each question in the survey and a complete set of basic statistics.
[7] Firms were chosen according to the Law on Special Great East Japan Earthquake Reconstruction Areas. Plants within the exclusion zone surrounding the Fukushima Daiichi nuclear power plant were excluded from the survey.
[8] Although the survey was undertaken in February 2012 the vast majority of aid was received by firms before September 2011.

on firms' transaction partners from Tokyo Shoko Research ("Kigyou Soukan Fairu"), a large corporate research company in Japan, which lists the number of trading partners of each plant. After merging these datasets and removing plants that were missing certain key variables we were left with 1,283 plants. Table 1 provides definitions of the variables within our dataset.

[Table 1 about here]

2.2 Plant Damage

The RIETI survey required plants to categorise their damage levels into one of 4 categories, separately for both earthquake damage and tsunami damage. The four categories correspond to no damage, minor damage, more severe partial damage and major damage. For convenience, for the remainder of the paper we categorise these damage types into no, minor, medium and major damage. Table 2 provides the number and percentage of plants within our sample that experienced each damage type. Starting with earthquake damage we see that 366 plants, or 28.6% of the sample, experienced no earthquake damage, 811 plants, or 63.2% of our sample, experienced minor earthquake damage, while 6.69% and 1.55% of our sample experienced medium and major damage, respectively. With regard to tsunami damage, the vast majority (94.3%) of our sample experienced no tsunami damage and were presumably located inland, while 1.2% of the sample experienced minor and medium damage and 3.4% of the sample experienced major tsunami damage.

[Table 2 about here]

To obtain a better understanding of the geographical location of plants prior to the earthquake Figure 1 provides a map of Northern Japan with each plant in our sample represented by a black dot. The coloured shading shows the degree of peak ground acceleration which is a measure of the intensity of the earthquake with darker areas representing the greatest intensity. Finally, the blue shaded area along the coast shows the extent of tsunami flooding. In Figure 2 we enlarge a key section of Figure 1 to better illustrate the shading and details.

[Figure 1 and Figure 2 about here]

As a final descriptive exercise, in Table 3 we show the composition of our sample in terms of industrial sectors. In terms of the composition of our sample, 12.9% of plants are from the Fabricated Metals industry, 12.8% are from the Food industry and the rest are fairly evenly distributed over the remaining 23 industries. Damage is also fairly evenly distributed across sectors, with a few exceptions: 30% of plants in the Production Machinery sector experienced major damage and the same proportion experienced medium damage. Thus this sector was particularly badly affected by the earthquake. In terms of tsunami damage, the most affected sector was Beverages, Tobacco and Feed of which 16.2% of plants experienced major tsunami damage. These results are indicative of a degree of plant level clustering for certain sectors.[9]

2.3 Pre-Earthquake Planning

A key feature of the RIETI survey is that it collected information on the extent to which, prior to the earthquake, plants had in place policies to protect their operations from the effects of a future earthquake or natural disaster such as a typhoon or flood event. More specifically, plants were asked whether they had arranged alternative transportation methods in the event of an earthquake (Transport_subs_policy); whether they had made alternative production arrangements with other firms to enable current orders to be fulfilled (Prodn_subs_policy); whether they had an existing business continuity plan (BusinessContinuityPlan or BCP); and whether they had deliberately diversified parts suppliers to minimise potential disruption to the supply chain (DiversifiedPartsSuppliers).[10]

Table 4 provides summary statistics for all of our variables, including each of these four planning variables. The results indicate that the proportion of plants that had undertaken any of the pre-quake plans ranges from 8.6% in the case of the adoption of a business continuity plan to 2.2% in the case of transport planning.

[9] Shimizu and Matsubara (2014) present an excellent summary of the recovery process of manufacturing industries in the Tohoku region and have a discussion on the need for investment in the areas seriously damaged by the earthquake.

[10] The Development Bank of Japan (2011) provides more information on firm disaster planning and BCPs for the Great East Japan Earthquake. In this research paper they surveyed 28 companies from May-June 2011 that were impacted by the earthquake. Of these firms 55% were manufacturing, 30% were transportation and 15% were wholesalers and retailers. 30% of firms had a BCP (training based), another 30% has a BCP but did not use or had no training and the final 30% had no BCP but did have some disaster planning.

2.4 Post-Earthquake Aid

Another key feature of the RIETI survey that we exploit in our analysis is the collection of information on whether plants received post-earthquake aid and, if so, what type of aid they received. The survey distinguishes between aid from banks, which typically took the form of loans at subsidised interest rates ('Bank Aid')[11], aid directly from government which typically took the form of direct cash payments or subsidised loans or rents ('Govt Aid')[12], aid from friends and family ('Friend Aid'), aid from other firms ('Firm Aid')[13], aid from customers or suppliers ('Partner Aid')[14] and aid from volunteers and non-governmental organisations (NGOs) which we call ('Voluntary Aid'). The aid tended to be targeted at SMEs and primarily those that experienced direct physical damages. For government special lending, loans were available for 15 years for investment and 8 years for working capital at discounted interest rates or even 0% interest rate if the plant was totally destroyed. To qualify for the Emergency Guarantee for Restoration funds firms had to demonstrate their level of damage via the provision of a certificate of damage. In addition to similar but smaller aid support, there was also an employment fund that targeted damaged firms with money provided to employees who had to leave work because of the earthquake and who were

