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Natural Disasters, Industrial Clusters and Manufacturing Plant Survival

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Abstract

In this paper, we examine the role of industrial clusters and infrastructure in mitigating or magnifying the impact of the 1995 Kobe earthquake on the survival of manufacturing plants and their post-earthquake economic performance. Our methodological approach is to use information on building-level and infrastructure damages and other plant and building-characteristics including district-level variables to control for spatial dependencies to estimate a cox-proportional hazard model. Our results show that plants that were members of existing clusters were less likely to survive although we found some evidence that damaged plants in stronger clusters had a better survival probability. Further analysis shows that the strength of the cluster had no impact on a number of performance indicators including productivity, employment and output. Road damage in the nearby locality has a negative impact on plant survival.

Keywords: Earthquake, Industrial clusters, Natural disaster, Survival analysis, Productivity

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

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Introduction

There is a burgeoning literature that investigates the impact of natural disasters on economic growth (Loayza *et al.* 2009, Hochrainer 2009, Hallegatte and Dumas 2009, Strobl 2011 and Ahlerup 2013). The majority of the studies that estimate the macroeconomic impact of particular events on economic growth tend to be cross-country studies and generally find mixed results.[1] However, despite the considerable economic damage caused by natural disasters there has been surprisingly little research undertaken on the effect of disasters on economic activity and even fewer studies that look at the role of agglomeration economies or industrial clusters on the impact of disasters.

The motivation for this paper is to provide a missing piece in the natural disasters literature by being one of the first papers to take a microeconomic approach to examine the impact of natural disasters at the local level. Specifically, we re-examine the Kobe earthquake that struck off the coast of Japan on January 17th 1995 to investigate the impact of the earthquake on the probability of plant survival with emphasis on the role of industrial clusters and infrastructure damage to see whether they have any discernible effect on the probability of a plant surviving.[2] One particular aspect of the Kobe earthquake is that despite dire warnings of a decade long recovery, the effect on the Japanese economy as a whole was, if anything, positive with even 1995 experiencing higher growth than any of the preceding ten years (Horwich 2000). One argument for the limited national economic effect is the substitution of the productive capacity damaged in the disaster to other parts of the country which have excess capacity. However, while the national economic recovery was relatively rapid, this was not the case at the local level. As Edgington (2010) points out, even by 2006 manufacturing output in Kobe was only 83% of its 1991 level and retail sales only 86%. Furthermore, in 2005 69% of small firms reported that their profits had not returned to pre-quake levels (Nikkei Weekly 2005).

The contribution of this paper is two-fold. First, building on Cole *et al.* (2014) we construct a measure of building-level damage as a result of the Kobe earthquake using geo-coding techniques and building level surveys from the Japanese and Kobe City government. We then employ a proportional hazards modelling approach to estimate the impact of plant-level damage

[1] See Feblermayr and Gröschl (2014) for a survey of the economics of natural disasters paying close attention to those studies that use EM-DAT and others that use data based on geophysical and meteorological data. In a review of 14 of the main studies that examine the economic impact of natural disasters they find 12 use EM-DAT data. Of the 368 point estimates in these 14 studies, 35% of estimates are statistically insignificant at the 10% level. Of those that are statistically significant 44% are positive and 56% are negative.

[2] Although officially known as the Hanshin-Awaji Great Earthquake it is also known as the Hanshin or Kobe earthquake. In this paper we will following Horwich (2000) and refer to the Kobe earthquake.

on firm survival over time controlling for geographic, regional and plant characteristics including our cluster measures. Second, we estimate a series of panel fixed-effects models to investigate the economic performance of surviving plants and whether clustering influences plant performance.

Earthquakes provide an effective natural experiment in part because they are so difficult to predict. From the point of view of economic analysis, this unpredictability means that earthquakes can be considered to be a truly exogenous shock. Damage from an earthquake tends to be divided into primary and secondary effects, with the former consisting of the physical damage to buildings and infrastructure and the latter referring to the damage to the wider geographical area.[3] The channels by which an earthquake effects plant survival are as follows. First, an earthquake can be considered as a traditional cost shock as the firm has to pay for repairs to damaged buildings and machinery. A disaster can also be considered a demand shock if local customers are damaged and subsequently delay or cancel existing orders either temporarily or permanently. An earthquake can also be considered a supply shock if the damaged plant is unable to fulfil orders from existing customers who then go elsewhere or if the plant is undamaged but is still unable to fulfil orders due to damage to the plants that supply intermediate goods as part of the firms larger supply chain. Of relevance to this paper is the fact that earthquakes can have a unique impact on plant activity when plants of the same sector are located within a relatively small geographical area. Different plants or groups of plants can be impacted differently depending on the type of earthquake and the nature of the shake patterns produced by the earthquake. This has implications for plants that are geographically concentrated in relatively small areas.

Paul Krugman in his recent Stockholm lecture[4] argued that second nature agglomeration where firms want to be close to other firms for reasons other than to be close to natural resources of climate (first nature agglomeration) no longer holds for developed countries like Japan. Kim (1998), Brulhart and Traeger (2005) and Combes *et al.* (2008) have shown that agglomeration economies in developed countries appear to be unravelling. However, as Brülhart (2009) points out, agglomeration economies are still very strong in developing countries that account for 85% of the world's population. Clusters are however still important drivers of growth in developed countries. For example, Duranton and Overman (2005) examine UK postcode districts and find that more than half of all industries are significantly more clustered than a random location

[3] The heterogeneous nature of earthquakes is a result of the damage from the associated landslides, fires, soil liquefaction, floods and Tsunamis that can occur at the time of the earthquake and depend on local conditions.
[4] Paul Krugman's Nobel slides can be found at http://nobelprize.org/nobel_prizes/economics/laureates/2008/.

process would suggest although because most clustering occurs at a spatial scale below 50 kilometres they are missed in the aggregate studies. Simpson (2007) also finds evidence of increased clustering in the UK between 1997 and 2005. This leads to the hypothesis that an exogenous shock may further weaken agglomeration economies to the extent that previously viable clusters in Kobe are no longer self-sustainable leading to large scale exits of cluster members. There is anecdotal evidence from the non-leather shoe industry in Kobe that in the face of increased competition from China the earthquake was the trigger for the rapid decline of this industry as agglomeration economies were no longer sufficient to maintain current production and employment levels.

Hence, we expect agglomeration economies and clustering to matter for three reasons. First, if the earthquake leads to the exit of plants in that industry it may have the effect of weakening the agglomeration economies and a subsequent underperformance of plants in that cluster that had previous benefited from the now defunct agglomeration economics and hence leads to additional plant exit. Second, being a member of a geographical and industrial cluster may also lead to the cannibalisation of damaged firms by those left undamaged as they take market share from the injured party. Alternatively, being in a cluster may act as a defence against damage to an individual plant if resources can be shared or if there is a stock of potential employees in that location previously attracted by the location of the cluster that can now be employed as substitutes for previous employees that may have been killed, injured or migrated away from Kobe. Which effect is the stronger requires empirical investigation.

Our results show that clustering has a negative impact of plant survival probabilities suggesting a cannibalisation of the business by the surviving members of the cluster although being in a cluster appears to have little impact of subsequent firm performance. Our infrastructure variable based on the local road damage is a positive determinant of plant exit as expected.

The reminder of this paper is organised as follows. Section 2 provides a little background to the Kobe earthquake while Section 3 describes our data and the methodological approach. Section 4 presents the results and section 5 concludes.

