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Matthew A. COLE
University of Birmingham

Robert J R ELLIOTT
University of Birmingham

OKUBO Toshihiro
Keio University

Eric STROBL
Ecole Polytechnique

RIETI
Research Institute of Economy, Trade & Industry, IAA

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Natural Disasters and Plant Survival:

The impact of the Kobe earthquake

Matthew A. COLE[1], Robert J R ELLIOTT[1], OKUBO Toshihiro[2] and Eric STROBL[3]

[1] University of Birmingham, UK
[2] Keio University, Japan
[3] Ecole Polytechnique, France

Abstract

This paper examines the impact of the 1995 Kobe earthquake on the survival of manufacturing plants and their post-earthquake economic performance. The evidence from macroeconomic studies of the impact of natural disasters on economic growth is mixed with some papers finding a small negative effect while others often finding a positive effect. However, the local effects of disasters are often overlooked. In this paper, we undertake a detailed study of the local effects of the Kobe earthquake. We employ a micro-econometric approach based on carefully geo-coded data on initial plant locations and a building-level survey to measure accurately the damage to the buildings where the plants were located. Including plant and building characteristics as well as district-level variables to control for spatial dependencies, our results show that the greater the level of damage a plant experienced, the lower was its probability of survival. Interestingly, this effect persists for some years, although it diminished over time. Further fixed-effects panel analysis shows evidence of falling total employment and value added associated with earthquake damage. However, we find some evidence of creative destruction with the average plant experiencing a short-run increase in productivity although this advantage disappeared over time.

Keywords: Earthquake, Natural disaster, Survival analysis, Productivity

JEL classification: C4、C23、D22、O40、Q54

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1. Introduction

Natural disasters can have a devastating impact on infrastructure, people and firms in the locally affected area. In the immediate aftermath of a disaster rapid government and international action is required to provide humanitarian support and to aid reconstruction. To discern how funds can be most efficiently allocated it is important to understand the relationship between natural disasters and economic activity. Moreover, the rise of megacities such as Tokyo, Mexico City and Tehran in areas of high seismic risk means that it is increasingly important to understand not only the human costs but also the economic impact of earthquakes on developed and developing countries.

Despite the considerable economic damage caused by natural disasters there has been surprisingly little research undertaken on the effect of such disasters on economic activity. and what has been done has tended to focus on cross-country studies that estimate the macroeconomic impact of particular events on economic growth (see e,g. Loayza *et al.* 2009, Hochrainer 2009, Hallegatte and Dumas 2009, Strobl 2011 and Ahlerup 2013). The results from these various macroeconomic studies are mixed although numerous papers find some short term negative effects on growth whilst others that find no effect or even a positive long-term effect.[1]

Of all the different types of natural disaster, earthquakes are one of the most devastating, 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. Earthquakes also have a unique impact on plant activity since plants within relatively small geographical areas can be impacted very differently depending on the type of earthquake and the nature of the shake patterns produced by the earthquake.[2]

Existing macroeconomic studies of earthquakes tend to reinforce the results from the more general natural disasters literature by suggesting that the economy of the affected country will tend to recover relatively quickly with output postponed rather than lost altogether. Horwich (2000) for example found that less than fifteen months after the Kobe (Great Hanshin)

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[1] See Cavallo and Noy (2009) for a survey of the economics of natural disasters. Research in this area has been invigorated in recent years by the predictions of climate change models that predict more frequent and extreme whether events (Parry *et al.* 2007).

[2] Analysis is complicated by the heterogeneous nature of earthquakes which can include landslides, fires, soil liquefaction, floods and Tsunamis.

earthquake that struck off the Japanese coast in 1995, national manufacturing activity was at 98% of the projected pre-earthquake level.[3] Part of Horwich's (2000) argument for the limited national economic effect of the Kobe earthquake is the substitution of the productive capacity damaged in the disaster to other parts of the country which have excess capacity hence limiting the national effect (an issue largely glossed over in the macroeconomic literature). 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).

Hence, 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 on plant survival and subsequent economic performance at the local level. Specifically, we re-examine the Kobe earthquake that struck off the coast of Japan on January 17th 1995. Our main contribution is to generate a measure of the damage incurred by plants at the individual building level in the earthquake zone using geo-coding techniques and building level surveys from the Japanese and Kobe City government. In the first stage we employ a proportional hazards modelling approach to estimate the impact of plant-level damage on firm survival over time controlling for geographic, regional and plant characteristics (e.g. age, size, average wages and agglomeration economies). In stage two we take a panel fixed-effects approach to investigate the economic performance of plants in terms of employment, value added and productivity for those plants that survived the earthquake. Given the relatively benign long term macroeconomic effects of the Kobe earthquake (in terms of growth, inflation and interest rates), the Kobe event provides an ideal experiment to examine the short and medium term effects of natural disasters on plant survival.

Our results show that plants that were more severely damaged were less likely to survive although the effect diminished over time. Our results also suggest that firms can continue to suffer from the negative effects of natural disasters for a longer period that the macroeconomic evidence suggests. When we examine the impact of the Kobe earthquake on value added and employment we find a short term decline as damaged factories are repaired and production moved elsewhere. However, the recovery is fairly rapid. Interestingly, when we consider the

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[3] 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.

effect of the earthquake on productivity we find a positive short term effect which could be considered to be tentative evidence for forces of creative destruction.