[11] Bank aid consists primarily of loans that are part of lending schemes legislated by government. A number of these special lending schemes are operated by the Japan Finance Corporation, which is a public corporation owned by the Japanese government. See https://www.jfc.go.jp/n/finance/search/shinsaikashitsuke.html. In addition, there is a lending scheme for SMEs directly damaged by the Tohoku earthquake and Tsunami called the Emergency Guarantee for Restoration funded by the Japanese government. To complement government lending schemes there is also the Tohoku Reconstruction Fund that was established jointly by the Development Bank of Japan and local banks in the Tohoku area.

[12] Direct cash payments were part of employment adjustment funds which were aimed at maintaining employment levels. See Hamaguchi (2015) for more details.

[13] Many firms in non-damaged areas provided damaged firms with their technology, know-how, machines, equipment and employees without charge. Some firms financially supported entrepreneurs and new business that were started in damaged areas. The Security Encouragement Fund, which collected money from individuals by Music Securities, provided funds to some local SME in damaged areas. Takaura (2013) studies how 225 Japanese companies listed on the Nikkei Stock Average Index socially contributed to damaged areas and damaged firms. UNCRD (2012) describes a number of case studies on how local firms survive and recover from the earthquake damage and how they contribute to the reconstruction of their local communities and other local firms.

[14] Partner aid includes aid from firms (in the same sector) and includes for example (1) the lease or provision of idle machineries and equipment; (2) the transfer of technology, advice, management, know-how, skill, (3) the provision of their products and services to damaged firms (or good sold more cheaply), (4) buying the products of damaged firms (mainly foods and consumption goods) and (5) to provide support for new business. Todo et al.(2013) provide examples of firms allowing transaction partners to use their plant and machinery in order to fulfil orders and to maintain supply chains.

living in the damage area. Table 4 shows that the proportion of plants receiving aid ranged from just 1.3% who received Voluntary Aid to a high of 15% who received Bank Aid.

[Table 4 about here]

In Table 5 we show the proportion of plants receiving aid by damage type and level. One can see, for example, that 44% of plants that experienced major earthquake damage were recipients of Bank Aid while 29.4% were recipients of Govt Aid. In the case of tsunami damage over half of the plants that experienced major tsunami damage were recipients of Bank Aid, Govt Aid and Partner Aid. Since each column sums to more than 100 we can infer that plants often received more than one type of aid.

[Table 5 about here]

For the case of Bank Aid and Govt Aid, the criteria for receiving aid was entirely based around the extent to which the plant was directly damaged or otherwise affected by the earthquake and/or tsunami. While in most cases the impact experienced by plants was in the form of direct damage, some plants were not directly damaged but were adversely affected by damage in the surrounding area, damage to infrastructure and/or damage to suppliers/customers. Indeed, the final column of Table 5 provides the proportion of plants that experienced no direct earthquake or tsunami damage that still received some aid. We can see, for example, that 3.9% of undamaged plants still received Bank Aid and 2.7% received Partner Aid.

Yaguchi (2014, Ch.5) presents information for a number of case studies on the aid from manufacturing and service firms and establishments. For example, Toyota has many parts and components suppliers and subsidiaries in Tohoku area, and by keeping or increasing their employment in the Tohoku area, Toyota contributes to increased levels of employment in Tohoku area. In July 2012, Toyota established a new subsidiary company "Toyota Motor East Japan" by merging three automobile companies with a new headquarters in the Miyagi prefecture (Tohoku area). Toyota also increased the local contents in parts and components inside the Tohoku area. Finally, in April 2013 Toyota opened the Toyota School in Miyagi prefecture which is an engineering school and job training centre aimed at developing new technologies in an attempt to create an automobile industrial cluster in Tohoku. Yaguchi (2014, Ch.6) also goes on to show how some local firms in Tohoku managed to maintain employment levels and provide aid to other firms.

3 Methodology

In order to examine the effect of pre-disaster planning and post-disaster aid on plants' post-disaster performance we begin by estimating equation (1):

$$STOP_i = \alpha_0 + \alpha_1 PLAN_i + \alpha_2 D_i + \alpha_3 X_i + \varepsilon_i \qquad (1)$$

where $STOP_i$ is the number of days for which plant-level operations stopped as a result of the earthquake and/or tsunami for each plant *i*, $PLAN_i$ is a vector of variables capturing pre-disaster planning, D_i is a vector of variables capturing earthquake and tsunami damage and X_i is a vector of other control variables. Since Todo *et al.* (2014) indicate that supply chain networks can increase plants' resilience to disasters, vector *X* contains the number of trading partners for each plant. It also includes a variable to measure whether or not plants produce a single product or multiple products under the hypothesis that producing multiple products could increase a plant's disaster resilience. Vector *X* also includes whether or not plants have foreign affiliates which could potentially insulate plants to some extent from perturbations to the domestic market and lead to a higher probability of obtaining external sources of funding or aid in kind. Finally, to control for sector specific effects we include 25 sector dummies. Since the dependent variable (*STOP*) is a count variable we estimate equation (1) using negative binomial estimation with robust standard errors.[15]