1. The Kobe 1995 earthquake and the Japanese economy

The earthquake that shook the Hanshin region of Western Japan that includes the city of Kobe occurred on the 17th January 1995 at 5.46am and lasted for a little under one minute. The strength of the earthquake was 7.2 on the Richter scale. Kobe is 430 km southwest of Tokyo and is an important port city with a population of approximately 1.5 million that contributed around 10% of Japan's total GDP before the earthquake (Orr 2007). The epicentre was approximately 25 km from central Kobe and was the first major earthquake to strike a Japanese urban area since the end of World War II. As a port city Kobe was home to a large number of working class and immigrant communities as well as a middle class involved in the shipping and industrial sectors. As one of Japan's older cities it had a very high population density (between 6,000 and 12,000 people per square kilometre) with a housing stock in the older parts of the city often constructed using heavy roof tiles and light frames. This design was useful for withstanding storms but was not well suited to protect the inhabitants against earthquakes (Orr 2007).[5]

According to the City of Kobe (2012) a total of 4,571 people were killed with a further 14,687 injured. A notable 59% of those who died were over the age of 60, the majority of whom died due to crush related injuries. By the end of January 1995 there were nearly 600 shelters operating which at their peak were being used by 236,899 individuals by the end of that month. The damage to buildings was considerable. The number of fully and partially collapsed buildings was 67,421 and 55,145 respectively. Fire damage caused the complete destruction of 6,965 structures with 80 and 270 being half burned and partially burned respectively (covering a total area of 819,108 m^2).[6]

Utilities were also severely impacted. In addition to city-wide power and industrial water failure, 25% of phone lines were out and 80% of gas supplies no longer operated. The total damage was estimated to be around 6.9 trillion Yen. It is worth noting that only 3% of Kobe homeowners had earthquake insurance and even those that did had a $100,000 limit on the payments. However, the value of most Japanese homes is closely correlated with the land price which retained its value and enabled homeowners to borrow against this value to rebuild. It be should be noted that many landowners chose to sell their land to speculators rather than rebuild and those renting usually moved elsewhere rather than wait for their homes to be rebuilt.

[5] Much of the factual information in this section is derived from Edgington (2010) who provides detailed information on the reconstruction of Kobe and the geography of the crisis and the report of the UNRCD (1995) called the "Comprehensive Study of the Great Hanshin Earthquake".

[6] Firestorms were a particular problem in the narrow streets of the older districts where the traditional wooden houses were still prevalent. The older districts were also the areas where the older residents and students tended to live often in low-cost housing while the middle classes tended to live outside of the centre in higher quality and newer homes (Shaw and Goda 2004).

Most importantly for this paper is the effect on industry and particularly on the existing clusters that were located in Kobe often in relatively small geographical areas. According to the City of Kobe (2012), many large manufacturers suffered damage to their main factories and had production lines interrupted. For the small and medium sized enterprises damage was extensive. The examples given in the City of Kobe (2012) report note that 80% of factories were damaged in the non-leather shoe industry and 50% of the Sake breweries were seriously damaged. In addition, the tourism and agriculture and fishing sectors were damaged. It is interesting to note that although the overall mining and manufacturing production index in September 2007 was 119.8% of the September 1994, similar values for non-leather shoes and Sake Breweries are only 78.8% and 40.4% respectively suggesting a de-agglomeration effect (Maejima 1995 and Sumiya 1995). This impact on local industry is often masked by the aggregate Japanese GDP values which had surpassed the 1994 value as soon as 1998. Chang (2001) points out that this was mainly a result of construction induced economic stimulus. In terms of the local economy, tourism fell by over 50% between 1994 and 1995 whilst retail spending in the main department stores fell by more than 45% with only 76.2% of retail stores reopening meaning that 2,281 stores remained closed (Takagi 1996).

One of the major concerns for local industry is the decrease in gross production as a result of companies moving some or all of their production to other parts of Japan. This was exacerbated by damage to roads, rail and the port which further encouraged firms to relocate. The concern was that once production had moved it would not return following the period of reconstruction.[7] This is particularly important for those sectors that had previously enjoyed strong economies of agglomeration such as the non-leather shoe and Sake industries. Problems were also exacerbated by the displacement of shipping from the port of Kobe to nearby ports in China and South Korea a lot of which did not return even after the Port reconstruction. Further difficulties were caused by the collapse of the Hyogo Bank in Kobe following business and individual bankruptcies from the bank's borrowers which in turn lead to a fall in local land prices and hence further bad loan difficulties (Edgington 2010). In Kobe the damage from the earthquake coupled with an industrial structure that relied on the traditional heavy industries of shipbuilding and steel meant that recovery in certain sectors was challenging. This also meant that the City of Kobe had to incur considerable debt to continue to pay for the city's reconstruction. Johnston (2005) points out that by the end of 2005 the City of Kobe had more than 3 trillion Yen in municipal bonds outstanding and was effectively bankrupt. Given firms

[7] Ashitani (1995) highlights the example of Sumitomo Rubber Industries who closed and relocated a plant that had been operating since 1909 to Aichi and Fukushima prefectures taking 840 employees with them.

also took on considerable borrowings following the earthquake they too came under financial pressure due to the relative slow growth of the Japanese economy.

However, as Horwich (2000) points out, whilst the non-interest loans and subsidies for factory construction certainly helped not all firms could get access to these funds leading to further bankruptcies. It must be remembered that whilst these loans were welcomed by business and in many cases meant that the business was able to continue the increased debt burden was to lead to continued bankruptcy over the next 10 years (Edgington 2010).

One mitigating factor that helped the larger companies is that Kobe was membership of wider conglomerates (keiretsu) which had access to funds to enable rapid recovery. Examples include Kobe Steel, Kawasaki Steel and Mitsubishi Heavy Industries. However, small and medium sized enterprises were less fortunate. Edgington (2010) cites a Kobe Chamber of Commerce survey that found that for the first one or two years following the earthquake large numbers of businesses and retailers were operating out of tents and prefabricated buildings with many others suffering continued financial problems that often resulted in the closure of the business. (HERO 1998). Moreover, the small and medium sized firms found it difficult to benefit directly from the large construction projects that were often lead by Tokyo headquartered corporate companies. According to Saito (2005) the most affected firms were those reliant on local demand and those who faced lost cost competition from China. Likewise, after 1997 when the construction phase was largely complete there was a further round of business failure as construction related money dried up.

We also briefly address the reconstruction efforts that were implemented following the earthquake. Given the heterogeneous nature of the reconstruction expenditure it is important to have an understanding of the decision making process. Although considerable effort was targeted at house building, neighbourhood community reconstruction projects and health care, in this paper we are primarily concerned with economic revitalization. The main targets according the City of Kobe (2012) were to secure job opportunities through early recovery, to promote local industries that are perceived to be central to urban restoration, to create new businesses and to encourage growth industries to move to Kobe which will result in a more sophisticated industrial structure. Much of this work came under the Hansin-Awaji Economic Revitalization Organization which operated between December 1995 and March 2005. Emergency measures provided by the government to firms included an emergency loan system (ended 31st July 1995) which provided 94.9 billion Yen in loans in 5,979 cases and a further 23.2 billion Yen in 4,129 cases for unsecured loans. In addition 170 new temporary factories were built. Between 1998 and 2005 it was also possible to receive targeted loans and business guidance on how to re-open a business in Kobe. Similarly, certain tax reductions were made available for rebuilding businesses. Publically operated factories were also built that could be rented (1996-1999). Other initiatives include a rental assistance scheme to operate in private factories and interest subsidies for small and medium sized businesses that wanted to invest in new equipment. Finally, to help attract new industries and international trade, the Kobe Enterprise Zone was approved in January 1997 which had attracted 374 firms by 2006 and was the attempt to rebuild clusters in Kobe albeit in very different sectors.[8]

One important aspect of the damage discussed so far is the heterogeneous nature of the destruction across the nine major wards of Kobe. Of the nine wards, Higahi Nada, Nada, Chuo, Hyogo, Nagata, Suma, Tarumi, Nishi and Kita the most damage occurred in Nagata, Higashi Nada and Nada respectively. The geographical clusters of firms in certain areas meant that certain sectors were severely damaged whilst others experienced only minor damage.