Whilst a useful measure of the negative impact of a shock such as an earthquake, the number of days of stopped operations is still a very short term measure of the earthquake's impact. The average number of days of stopped operations was 16 (from Table 4) and 90% of plants experienced fewer than 30 days of stopped operations. Given the administrative processes that firms had to go through to obtain any form of aid it is likely that many types of aid would not have reached plants within this short period. Hence, we do not include the aid variables within equation (1).[16]

[15] A Poisson model is not appropriate in our case as our data are over-dispersed. However, the results were quantitatively and qualitatively similar. Results are available from the author upon request.

[16] In unreported estimations we do include the aid variables and find them all to be statistically insignificant.

The second part of our analysis examines the medium term impact of the earthquake and the extent to which pre-disaster policy and post disaster aid affected post-earthquake plant-level sales. We estimate equation (2):

$$SALES_{it} = \alpha_0 + \alpha_1 SALES_{it-1} + \alpha_2 PLAN_i + \alpha_3 AID_i + \alpha_4 D_i + \alpha_5 X_i + \varepsilon_i \qquad (2)$$

where $SALES_{it}$ are the log of total sales of plant *i* for the period April to September 2011, $SALES_{it-1}$ are the log of total sales over the period April to September 2010 and AID_i is a vector of variables capturing post-disaster aid. Other variables are as previously defined. Equation (2) is estimated using OLS with robust standard errors.

Finally, note that equations (1) and (2) also include terms capturing the interaction between pre-earthquake planning variables and both earthquake and tsunami damage, and between the aid variables are earthquake and tsunami damage. To keep the number of interaction terms manageable rather than using individual dummy variables for each level of earthquake and tsunami damage that we used previously, we utilise a single damage index to capture earthquake damage and an equivalent index to capture tsunami damage. It should be noted that our results are consistent with those estimated using individual damage dummies.

The cross-sectional nature of our analysis (albeit with sales data pre and post earthquake) inevitably limits our ability to deal with endogeneity concerns. Such concerns could arise through reverse causality if, for example, a firm that experienced a reduction in sales was more likely to receive aid. If true, then this would exert negative pressure on the estimated coefficients on aid suggesting that ours would be conservative estimates. The fact that we don't find a significant negative relationship between any type of aid and sales, and in some cases find a positive significant relationship suggests that the extent of any reverse causality is limited. Reverse causality between *pre-earthquake* planning and *post-earthquake* sales would appear to be less of a concern but the above argument would still apply. Alternatively, endogeneity could arise if an unobserved variable influenced both post-earthquake sales and aid (or post-earthquake sales and pre-earthquake planning). Although it is not obvious to us what such a variable could be, our cross-sectional data means we are unable to explore this issue further other than through our various controls including industry dummies.

4. **Results**

Table 6 provides our estimates of the number of days of stopped operations from equation (1). As expected, models (1) to (7) clearly show that earthquake damage and tsunami damage are positive and significant determinants of the number of days of stopped operations. The numbers reported in Table 6 are incident rate ratios. Taking model (1) as an example, this means that if Quake Damage increased by 1 unit, the number of days of stopped operations would increase by a factor of 1.47. The equivalent figure for Tsunami Damage is 2.18 indicating that, on average, Tsunami damage had a greater impact on the duration of stopped operations than did earthquake damage.

In models (1) to (5) the pre-disaster planning variables are added incrementally while model (6) includes them all together. In model (7) we include the interactions between all of the planning variables and all of the damage variables but for reasons of space we only report those interaction terms that are statistically significant. It is only in model (7) that any of the planning variables become statistically significant where we find that having a transport substitution policy and a business continuity plan reduces the days of stopped operations by a factor of 0.43 and 0.64, respectively. The fact that these variables are significant despite the inclusion of interactions between the damage and the policy variables suggests that these two policies are benefiting undamaged plants. However, we also find that earthquake damaged plants that had production substitution policies had more days of stopped operations (coefficients greater than 1), presumably reflecting the fact that the pressure to resume operations was lessened for those plants with such a policy. In this case, production would be shifted to an undamaged plant allowing the damaged plant to be rebuilt or repaired to a potentially higher specification. Finally, tsunami damaged plants that had business continuity plans in place experienced fewer days of stopped operations where stopped operations were found to be reduced by a factor of 0.71.

Finally, in terms of the other control variables included in models (1) to (7), the results show that only the presence of overseas affiliates is statistically significant. Plants that have such affiliates experienced a reduction in stoppages by a factor of 0.65 to 0.66. This suggests that plants with affiliates are more resilient to natural disasters and perhaps reflects the fact that such plants are less dependent on the disrupted local market and potentially local suppliers that may have been damaged in the disaster.

We now consider the impact of the earthquake and tsunami on the sales growth of plants in the period immediately following the disaster. Table 7 provides our estimates of equation (2) in which the dependent variable is the log of post-earthquake sales. Model (1) includes our damage indices and basic controls, model (2) introduces the pre-disaster planning variables, model (3) includes the post-disaster aid variables, model (4) includes both planning and aid variables, model (5) includes interactions between the aid and damage variables and finally model (6) includes interactions between the planning and damage variables. Note that following on from Table 6 we only report statistically significant interactions terms in Table 7.

With regard to the damage variables we find that earthquake damage is not a statistically significant determinant of post-earthquake sales. However, tsunami damage is statistically significant and negative in 5 of our 6 models. The magnitude of the coefficients is between -0.41 and -0.44 which tells us that a 1 unit increase in the tsunami damage index results in a reduction of post-earthquake sales of between 33.6% and 35.6%.[17]

Turning to the planning variables, in model (4) we find that plants with a transport substitution policy experienced increased sales while those with a production substitution policy experienced a reduction in sales. This latter result is consistent with our results in Table 6 and suggests that production is shifted elsewhere (temporarily at least). When interactions between the planning variables and the damage variables are included in model (6) we find that it is earthquake damaged plants with transport substitution policies that experienced increased sales. Model (6) also shows that tsunami damaged plants with business continuity plans and with diversified parts suppliers also experienced increased sales. In terms of magnitude, taking the example of diversified parts suppliers, we find that a one unit increase in tsunami damage reduced sales by 8.6% for plants with diversified parts suppliers compared to a reduction of 34.9% for tsunami damaged plants without such a policy.[18]

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[17] When the estimated coefficient on tsunami damage is -0.41 the effect of tsunami damage on sales is calculated as exp (-0.41)-1 = 0.336.

[18] The marginal effect of tsunami damage in the presence of diversified parts suppliers (from model 6) is calculated as exp((-0.43 + (0.34 * diversified parts supplier dummy))-1) = 0.086.

Turning to the aid variables, models (3), (4) and (6) indicate that bank aid and partner aid are statistically significant and positive determinants of post-earthquake sales. Recipients of bank aid experienced sales growth of between 11.6% and 13.9%, relative to those with no aid, depending on our model. Equivalent figures for partner aid are between 20.9% and 23.3%. Model (5), which includes interactions between the damage variables and the aid variables, reveals that it is tsunami damaged recipients of bank and partner aid that experienced a statistically significant increase in sales. Aid was not statistically significant for undamaged plants.[19] A one unit increase in tsunami damage reduced sales by 14% for recipients of bank aid, and by 47% for recipients of partner aid, compared to a reduction in sales of 52.3% for tsunami damaged plants that did not receive such aid.[20]

Finally, of the other control variables reported in Table 7 pre-earthquake sales are a positive and strongly significant determinant of post-earthquake sales and the number of trading partners is positive and weakly significant (at 10%) in some models. This latter result suggests that, other things being equal, a greater number of trading partners may provide some resilience to the economic shocks from a natural disaster and is consistent with the findings of Todo *et al.* (2014).

5. Conclusions

In this paper we have examined the impact of pre-disaster planning and post-disaster aid on the performance of plants that were in the region affected by the Great East Japan Earthquake in 2011. Our results show that, unsurprisingly, both the earthquake and the subsequent tsunami had a significant and positive effect on the length of time that firms' operations ceased, with tsunami damaged plants taking longer to recover. However, when we consider the sales growth in the six months following the earthquake we find that only tsunami damage has a negative effect. Indeed, we find that plants that had in place a business continuity plan recovered more quickly than plants without such a plan. Perhaps more surprisingly we find that plants that have a production

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[19] This is despite the fact that 3.9% of bank aid recipients and 2.7% of partner aid recipients were not directly damaged themselves (from Table 5).

[20] Calculated as exp(-0.75 + (0.60*bank aid dummy))-1 = -0.14 and exp(-0.75 + (0.12*partner aid dummy))-1 = -0.47. Note that the coefficient on the tsunami damage index (of -0.75) is not statistically significant in model 5 and so these estimates should be treated with caution.

substitution policy take longer to restart operations suggesting that production was shifted temporarily elsewhere allowing the firm the flexibility to repair damaged building perhaps to a higher specification.

In terms of the aid variables our results suggest that bank aid and partner aid were the more important forms of aid for post-quake sales growth, especially so for tsunami damaged plants whereas other forms of aid including government aid appear to have had a negligible effect. However, it is worth noting that bank aid was largely administered on behalf of the government so may be capturing the effect of government aid indirectly.

Although our results provide a rather mixed story there are implications for policy. Our results suggest that plants should put in place business continuity plans and also firms with multiple plants should plan to switch production in the case of a natural disaster. For policymakers it appears that directing aid through the local banking system has the largest benefits and that indirectly, encouraging firms to build relationships with foreign affiliates can help to secure supply chains allowing a faster recovery in terms of sales growth. In future work we would like to explore further the mechanisms by which different sources of aid affect firm behaviour and link this with labour and employment outcomes.