In addition to the magnitude, depth and timing of the earthquake, the scale of the destruction was caused by two key factors. First, the soil in many areas of the city was soft and water saturated which led to landslides and structural damage as a result of liquefaction. This meant that damage was concentrated in a narrow area of soft soil 30km long and just 2km wide (Orr 2007). Second, Kobe itself is located on a narrow strip of land between the Rokko mountains and Osaka Bay which meant that city lifelines were easily cut not least because they were almost all installed prior to more recent building codes. Hence, immense damage was caused to infrastructure including the "earthquake proof" expressway and high-rise buildings. In addition, tunnels and bridges were destroyed and train tracks buckled. Figure 1 presents a map of the greater Kobe region and includes the major fault lines of the earthquake and the twelve different wards affected by the earthquake.

[Figure 1 about here]

In terms of utilities it is important to observe that within seven days of the quake electricity had been restored and within 100 days restoration of industrial water, gas and telephone lines had all be completed. By the end of 1995 all railway and bus lines were fully operational with roads and nearly all bridges being fully restored by the end of September 1996. Hence, although

[8] In a related development the Port of Kobe had largely been redeveloped by the end of March 1997. However, the number of containers handled by the Port of Kobe in 2997 was still only 84.8% of the 1994 value although the total value of imports in 2007 was 106.4% of the 1994 value and exports were 95.3% of the 1994 value.

infrastructure damage is thought to have an effect on economic performance the Japanese government tried to ensure that the disruption was a low as possible.

2. Data

2.1 Plant level damage

Our data consists of 1,846 manufacturing plants from 1992 from the Japanese Manufacturing Census (Japanese Ministry of Economy, Trade and Industry) and the Establishment and Enterprise Census (Japanese Ministry of Internal Affairs and Communications) which we follow until their death or until the end of our sample period in 2007. Both datasets are exhaustive and have no minimum size requirement. Hence, there is no problem with plants leaving the sample due to their size dropping below a minimum threshold. This means we can identify precisely when a plant closed down. One caveat is that we cannot capture plants that moved elsewhere within Japan which would appear in the data as a closed plant. From a local Kobe perspective this still represents an exit from the local economy.

To identify the level of damage to each plant we utilise 'Shinsai Hukkou Akaibu' (archive on the damage of the 1995 Hyogo-Awaji earthquake) by Kobe City Office and Toru Fukushima (University of Hyogo), together with 'Zenrin's Residential Map, Hyogo-ken Kobe city 1995' from Toru Fukushima (University of Hyogo). These sources provide a highly detailed map of Kobe and assigns one of five colors to each building related to the damage incurred. Hence, shortly after the earthquake each registered building (prior to the earthquake) was surveyed and classified as one of five categories:

Green: No damage (damage was not more than 3 per cent of the building's total value).

Yellow: Partially collapsed (damage was between 3-20% of the building's value).

Orange: Half collapsed (damage was between 20-50% of the building's total value; typically this constituted damage to the principal structures such as walls, pillars, beams, roof and stairs).

Red: Fully collapsed (damage was between 50-100% of the building's total value; typically this constituted damage to the principal structures such as walls, pillars, beams, roof and stairs)

Pink: Fire damage (damage was between 50-100% of the building's total value).

We then calculated a damage index between 0 and 1 given by the percentage loss of value associated with each colored building using the median between the category thresholds (11.5% for yellow, 35% for orange, and 75% for red) except for green buildings which, for simplicity, was given a loss of value of 0%. Using the lower and upper threshold of the percentage loss values of each damage category did not change the key results. Within a Chome there is considerably heterogeneity which demonstrates the importance of using building level measures of damage.

In addition, we create summary measures of damages by chome where a chome is a small administrative unit (3,179 in the Kobe-Hanshin area). More specifically, we were able to create a chome indicator of the loss in value given by;

$$CHOMEdamage_j = \frac{(w_{pink} \times pink) + (w_{red} \times red) + (w_{orange} \times orange) + (w_{yellow} \times yellow) + (w_{green} \times green)}{total}$$

where total is the total number of buildings and red, orange, yellow, and green are the number of buildings within chome *j* that are classified in these categories. The weights *w* are the loss in value associated with each color, where, as we did for our individual plant-level damage indicator, we assume that losses are the midway points between the thresholds (except for the green category). Our *CHOMEdamage* index reveals a wide variation of damages across chomes.

As a robustness check we include an alternative proxy for building-level damage using a Kobe earthquake gridded shake-map generated by Fujimoto and Midorikawa (2002) to allocate peak ground acceleration values to each plant's building. A weakness with this approach is that the grids of the shake-map are fairly large and hence not ideal to proxy localised damage.[9]

To control for infrastructure damage we create a measure of the road damage incurred as a result of the earthquake within each chome. Using maps provided by the Construction Engineering Research Institute together with a research report on the damage from the earthquake we create a dummy variable equal to one if a chome suffered serious road damage to its major roads.[10] Serious road damage is defined as the road being impassable due to landslides, building collapse, large cracks and cave-ins or the collapse of bridges.

Although the Kobe earthquake was unanticipated and few preventive measures had been in place, one might still have other endogeneity concerns. In particular, certain building types are

[9] We assume that the age of the building was the medium value between categorical thresholds. For example, buildings constructed between 1955 and 1965 were assumed to be 44 years old in 1994.
[10] Chapters 5 to 9 of *Hanshin Daishinsai Higai Joukyo Chosa Houkoku Sho*, 1995.

more prone to earthquake damage *ceteris paribus* than others. If the less (more) productive plants were more likely to be in such buildings then the scale of damage may be correlated with these aspects. While we do not have information on building characteristics at the building level, local authorities collated information on buildings at the chome-level. These include the number of buildings by age categories and building types (brick, cement, wood and iron). We use these to calculate the average age and shares of building types within any given chome. In addition, the chome-level data contains information on the number of buildings by building material type which we include to control for building type at least at the chome-level. Chomes tended to be relatively homogenous in their building type. For example, in 50% of all chomes the dominant building type constituted over 75% of all buildings. In only 1% of these administrative units did the dominant building type cover less than 40% of total buildings in a chome. Similarly, while the average age of buildings for those built after 1945 was about 33 years, the standard deviation within chomes was only 8 years. We are thus reasonable confident that there is little within chome-level heterogeneity in terms of building age and type so that including our chome-level variables should alleviate any concerns regarding building characteristics being an omitted variable likely to bias the results of our econometric analysis.[11]

2.2 Data descriptives

Table 1 provides a summary of the industrial structure in Kobe which enables us to identify the significant economic clusters as well as estimates of the average plant level damage for each industry using the previously defined colors pink (fire), red (severe) and orange (moderate).

[Table 1 about here]

As shown in Table 1, rubber was the industry with the largest number of plants, reflecting the fact that this industry includes the non-leather shoe firms that have been previously discussed. The rubber industry also experienced a high level of moderate to severe damage (46.1%) with only the non-ferrous metals industry experiencing greater damage. Other industrial clusters include printing, metal products, metal products, food manufacturing and leather and fur products with smaller clusters in general manufacturing, textiles and transport machinery. We

[11] Nevertheless, to ensure that plant characteristics are not influencing the earthquake damage incurred by plants we estimate a cross-sectional regression expressing plant-level earthquake damage as a function of pre-earthquake plant-level characteristics. None of these plant-level characteristics is a statistically significant determinant of plant-level earthquake damage (even at 10% significance levels). These results are available upon request.

are reassured that these summary statistics match the anecdotal evidence and Kobe City statistics previously discussed.