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Table 1. Variable definitions:

Days of stopped operations	Number of days for which the plant's operations ceased
Sales (post-quake)	Sales for the period April to September 2011
Sales (pre-quake)	Sales for the period April to September 2010
Quake Damage	A single variable measuring earthquake damage on a scale of 0 to 3, where 0 is no damage, 1 is minor damage, 2 is more severe partial damage (medium damage) and 3 is major damage
Tsunami Damage	A single variable measuring earthquake damage on a scale of 0 to 3, where 0 is no damage, 1 is minor damage, 2 is more severe partial damage (medium damage) and 3 is major damage
single_product	A dummy variable for plants that produce one product only
export_dum	A dummy variable for plants that export
overseas_dum	A dummy variables for plants with overseas affiliates
NumTradingPartners	The total number of trading partners for each plant
Transport_subs_policy	A dummy variable for plants that undertook pre-quake planning for an alternative transportation method for the plant's products in the event of a natural disaster
Prodn_subs_policy	A dummy variable for plants that undertook pre-quake planning for alternative production arrangements with other plants in Japan in the event of a natural disaster
BusinessContinuityPlan	A dummy variable for plants that had a pre-existing business continuity plan (BCP)
DiversifiedPartsSuppliers	A dummy variable for plants that had deliberately diversified their parts and component suppliers pre-natural disaster
Bank_aid	A dummy variable for plants that received financial aid from banks following the earthquake following the earthquake
govt_aid:	A dummy variable for plants that received aid from government, local government or public bodies following the earthquake
friend_aid	A dummy variable for plants that received aid from friends and relatives following the earthquake
plant_aid	A dummy variable for plants that received aid from other plants in the same industry following the earthquake
partner_aid	A dummy variable for plants that received aid from trading partners following the earthquake
vol_aid	A dummy variable for plants that received aid from volunteer workers following the earthquake

All variables are from the RIETI special survey, with the exception of NumTradingPartners which comes from Tokyo Shoko Research.

Table 2. Earthquake and Tsunami Damage in Our Sample

	Number of Plants in our Sample	% of Plants in our Sample
Major Earthquake Damage	20	1.55
Medium Earthquake Damage	86	6.69
Minor Earthquake Damage	811	63.2
No Earthquake Damage	366	28.6
Major Tsunami Damage	44	3.4
Medium Tsunami Damage	15	1.2
Minor Tsunami Damage	15	1.2
No Tsunami Damage	1210	94.3

Table 3. Composition of Sample and Damage by Sector

Sector	No. plants	% plants	Major Quake Damage*	Medium Quake Damage	Minor Quake Damage	Major Tsunami Damage	Medium Tsunami Damage	Minor Tsunami Damage
Food	164	12.8	2.4	8.5	60	4.2	1.2	1.2
Beverages, tobacco & feed	37	2.9	2.7	5.4	51	16.2	5.4	2.7
Textile mill products	27	2.1	3.7	11.1	67	0	0	0
Lumber and wood products	61	4.8	1.6	4.9	54	8.2	0	1.6
Furniture and fixtures	7	0.6	0	0	57	0	0	0
Pulp, paper & products	27	2.1	0	11	52	3.7	0	3.7
Printing	91	7.1	1.1	14	63	2.2	1.1	2.2
Chemical products	15	1.2	0	0	93	0	0	0
Petroleum and coal products	3	0.2	0	0	67	0	0	0
Plastic products	65	5.1	0	6.2	74	1.5	0	0
Rubber products	8	0.6	0	13	75	0	0	0
Leather products	1	0.08	0	0	0	0	0	0
Ceramic, stone and clay products	100	7.8	3	5	50	1	2	0
Iron and steel	25	2.0	0	4	68	0	0	4
Non-ferrous metals	25	2.0	4	12	68	0	0	0
Fabricated metals products	165	12.9	1.2	4.2	72	4.8	1.2	0.61
General purpose machinery	8	0.6	0	0	37.5	0	0	13
Production machinery	67	5.2	30	30	64	3	1.5	0
Business oriented machinery	25	2.0	0	8	40	4	0	0
Electronics	25	2.0	0	16	56	0	0	0
Electrical machinery	115	8.9	1.7	6.1	69	1.7	0.87	2.6
IT equipment	12	0.9	0	17	67	0	0	0
Transport equipment	49	3.8	2	4.1	57	6.1	0	2
Misc. equipment	134	10.4	0	5.2	68	3	1.5	0.74
Non-manufacturing	27	2.1	3.7	3.7	67	3.7	7.4	0

* the % of plants in each sector that suffered that level of damage

Table 4. Descriptive Statistics:

	Mean	Standard deviation	Min	Max
Quake Damage	0.81	0.63	0	3
Tsunami Damage	0.15	0.62	0	3
Days of stopped operations	16.08	28.48	0	300
Sales (post-quake) (10,000 Yen)	81910	1644011	32	1,505,142
Sales (pre-quake) (10,000 Yen)	80782	1507183	19	1,970,500
single_product	0.48	0.50	0	1
export_dum	0.29	0.45	0	1
overseas_dum	0.03	0.16	0	1
NumTradingPartners	8.23	5.58	1	35
Transport_subs_policy	0.022	0.15	0	1
Prodn_subs_policy	0.032	0.18	0	1
BusinessContinuityPlan	0.086	0.28	0	1
DiversifiedPartsSuppliers	0.051	0.22	0	1
Bank Aid	0.15	0.36	0	1
Govt Aid:	0.091	0.29	0	1
Friend Aid	0.033	0.18	0	1
Plant Aid	0.052	0.22	0	1
Partner Aid	0.12	0.32	0	1
Voluntary Aid	0.013	0.11	0	1

Table 5. The Percentage of Plants Receiving Aid by Damage Level and Type

	Earthquake Damage				Tsunami Damage				No tsunami or earthquake damage
	Major*	Medium	Minor	None	Major	Medium	Minor	None	
Bank Aid	44.1	34.6	15.9	8.6	52.7	69.6	38.1	13.0	3.9
Govt Aid	29.4	23.1	7.8	7.3	54.1	47.8	23.8	6.6	2.3
Friend Aid	14.7	10.0	2.5	3.0	31.1	34.8	9.5	1.7	0
Plant Aid	17.6	12.3	4.4	4.7	47.3	34.8	23.8	3.0	0.6
Partner Aid	23.5	23.1	12.0	7.8	55.4	52.2	42.9	9.1	2.7
Voluntary Aid	8.8	4.6	0.5	1.7	20.3	17.4	4.8	0.3	0

* e.g. the percentage of plants that experienced major earthquake damage that were recipients of each type of aid

Table 6. Dependent Variable: Number of Days of Stopped Operations

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Quake Damage	1.47***	1.47***	1.46***	1.47***	1.47***	1.46***	1.40***
	(0.045)	(0.046)	(0.045)	(0.044)	(0.045)	(0.039)	(0.040)
Tsunami Damage	2.18***	2.19***	2.18***	2.18***	2.18***	2.18***	2.13***
	(0.090)	(0.094)	(0.089)	(0.090)	(0.090)	(0.094)	(0.11)
Transport_Subs_Policy		0.84				0.73	0.43**
		(0.15)				(0.21)	(0.17)
Prodn_Subs_Policy			1.05			1.28	0.79
			(0.089)			(0.21)	(0.15)
BusinessContinuityPlan				0.87		0.87	0.64***
				(0.087)		(0.086)	(0.098)
DiversifiedPartSuppliers					0.88	0.90	1.06
					(0.12)	(0.12)	(0.18)
Prodn_subs_policy*Quake Damage							1.50*
							(0.31)
BusinessContinuityPlan*Tsunami Damage							0.71***
							(0.093)
Sales (pre quake)	0.98	0.98	0.98	0.98	0.98	0.99	0.98
	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)	(0.017)
NumTradingPartners	0.99	0.99	1.00	0.99	0.99	1.00	1.01
	(0.074)	(0.074)	(0.075)	(0.075)	(0.075)	(0.075)	(0.075)
Single_Product	0.94	0.94	0.94	0.94	0.94	0.93	0.94
	(0.061)	(0.061)	(0.061)	(0.061)	(0.061)	(0.060)	(0.060)
Overseas_Dum	0.65***	0.65***	0.65***	0.66***	0.65***	0.65***	0.66***
	(0.092)	(0.091)	(0.092)	(0.096)	(0.091)	(0.094)	(0.093)
Observations	913	913	913	913	913	913	913

We report incident rate ratios from negative binomial estimations. Robust standard errors in parentheses. *** p<0.01, ** p <0.05, * p<0.1.
Note that all interactions between the pre earthquake planning variables and Quake Damage and Tsunami Damage were included but, for reasons of space, only those that are statistically significant are reported. Industry dummies are included.

Table 7. Dependent Variable: Log of Sales (post-quake)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
Quake Damage	0.055	0.060	0.039	0.044	0.045	0.048
	(0.063)	(0.058)	(0.058)	(0.054)	(0.065)	(0.032)
Tsunami Damage	-0.41***	-0.41***	-0.44**	-0.44**	-0.75	-0.43***
	(0.13)	(0.14)	(0.19)	(0.19)	(0.48)	(0.15)
Transport_Subs_Policy		0.41		0.46**	0.52**	-0.020
		(0.24)		(0.20)	(0.22)	(0.68)
Prodn_Subs_Policy		-0.51		-0.52*	-0.49	0.081
		(0.31)		(0.30)	(0.31)	(0.95)
BusinessContinuityPlan		0.028		0.023	0.045	-0.17
		(0.091)		(0.086)	(0.074)	(0.13)
DiversifiedPartSuppliers		0.032		0.023	-0.0044	0.18
		(0.048)		(0.042)	(0.050)	(0.11)
Bank Aid			0.13**	0.12**	0.023	0.11*
			(0.057)	(0.054)	(0.18)	(0.059)
Govt Aid			-0.18	-0.19	0.058	-0.16
			(0.13)	(0.13)	(0.28)	(0.11)
Friend Aid			-0.020	-0.038	-0.24	-0.079
			(0.25)	(0.25)	(0.34)	(0.27)
Plant Aid			0.11	0.13	-0.15	0.079
			(0.18)	(0.19)	(0.29)	(0.18)
Partner Aid			0.19***	0.19***	0.18	0.21***
			(0.050)	(0.050)	(0.20)	(0.061)
Voluntary Aid			-0.14	-0.19	-0.22	-0.36
			(0.74)	(0.72)	(0.51)	(0.65)