Table 2 presents the average damage percentages for the seven main Wards in the City of Kobe again making the distinction between Pink (fire), Red (severe) and Orange (moderate) damage levels. The largest number of plants were located in the Nagata Ward which was home to the non-leather shoe industry cluster. The Nagata Ward also experienced a high level of damage with over 42% of plants experiencing moderate to severe damage.

[Table 2 about here]

3. Methodology

To investigate the effect of earthquake damage on plant survival we follow Cole *et al.* (2014) and consider a simple nonparametric estimate of the survivor function $S(t)$, which is the probability of a plant surviving beyond time t. The Kaplan-Meier function estimates the survival function as follows:

$$\hat{S}(t) = \prod_{t_j<t} \frac{n_j - d_j}{n_j} \qquad (1)$$

where n_j is the number of plants that have survived to t_j years of age and d_j is the number of plants that die at age t_j.

We then estimate a Cox proportional hazards model (Cox 1972) where we denote the hazard rate of plant i by λ_{it} which represents the probability that the plant exits in interval t to $t+1$, conditional upon having survived until period t given by;

$$\lambda_{it} = \lambda_0(t) exp(Z\beta) \qquad (2)$$

where $\lambda_0(t)$ is the baseline hazard, t is the analysis time, Z is a vector of explanatory variables and β are our parameters to be estimated. In a Cox model the baseline hazard is not given a particular parameterization and is left un-estimated. However, the proportional hazards assumption requires each plant's hazard to be a constant multiplicative replica of another plant. From equation (1), the effect of the function $exp\ (Z\beta)$ is to scale up or down the baseline hazard function that is common to all units. This implies that the effect of covariates is fixed over time. This assumption is tested by analysing the residuals following Grambsch and Therneau (1994).[12]

Vector *Z* contains our earthquake damage variables and other variables thought likely to influence plant survival. We begin with our clustering measures. We construct four measures of agglomeration effects to capture the extent to which plants are geographically clustered to assess whether this influences plant survival. In our main analysis we include the variable *ClusterPlants* which measures the number of plants within the same industry and same Chome (but not neighbouring Chomes). Our other three measures are *ClusterPlantsNb* which measures the number of other plants within the same industry as plant *i* within the same, or neighbouring, Chomes, *ClusterEmpNb* which measures the level of employment within the same industry as plant *i* within the same, or neighbouring, Chomes and *ClusterEmp* which measures the level of employment within the same industry and same Chome. Table 3 provides some summary statistics for industry-averaged values of *ClusterPlantsNb* for 1992 and 2007. In both years, the most clustered industries were Rubber Products and Leather and Fur. However, it is noticeable that the degree of clustering has fallen over the period 1992-2007 in most industries.[13]

[Table 3 about here]

Although older plants are more likely to survive than younger plants we cannot include plant age directly into a Cox proportional hazards model as it would be collinear with the baseline hazard function. Hence we include each plant's age in 1995 (*AGE*) as a time invariant measure of plant age. To control for plant size we include dummy variables for three of the four quartiles of total employment (the second quartile dummy is omitted). We also include a measure of plant average wage (*WAGE*) as a proxy for workers average skill level and also a measure of total factor productivity (TFP) as we expect more productive plants will be more likely to survive. To calculate TFP we follow Cui *et al.* (2012) and construct a measure of TFP that does not require a direct measure of capital.

Our infrastructure variable *ROADdamage* is included to capture the extent of the damage to local roads which would impact on the ability of the plant to trade (a plant would find it hard to get goods in or out of the building even if the building were undamaged). We also control for whether a plant belongs to a multi-plant firm (*MULTI*), whether the plant moved location within

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[12] Specifically we test for a nonzero slope in a generalized linear regression of the scaled Schoenfeld (1982) residuals on functions of time.

[13] These summary statistics are very similar for the other three cluster measures *ClusterPlants, ClusterEmp* and *ClusterEmpNb*.

Kobe over the sample period (*MOVE*) and whether the plant is located in a designated reconstruction priority zone (*RECON*) in which government assistance was provided and planning rules were relaxed.

We also include 162 industries dummies, year dummies and regional Ward dummies. As additional controls we include five different dummies to capture the average age of the buildings within each plant's Chome and also the share of building construction types within each Chome which are classified as wood, reinforced concrete, steel or brick.

Having examined the effect of earthquake damage on plant survival more generally, we then specifically look at how such damage affects levels of employment, value added and productivity. We estimate a fixed effects panel model of the following form:

$$E_{it} = \alpha_i + \gamma_t + X\delta + \varepsilon_{it} \tag{3}$$

Where E_{it} denotes employment, value added or productivity in plant i, year t, X is a vector of explanatory variables, including earthquake damage, and α and γ are plant and year fixed effects, respectively. Equation (3) is estimated for our full sample of plants for the period 1992-2007 using Driscoll and Kraay (1998) standard errors which are robust to very general forms of cross-sectional and temporal dependence.[14]

Our variable are defined and summarized in Tables A1 and A2 in the appendix respectively. Observations include that the average plant age is just over 18. During this period 14% of plants are part of a multi-plant firm and 17% of plants moved physical location. Around 40% of plants were in one of eight special reconstruction zones. Most firms were built between 1966 and 1975 and are fairly equally distributed between brick, wood, steel and reinforced concrete. In terms of our cluster variables we can see significant heterogeneity with a relatively high standard deviations. For example, the mean for our employment cluster variable including neighbouring firms is 127 although the maximum value is 5712 and the standard deviation is 410.4. Average road damage for a chome was 18% with a standard deviation of 39 and a maximum value of 100%.

4. Results

[14] Our sample is now extended to 1992 in order to capture variation in damages pre and post-earthquake within each plant.

Table 4 presents our main survival analysis results including our infrastructure and main cluster variable. It is worth a brief explanation of the interpretation of hazard ratios. If the hazard ratio on a continuous variable (e.g. WAGE) is 1.1 then a 1 unit change in that variable will increase the hazard of plant death by 10%. Similarly, if the hazard ratio is 0.9 then a 1 unit increase in the variable will reduce the hazard by 10%. If the hazard ratio on a dummy (e.g. *MULTI*) is 1.6 it means that multi-plant firms face a 60% greater hazard than single plant firms. We need to be careful to interpret these relative to the omitted category when we include more than one dummy (e.g. *SIZE1*, *SIZE3* and *SIZE4* where the omitted variable is *SIZE2*).

[Table 4 about here]

Column (1) of Table 3 includes only our control variables including our measure of the degree of plant agglomeration (*ClusterPlants*) which measures the number of plants from the same 2-digit industry in a given Chome. This variable has a hazard ratio greater than 1. This suggests that plants that belong to a cluster are more likely to die and, although seemingly counter-intuitive, may reflect the increased competition associated with a heavy spatial concentration of plants from the same industry. This is also consistent with a Melitz-type story where fierce competition within a cluster raises the productivity threshold required to survive. Both *AGE* and *WAGE* have significant hazard ratios that are less than one, although both are very close to one. This implies that older plants and higher wage paying plants are less likely to die but the effect is small in terms of magnitude. We also find that smaller plants (*SIZE1*) are more likely to die whilst large plants are less likely to die. Plants that move within Kobe following the earthquake are less likely to close than those that stay in their original location. Interestingly, plants that are part of a multi-plant firm are more likely to close, a finding consistent with Bernard and Jensen's (2007) finding for US plants. *TFP* consistently displays a hazard ratio of less than 1 suggesting that productive firms are more likely to survive. Our variable to capture whether a plant was located in one of the eight special reconstruction zones is not significant.

In Columns (2), (3), (4) and (5) we include our different proxies for plant damage. In column (2) we include the distance to the earthquake epicentre as a proxy for damage. Surprisingly the hazard ratio is greater than one suggesting that the further away from the epicentre the greater the chance of plant closure. This result may reflect the actual pattern of the earthquake damage which was concentrated in a narrow strip of land stretching away from the epicentre, as shown in Figure 1. In column (3) we use a variable constructed from the earthquake's shake-map as a proxy for damage, but this *SHAKE* variable is not statistically significant. In column (4) we include the average building damage at the Chome-level (*CHOMEdamage*) as well as chome-level road damage (*ROADdamage*). Neither variable is statistically significant. In the case of *CHOMEdamage*, this lack of significance may be explained by the considerable damage heterogeneity within any single Chome.

In Column (5) we include our building-level damage variable (*DAMAGE*). This variable is statistically significant with a hazard ratio of 1.61 suggesting that a 1 unit increase in damage leads to a 61% increase in the probability of plant closure. In Column (6) we also control for the average level of *CHOMEdamage* and *ROADdamage* but these have little effect on the *DAMAGE* variable. In column (7) we interact the chome-level damage, road damage and building-level damage variables with time. This is intended to capture the fact that the impact of the damage function may decline over time. Now we find that *CHOMEdamage* and *ROADdamage* are statistically significant. All three damage variables have hazard ratios greater than one with the interaction terms being below one. As expected, this suggests that the impact of earthquake damage on plant death declines over time. Hence, there is a significant short term impact of chome and road damage but this decline over time.

We now look more closely at the impact of clustering on survival. Table 5 reports some further investigations into the effect that belonging to a cluster has on plant survival. Models 1 to 4 each include one of the four cluster variables defined in Section 4. These cluster variables are also interacted with *DAMAGE*. The hazard ratios on the cluster variables continue to be greater than one, with all four being statistically significant. It would therefore appear that, other things being equal, belonging to a cluster in Kobe city was not good for the probability of plant survival. This perhaps reflects the increased local competition and cannibalisation that results from clusters for firms who are predominantly serving the local market.[15] Table 5 also reports the hazard ratio on clusters interacted with *DAMAGE*. We now find subtly different results that need careful interpretation. For the two clusters measures that look at the number of nearby firms, damages interacted with our cluster measures gives a negative effect (and significant when we including neighbouring cluster firms) on plant death implying that damaged firms who belonged to a cluster were less likely to die than other damaged plants in non-clustered industries. The effect of the employment based clusters interacted with *DAMAGE* are positive but not statistically significant.

[Table 5 about here]

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[15] Our sample provides export data only for 2002 onwards and so we are unable to explore further the effect of clusters on firms who serve domestic and overseas markets.

In Table 6 we estimate a panel fixed-effects model to examine the impact of the earthquake on employment, value added, TFP and labor productivity including our *ClusterPlants* variable. It is important to note that this is only for those firms that survived until the end of the period. For each of our left hand side variables we run the regression with and without the time interaction terms. In all cases, our *ClusterPlants* variable is an insignificant determinant of plant performance.

More generally, the results for employment show that the more damaged a plant is, the greater the reduction in its employment although the effect is very small. The calculated elasticity for *DAMAGE* in model (1) indicates that a 1% increase in *DAMAGE* would reduce employment by 0.033%. Chome level damage also reduces employment, perhaps reflecting the effect of local infrastructure damage on individual plants, although we note that *ROADdamage* is not statistically significant. The time interactions suggest that the effect of Chome damage falls over time whilst time interacted with plant level damage is not statistically significant. The time variable is also negative and significant. In terms of the other controls, *AGE*, *MULTI* all increase employment levels, while *WAGE* reduces employment.

[Table 6 about here]

Value added is negatively affected by plant, chome and road damage although plant damage is not statistically significant when *DAMAGE*time* is included. In terms of the other controls, being in a reconstruction zone, having higher wages and being an older plant all increase value added, while belonging to a multi-plant firm reduces value added.

For productivity we find that our damage variable returns a positive and significant coefficient for TFP and labor productivity when we include time interaction terms, with the interaction terms themselves being negative. This suggests that the earthquake had a positive effect on productivity although this effect reduces over time. The effects are relatively small but last a number of years. For example, calculating the elasticity for *DAMAGE* from the final labor productivity model in Table 6, tells us that a 1% increase in *DAMAGE* would increase labor productivity by 0.036%. Furthermore, *DAMAGE* continues to have a positive effect on labor productivity until 2004. The effects for TFP are very similar. This finding could be taken as evidence of a Schumpeterian creative destruction effect. For those plants that survived, those that were more damaged improved their productivity. This result could be driven by a number of mechanisms; namely a reduction in workers relative to capital inputs and output; a reduction in capital relative to labor inputs and output or an increase in output relative to capital and labor inputs. The precise mechanisms at work remain a topic for future research. We also note that while *CHOMEdamage* is not statistically significant, the effect of *ROADdamage* on productivity is negative and significant. Both of our productivity variables were positively influenced by the level of wages, the age of a plant and whether or not it was within a reconstruction zone. Belonging to a multi-plant firm appears to reduce productivity.

Finally, we re-estimate the models in Table 6 using our three additional cluster variables. Table 7 provides the estimated coefficients on the cluster variables alone. As can be seen, the cluster variables are generally insignificant determinants of plant performance.

[Table 7 about here]

5. Conclusions

In this paper we investigate the impact of the Kobe 1995 earthquake on plant survival in the thirteen years following the event using a micro-econometric approach putting special emphasis on the role of clustering. In this paper we argue that a largely overlooked aspect of natural disasters is the local economic impact. More precisely we examine how the clustering of plants influences plant survival or plant performance. To test the local impact of an earthquake on plants we measure damage in a number of different ways including a measure of building level damage. The heterogeneous nature of the damage caused by earthquakes on individual plants means that previously employed aggregate measures may be misleading.

Our results show that plant survival is negatively impacted by plant-level damage and this effect persists for a number of years. Damaged plants are more likely to fail than undamaged plants and this holds true until 2003 – that's eight years after the earthquake. When we examine four different levels of earthquake damage separately we find that the two most severe forms of damage provide a greater, and longer lasting, risk of plant death than the two lesser levels of damage. The most severely damaged plants faced a greater risk of death, relative to undamaged plants, until 2004. The least damaged plants experienced this effect until the year 2000. In short, these negative impacts appear to be longer lasting that the macroeconomic results suggest.

Our clustering results show that plants that have been damaged are more likely to die than plants with a lower degree of clustering perhaps reflecting a cannibalisation effect due to the competitive pressures within the cluster which acts as a cleansing influence on the cluster. This is consistent with a Melitz-type story where fierce competition within a cluster raises the productivity threshold required to survive. However, our performance results fail to find evidence that productivity increases in those clusters with the highest indices. Our fixed-effects models also indicate that the earthquake had a significant negative impact, but also reveal some evidence of creative destruction type behaviour among those plants that survived. We find that productivity increased in the year following the earthquake although this increase in productivity decreased over time, again until approximately 2004. We find that employment fell in those plants that experienced the greatest damage although this effect was less pronounced for value added. The employment results match the Kobe level statistics that show a large increase in unemployment in the years following the earthquake.

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Figure 1: Observed Seismic Intensity Map of the Kobe Earthquake (source: Fujimoto and Midorikawa 2002).