(continued on next page)

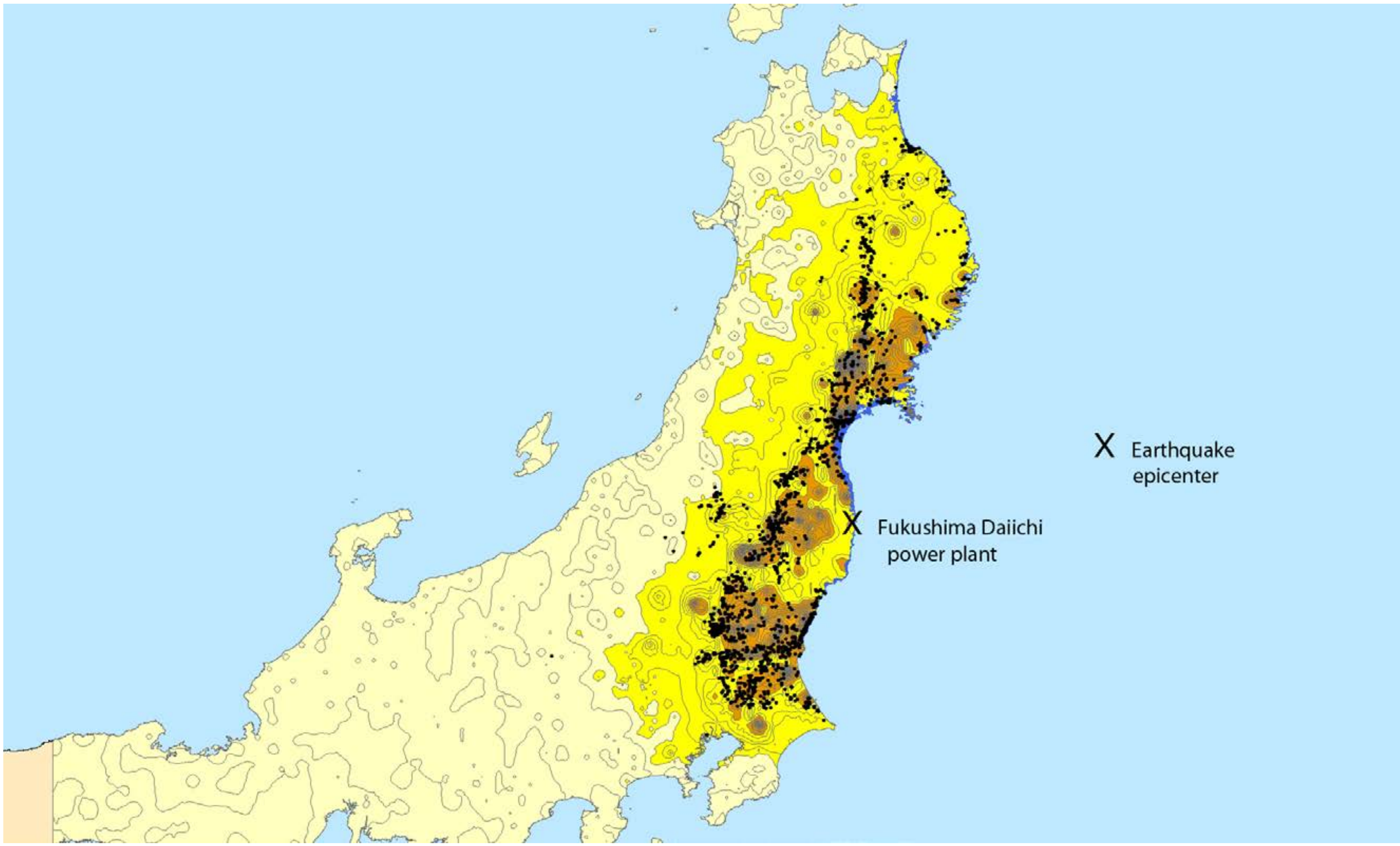
Table 7 continued. Dependent Variable: Sales (post-quake)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
Bank Aid*Tsunami					0.60**	
					(0.3)	
Partner Aid*Tsunami					0.12**	
					(0.06)	
Transport_Subs_Policy*Quake Damage						0.67***
						(0.22)
Prodn_Subs_Policy*Quake Damage						-0.88
						(1.07)
BusinessContinuityPlan*Quake Damage						0.27*
						(0.16)
DiversifiedPartSuppliers*Tsunami Damage						0.34***
						(0.14)
Log of Sales (pre quake)	0.94***	0.93***	0.93***	0.93***	0.93***	0.93***
	(0.023)	(0.023)	(0.024)	(0.023)	(0.022)	(0.023)
NumTradingPartners	0.11	0.11*	0.11	0.10	0.11*	0.11
	(0.068)	(0.064)	(0.070)	(0.066)	(0.062)	(0.067)
Single_Product	-0.031	-0.025	-0.020	-0.014	-0.016	-0.0072
	(0.042)	(0.043)	(0.046)	(0.046)	(0.044)	(0.050)
Overseas_Dum	-0.0014	0.0061	-0.014	-0.0039	-0.014	-0.026
	(0.074)	(0.082)	(0.067)	(0.071)	(0.079)	(0.084)
Observations	1,283	1,283	1,283	1,283	1,283	1,283
R-squared	0.722	0.724	0.725	0.727	0.738	0.734