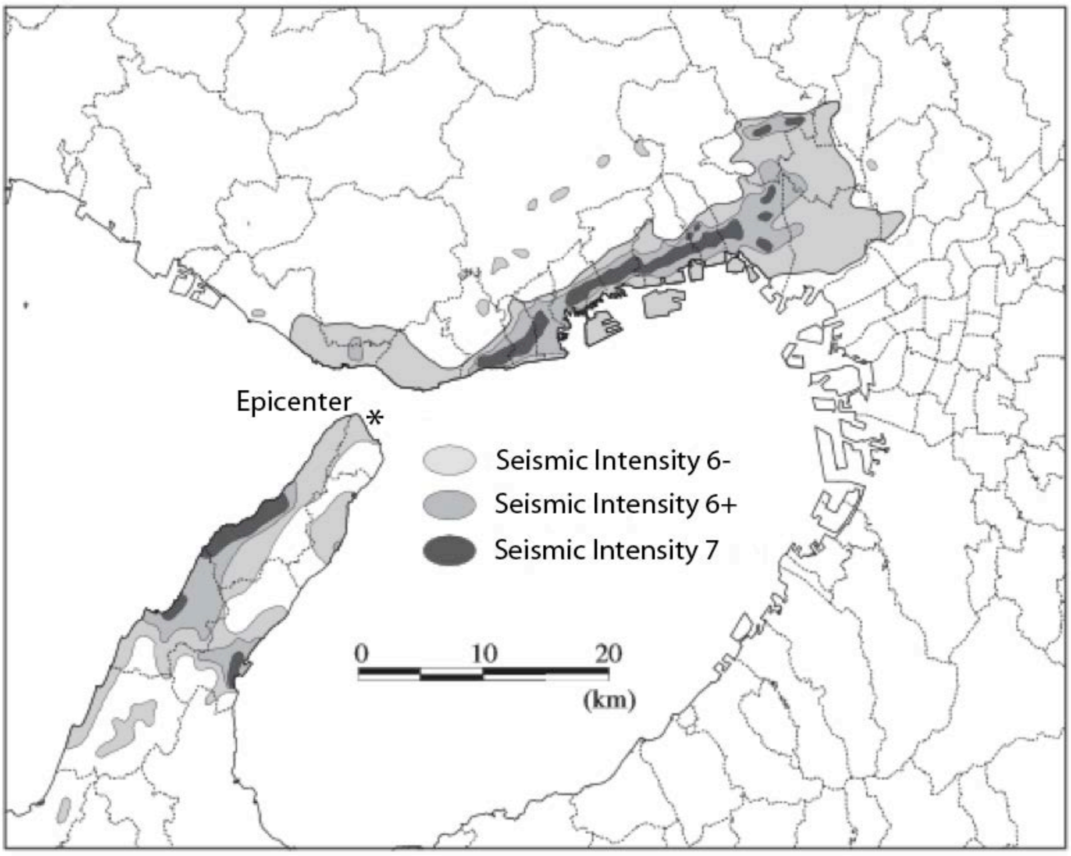

Table 1. Damage by Industry (ranked by All Damage)[1]

Industry	% of Sample	All Damage	PINK	RED	ORANGE	YELLOW
Non-Ferrous Metals	0.6	85.4	0	15.6	38.5	31.3
Rubber	17	76.2	5.5	24.8	15.8	30.1
Leather and Fur	6.8	74.8	7.5	19.8	16.8	30.7
Information & Communication Machinery	0.4	71.6	0	33.8	8.1	29.7
Pulp, Paper	2.5	71.5	3.4	16.5	21.7	29.9
Furniture	1.4	70.9	0	16.9	23.5	30.5
Industrial Machinery	6	69.1	0.6	14.1	14.9	39.5
Printing	10.5	68.1	0.9	16.5	19.1	31.6
General Machinery	4.6	63.4	1.2	10.4	11.4	40.4
Textiles	4.8	62.4	0	17.4	19.5	25.5
Plastic Products	1.8	60	0	14.9	17.6	27.5
Metal Products	8.6	59.3	1.9	11.2	18.5	27.7
Wood Lumber	1.8	58.3	0	16	17.3	25
Electronic Machinery	3	56.5	3.6	10.1	12.7	30.1
Transport Machinery	5.1	56.2	1.8	8.1	20.7	25.6
Chemicals	1.2	55.6	13.1	19.2	4.6	18.7
Beverages and Tobacco	2.1	55.5	0	9.1	13	33.4
Food	12.3	54.6	1.6	9.4	13.5	30.1
Electronic Devices & Semi-Conductors	0.6	52.1	0	8.3	24	19.8
Oil and Coal Products	0.5	49.4	16.1	0	1.2	32.1
Other Manufacturing	4.6	47.8	0.7	4.9	9.8	32.4
Porcelain and Pottery	1.3	42.9	6.1	18.1	6.1	12.6
Household Machinery	0.8	39.7	0	8.4	6.1	25.2
Iron and Steel	1.3	35.4	0	16.5	2.8	16.1
Newspapers	0.6	23.5	0	7.8	2	13.7

[1] Where 'All Damage' is the sum of pink, red, orange and yellow.

Table 2. Damage by Ward (ranked by All Damage)[1]

	% of sample	*All Damage*	*PINK*	*RED*	*ORANGE*	*YELLOW*
Nagata	38.7	75.8	3.5	21.3	18.1	32.9
Suma	6.4	63.4	14.4	11.9	17.8	19.3
Nada	5.5	60.9	1.4	20.4	10.4	28.7
Hyogo	20.4	60.73	0.23	11.1	16.4	33
Higashi Nada	14.5	50.76	0.86	14.5	12.5	22.9
Chuo	12.4	48.43	0.63	3.9	11.8	32.1
Tarumi	2.1	42.4	0	0	18.1	24.3

[1] Where 'All Damage' is the sum of pink, red, orange and yellow.

Table 3. Clustering by Industry 1992 and 2007.

Most Clustered Industries 1992	*ClusterPlantsNb**	Most Clustered Industries 2007	*ClusterPlantsNb*	% change in clustering 1992-2007
Rubber Products	60.91	Rubber Products	12.09	-80.2
Leather & Fur	21.77	Leather & Fur	5.60	-74.3
Industrial Machinery	7.39	Food	5.24	-6.7
Metal Products	7.38	Metal Products	4.73	-35.9
Food	5.62	Industrial Machinery	4.24	-42.6
Beverages & Tobacco	5.38	Beverages & Tobacco	3.60	-33.1
General Machinery	5.10	General Machinery	3.37	-33.9
Printing	5.04	Transport Machinery	3.27	-30.1
Transport Machinery	4.68	Printing	2.33	-53.8
Wood Lumber	2.37	Porcelein & Pottery	2.00	+72.4
Other Manufacturing	2.05	Plastic Products	1.75	+29.6
Electronic Machinery	1.61	Electronic Machinery	1.54	-4.3
Oil & Coal Products	1.38	Other Manufacturing	1.00	-51.2
Plastic Products	1.35	Iron & Steel	0.93	-24.4
Textiles	1.26	Oil & Coal Products	0.67	-51.4
Iron & Steel	1.23	Pulp, Paper	0.57	-47.2
Porcelein & Pottery	1.16	Wood Lumber	0.54	-77.2
Pulp, Paper	1.08	Non-Ferrous Metals	0.50	-12.3
Furniture	0.81	Information, Communication Machinery	0.50	+257
Chemicals	0.81	Textiles	0.48	-61.9
Non-Ferrous Metals	0.57	Chemicals	0.46	-43.2
Household Machinery	0.44	Household Machinery	0.43	-2.3
Electrical Devices & Semiconductors	0.18	Furniture	0.30	-63.0
Information, Communication Machinery	0.14	Electrical Devices & Semiconductors	0.01	-94.0

* *ClusterPlantsNb* provides the number of plants from the same industry within a plant's own chome or neighbouring chomes. Here this variable has been averaged by industry and so tells us which industries contain the greatest number of spatially concentrated plants.

Table 4. Main Results of Survival Analysis (Cox proportional hazard)

	1	2	3	4	5	6	7
DISTEPI		1.01***					
		(3.9)					
SHAKE			0.99				
			(-0.3)				
CHOMEdamage				1.12		1.06	1.79***
				(1.3)		(0.7)	(6.8)
ROADdamage				1.11		1.09	1.28**
				(1.4)		(1.2)	(2.0)
DAMAGE					1.61***	1.58***	3.01***
					(4.1)	(3.8)	(5.7)
*CHOMEdamage*Time*							0.87***
							(-5.9)
*ROADdamage*Time*							0.97*
							(-1.7)
*DAMAGE*Time*							0.87***
							(-4.3)
AGE	0.99**	0.99**	0.99**	0.99**	0.99**	0.99**	0.99
	(-2.2)	(-2.2)	(-2.2)	(-2.2)	(-2.3)	(-2.3)	(-2.0)
SIZE1	2.22***	2.22***	2.22***	2.23***	2.20***	2.21***	2.22***
	(10.6)	(10.6)	(10.6)	(10.7)	(10.6)	(10.6)	(10.5)
SIZE3	0.79**	0.79***	0.79***	0.80***	0.80***	0.80***	0.80***
	(-2.7)	(-2.7)	(-2.7)	(-2.6)	(-2.6)	(-2.5)	(-2.5)
SIZE4	0.93***	0.93***	0.94***	0.93***	0.94***	0.94***	0.94***
	(-3.9)	(-3.9)	(-3.8)	(-3.9)	(-3.8)	(-3.8)	(-3.7)
WAGE	0.99***	0.99***	0.99***	0.99***	0.99***	0.99***	0.99***
	(-5.0)	(-5.0)	(-5.0)	(-5.1)	(-5.1)	(-5.1)	(-5.2)
TFP	0.89**	0.89**	0.90**	0.89**	0.90**	0.90**	0.91**
	(-2.3)	(-2.3)	(-2.2)	(-2.3)	(-2.1)	(-2.1)	(-2.0)
MULTI	1.59***	1.59***	1.58***	1.59***	1.58***	1.57***	1.60***
	(4.3)	(4.3)	(4.2)	(4.3)	(4.3)	(4.2)	(4.4)
MOVE	0.76***	0.75***	0.76***	0.75***	0.74***	0.74***	0.76***
	(-3.4)	(-3.5)	(-3.4)	(-3.5)	(-3.6)	(-3.7)	(-3.3)
RECON	1.002	1.002	1.003	1.001	0.99	0.99	1.001
	(0.2)	(0.2)	(0.3)	(0.2)	(-0.2)	(-0.2)	(0.1)
ClusterPlants	1.03**	1.03**	1.03**	1.03**	1.02**	1.03***	1.03***
	(2.5)	(2.5)	(2.5)	(2.3)	(2.0)	(2.8)	(3.0)
observations	16,658	16,658	16,658	16,658	16,658	16,658	16,658
Wald	423418***	308594***	318471***	316411***	338214***	376717***	314058***

Each model contains controls for 3-digit industry, year, ward, age of buildings in a chome and type of buildings in a chome. ***, **, * denote statistical significance at 99%, 95% and 90% confidence levels, respectively. t-statistics in brackets.

Table 5. Survival Analysis Clustering Results

	1	2	3	4
DAMAGE	3.36***	3.65***	2.84***	2.93***
	(5.7)	(6.0)	(5.3)	(5.3)
*DAMAGE*Time*	0.87***	0.87***	0.87***	0.87***
	(-4.4)	(-4.4)	(-4.3)	(-4.3)
CHOMEdamage	1.77***	1.78***	1.76***	1.77***
	(6.6)	(6.5)	(6.7)	(6.7)
*CHOMEdamage*Time*	0.87***	0.86***	0.87***	0.87***
	(-5.9)	(-5.9)	(-5.9)	(-5.9)
ROADdamage	1.28**	1.29**	1.31**	1.32**
	(2.0)	(2.1)	(2.2)	(2.3)
*ROADdamage*Time*	0.97*	0.97	0.97*	0.97*
	(-1.7)	(-1.6)	(-1.7)	(-1.7)
ClusterPlants	1.04***			
	(3.2)			
ClusterPlantsNb		1.02***		
		(5.0)		
ClusterEmp			1.0001**	
			(2.3)	
ClusterEmpNb				1.0002**
				(2.5)
*DAMAGE*Cluster*	0.96	0.98***	1.002	1.0005
	(-1.3)	(-2.2)	(1.5)	(0.2)
AGE	0.99**	0.99**	0.99**	0.99**
	(-2.0)	(-2.1)	(-2.1)	(-2.1)
SIZE1	2.21***	2.21***	2.19***	2.19***
	(10.4)	(10.5)	(10.4)	(10.3)
SIZE3	0.80***	0.79***	0.80***	0.80***
	(-2.5)	(-2.6)	(-2.5)	(-2.5)
SIZE4	0.94***	0.94***	0.94***	0.94***
	(-3.7)	(-3.7)	(-3.6)	(3.6)
WAGE	0.99***	0.99***	0.99***	0.99***
	(-5.2)	(-5.3)	(-5.1)	(-5.3)
TFP	0.91*	0.90**	0.91**	0.91**
	(-1.9)	(-2.2)	(-2.0)	(-2.0)
MULTI	1.59***	1.61***	1.57***	1.57***
	(4.3)	(4.4)	(4.2)	(4.2)
MOVE	0.76***	0.75***	0.77***	0.76***
	(-3.2)	(-3.4)	(-3.2)	(-3.2)
RECON	0.99	0.99	0.99	1.0001
	(-0.04)	(-0.3)	(-0.02)	(-0.01)
observations	16,658	16,658	16,658	16,658
Wald	309805***	308641***	295867***	314926***

Each model contains controls for industry, year, wards, age of buildings in chome and type of buildings in chome. ***, **, * denote statistical significance at 99%, 95% and 90% confidence levels, respectively. t-statistics in brackets.

Table 6. Determinants of Value Added, Employment, TFP and Labor Productivity 1992-2008 (Fixed Effects Panel)