Ordinary least squares estimations. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

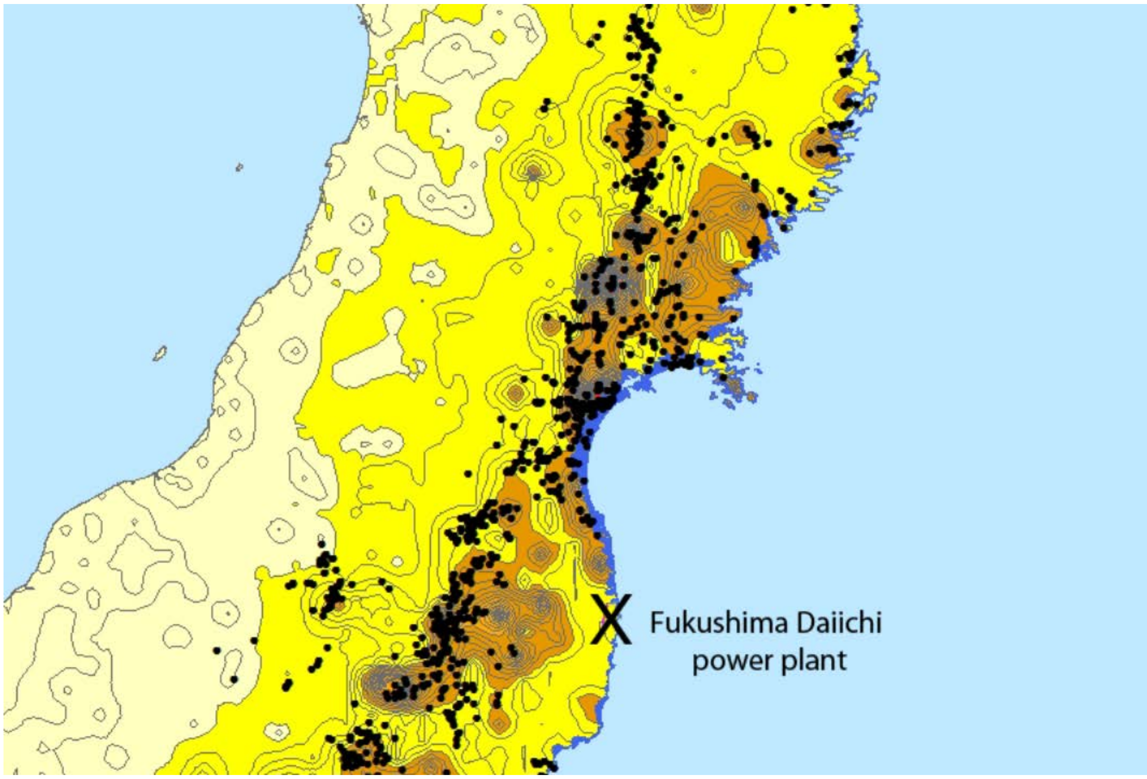
Note that all interactions between the pre earthquake planning variables and Quake Damage and Tsunami Damage were included as well as all interactions between the aid variables and Quake Damage and Tsunami Damage but, for reasons of space, only those that are statistically significant are reported. Industry dummies are included.

Figure 1. Map of Northern Japan Showing Earthquake Damage and Epicenter and the Location of Plants in Our Sample



Notes: (1) Black dots indicate plants in our sample, (2) Dark blue area on the coast is Tsunami flooded area; (3) Color shading – from red (1.2+), orange(0.3-1.2) until yellow (0.2-) – indicate degree of decreasing peak ground acceleration (%g).

Figure 2. Close up of Part of Affected Area



Notes: (1) Black dots indicate plants in our sample, (2) Dark blue area on the coast is Tsunami flooded area; (3) Color shading – from red (1.2+), orange(0.3-1.2) until yellow (0.2-) – indicate degree of decreasing peak ground acceleration (%g).