	logEMP	logEMP	logVA	logVA	TFP	TFP	logLabProd	logLabProd
DAMAGE	-0.067***	-0.071***	-0.045*	0.030	0.023	0.099***	0.017	0.097***
	(-9.9)	(-4.8)	(-1.8)	(0.7)	(0.9)	(3.8)	(0.7)	(2.8)
*DAMAGE*Time*		0.00058		-0.011**		-0.011***		-0.011***
		(0.2)		(-2.1)		(-4.8)		(-3.4)
CHOMEdamage	-0.041***	-0.029***	-0.037**	-0.044**	-0.0057	0.011	0.0043	-0.014
	(-7.8)	(-3.8)	(-2.6)	(-2.7)	(-0.6)	(1.2)	(0.3)	(1.2)
*CHOMEdamage*Time*		-0.0017*		0.0010		-0.0024**		0.0026
		(-1.8)		(0.4)		(-2.0)		(1.5)
ROADdamage	-0.0032	0.00034	-0.037**	-0.067***	-0.0062	-0.055***	-0.034**	-0.066***
	(-1.0)	(0.1)	(-2.7)	(-7.3)	(-0.4)	(-5.8)	(-2.5)	(8.9)
*ROADdamage*Time*		-0.00050		0.0042*		0.0070***		0.0045**
		(-0.5)		(1.9)		(3.0)		(2.2)
Time		-0.18***		-0.52***		0.039***		-0.34***
		(-136.0)		(-116.6)		(13.4)		(-97.7)
AGE	0.083***	0.15***	0.26***	0.46***	-0.019***	-0.034***	0.18***	0.31***
	(164.5)	(171.1)	(164.3)	(140.4)	(-16.9)	(-15.0)	(136.1)	(116.6)
WAGE	-0.00047***	-0.00047***	0.0011***	0.0011***	0.0017***	0.0017***	0.0016***	0.0016***
	(-18.8)	(-19.0)	(7.9)	(7.9)	(14.8)	(14.8)	(12.6)	(12.7)
MULTI	0.051**	0.051**	-0.028**	-0.029**	-0.057***	-0.059***	-0.077***	-0.077***
	(2.2)	(2.2)	(-2.0)	(-2.0)	(-3.7)	(-3.8)	(-3.3)	(-3.3)
MOVE	0.012	0.012	0.019	0.020	-0.0071	-0.0079	-0.0081	-0.0085
	(1.5)	(1.5)	(1.1)	(1.1)	(-0.5)	(-0.6)	(-0.7)	(-0.7)
RECON	0.0076	0.008	0.040***	0.040**	0.072***	0.071***	0.033***	0.033***
	(0.7)	(0.7)	(2.7)	(2.7)	(7.3)	(7.3)	(3.6)	(3.5)
ClusterPlants	-0.0011	-0.0011	0.00067	0.00066	0.0022	0.0021	0.0018	0.0018
	(1.0)	(1.1)	(0.4)	(0.4)	(1.6)	(1.5)	(1.6)	(1.6)
observations	11,688	11,688	11,688	11,688	11,688	11,688	11,688	11,688
R^2	0.11	0.11	0.15	0.15	0.10	0.10	0.14	0.14

Each model contains plant fixed effects. ***, **, * denote statistical significance at 99%, 95% and 90% confidence levels, respectively. t-statistics in brackets.

Table 7. Determinants of Value Added, Employment, TFP and Labor Productivity Using Additional Cluster Variables 1992-2008 (Fixed Effects Panel)

	logEMP	logEMP	logVA	logVA	TFP	TFP	logLabProd	logLabProd
ClusterPlantsNb	-0.000019	-0.000019	-3.95e-6	-1.32e-6	2.1e-6	2.91e-6	0.000011	0.00014
	(-1.6)	(-1.7)	(-0.09)	(-0.03)	(0.06)	(0.09)	(0.3)	(0.4)
ClusterEmp	-0.000023**	-0.000023**	-9.64e-6	-8.86e-6	0.000015	0.000015	0.000012	0.000013
	(-3.0)	(-3.0)	(-0.7)	(-0.6)	(0.9)	(1.0)	(1.0)	(1.1)
ClusterEmpNb	-0.00025	-0.00025	0.000097	0.000096	0.00065*	0.00064*	0.00036	0.00036
	(-0.8)	(-0.8)	(0.2)	(0.2)	(1.8)	(1.8)	(1.2)	(1.3)

Each model contains plant fixed effects and all of the plant-level controls reported in Table 5. ***, **, * denote statistical significance at 99%, 95% and 90% confidence levels, respectively. t-statistics in brackets

Appendix

Table A1. Variable Definitions[1]

Variable	
DISTEPI	Distance of plant to earthquake epicentre in kilometres
SHAKE	Estimated peak ground velocity in centimetres per second estimated at the 250m grid cell level by Fujimoto and Midorikawa (2002)
DAMAGE	Building-level damage index
CHOMEdamage	Chome-level damage index
ROADdamage	A dummy variable indicating if a chome suffered serious road damage
AGE	The age of the plant in years in 1995
SIZE (EMP)	The total level of employment at the plant
SIZE1to SIZE4	Dummy variables =1 if a plant is in the first, second, third or fourth quartiles of total employment, respectively
WAGE	The average annual wage per worker at the plant 10,000 Yen
TFP	Total factor productivity, as defined in the Appendix
MULTI	A dummy variable =1 if a plant is from a multi-plant firm
MOVE	A dummy variable =1 if a plant relocated within Kobe city
RECON	A dummy variable =1 if a plant is located within one of 523 priority reconstruction districts in which reconstruction costs were subsidised and regulations were reduced
Births	The number of new plants born within a chome
ClusterPlants	The number of plants belonging to the same 2 digit industry as the plant in question and within the same chome
ClusterPlantsNb	The number of plants belonging to the same 2 digit industry as the plant in question and within the same chome or neighbouring chomes
ClusterEmp	The level of employment within the same 2 digit industry as the plant in question and within the same chome
ClusterEmpNb	The level of employment within the same 2 digit industry as the plant in question and within the same chome or neighbouring chomes
VA	The level of value added in 10,000 Yen
LabProd	The level of value added per worker in 10,000 Yen
BUILDpre45	Share of buildings built pre 1945 by chome
BUILD46-55	Share of buildings built 1946-55 by chome
BUILD56-65	Share of buildings built 1956-65 by chome
BUILD66-75	Share of buildings built 1966-75 by chome
BUILD76-85	Share of buildings built 1976-85 by chome
BUILDafter86	Share of buildings built after 1986 by chome
BUILDbrick	Share of brick built buildings by chome
BUILDrconc	Share of reinforced concrete buildings by chome
BUILDsteel	Share of steel buildings by chome
BUILDwood	Share of wooden buildings by chome

[1] All monetary variables are expressed in year 2000 prices

Variables *SIZE, WAGE, MULTI, MOVE, VA* and *LabProd* come from the Manufacturing Census (Japanese Ministry of Economy, Trade and Industry).

Variable *AGE* is from the Establishment and Enterprise Census (Japanese Ministry of Internal Affairs and Communications). Our damage, building age and building type variables are from 'Shinsai Hukkou Akaibu' (archive on the damage of the 1995 Hyogo-Awaji earthquake) by Kobe City Office and Toru Fukushima (University of Hyogo), together with 'Zenrin's Residential Map, Hyogo-ken Kobe city 1995' from Toru Fukushima (University of Hyogo).

TableA2. Summary Statistics

Variable	Mean	Std. Dev.	Min	Max
DISTEPI	18.6	13.5	5.7	435.3
SHAKE	79.3	6.4	32.3	93.0
DAMAGE	0.22	0.27	0	0.75
CHOMEdamage	0.62	0.42	0.58	6.11
ROADdamage	0.18	0.39	0	1
AGE	18.1	15.0	1	42
SIZE (EMP)	33.2	206.0	3	5673
WAGE	355.9	174.4	67.8	1762.2
TFP	4.40e-12	0.68	-6.9	3.5
MULTI	0.14	0.33	0	1
MOVE	0.17	0.38	0	1
RECON	0.40	0.49	0	1
Births	0.13	0.67	0	35
ClusterPlants	1.5	3.0	0	20
ClusterPlantsNb	5.1	8.5	0	88
ClusterEmp	53.8	276.3	0	5687
ClusterEmpNb	127.0	410.4	0	5712
VA	69164.6	787135.5	3075.3	3.24e+07
LabProd	873.9	1270.6	2106.2	29654.7
BUILDpre45	0.13	0.18	0	0.89
BUILD46-55	0.058	0.071	0	0.46
BUILD56-65	0.17	0.15	0	1
BUILD66-75	0.29	0.19	0	1
BUILD76-85	0.16	0.15	0	1
BUILDafter86	0.18	0.19	0	1
BUILDbrick	0.25	0.16	0	0.65
BUILDrconc	0.22	0.15	0	0.64
BUILDsteel	0.28	0.27	0	1
BUILDwood	0.23	0.20	0	0.99