The reminder of this paper is organised as follows. Section 2 reviews the literature whilst Section 3 presents the background to the Kobe earthquake. Section 4 describes our data and the methodological approach we employ. Section 5 presents the results and section 6 concludes.

2. Literature Review

2.1 The Economic Impact of Natural Disasters

The literature on the economics of natural disasters is developing rapidly driven in part by concern about the impact of climate change on extreme weather events. However, the existing literature has tended to take a cross-country macroeconomic approach to examine the impact of a disaster on country level growth (often looking at 5-year growth rates). Because natural disasters are often associated with significant physical damage and human suffering intuitively one would expect a large negative effect of disaster on economic activity and growth. However, the results of the existing empirical studies in this area are mixed with authors finding negative, positive or no effect at all of a natural disaster on economic growth. The absence of a consensus on the average effects of natural disasters is illustrated by the results of two recent studies by Cuaresma *et al.* (2008) and Cavallo and Noy (2010) who argue that on average natural disasters have a positive and negative impact respectively.

A large number of papers do find the expected negative impact of natural disasters on growth. In theoretical growth models with increasing returns to technology in production any destruction of capital can lead to a longer term negative impact. Similarly, the destruction of infrastructure lowers returns to all factors of production. Such an effect is found most recently by Noy (2009) who finds a significant short-run effect, concentrated in developing countries only, but almost no long-term impact. Rasmussen (2004) in his study of the Caribbean finds that natural disasters lead to a reduction in same-year growth of more than two-percent and an increase in the current account deficit and public debt. More recently, Fisker (2012) finds that although there were no observable country level effects, an earthquake does have a negative impact on 5-year growth at the local level. However, Cavallo *et al.* (2010) only finds a negative effect for very large disasters and only then after political unrest (which lowers incentives to invest). Ahlerup (2013) argues that if the only negative effects are found for very large disasters then the intuitive assumption of a negative impact lacks robustness.

In contrast, there are a number of reasons why one might expect natural disasters to have a positive economic impact. Most relate to an endogenous reaction by the country and international community to the disaster in the form of a fiscal stimulus (multiplier effect) and foreign aid stimulating the locally affected area (Albala-Bertrand 1993). The disaster response can also result in the development of more effective infrastructure and increased productive effort in the unaffected areas of a country. Likewise, when more capital is destroyed than labour the return to capital increases resulting in short-term growth and the local workers may also be incentivised to work harder to compensate for inter-temporal losses (Melecky and Raddatz (2011). A positive impact on economic performance is found most recently by Ahlerup (2013) who, when controlling carefully for the endogenous nature of natural disaster losses and controlling for unobserved heterogeneity finds a clear positive effect on subsequent economic performance in the short, medium and long term. However, this effect is only for developing countries with the positive effect being driven by inflows of foreign aid combined with the degree of democracy. Loayza *et al.* (2009) support the argument that developing countries are more sensitive to natural disasters.[4]

One conclusion from the existing literature is that the type of disaster has an important influence on the magnitude and sign of the growth effect. The main negative impact tends to come from damage to essential intermediates such as the effect of drought on agriculture. The positive impact is more prevalent in those cases where there is physical damage to buildings and infrastructure and the reconstruction leads to positive returns. Loayza *et al.* (2009) argue that the previous literature suffered from over-aggregation since, in reality, different sectors experience different levels of impact. Moreover, they argue that there is a significant difference between moderate and severe disasters.[5]

Although some progress has been made in the macroeconomic literature there are very few papers that use firm or plant level data. There are some important exceptions. De Mel *et al.* (2011) conduct a field study of enterprises following the Sri Lanka tsunami and how they are able

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[4] Skidmore and Toya (2002) find a positive long-run effect of natural disasters on growth based on the Schumpeterian notion of creative destruction as capital is upgraded and optimised alongside infrastructure. However, Raddatz (2007) finds no negative effects from geological disasters whilst Melecky and Raddatz (2011) find a similar result from even large natural disasters.

[5] There is also a small political economy literature that investigates the relationship between income and deaths from natural disasters (Kahn 2004) and the extent of democracy and deaths (Stromberg 2007 and Toya and Skidmore 2007).

to recover from the disaster with or without direct aid and find that aid helps retailers but not manufacturing firms. For developed countries Leiter *et al.* (2009) examines European firms that have been affected by floods using regional data and find that employment growth is higher in regions that experienced major floods. Finally, Hosono *et al.* (2012) investigate the effect banks' lending capacity on firms' capital investment using the Kobe earthquake as an exogenous shock.[6]

Since our paper considers the 1995 Kobe earthquake it is also useful to comment on other research that considers this specific earthquake. One advantage of looking at the Kobe earthquake is that there is a great deal of background information available epitomized by Horwich (2000) who provides a detailed case study of the Kobe earthquake. Horwich (2000) concludes that despite dire warnings of a decade long recovery, the effect on Japan as a whole was, if anything, positive with even 1995 experiencing higher growth than any of the preceding ten years. Horwich (2000) argues that the positive effect was due to the recession in Japan at the time which had created excess capacity elsewhere in the economy which meant there was no effect on inflation, debt levels or interest rates (which actually fell).

2.2 The Kobe 1995 earthquake and the Japanese economy

In this section we provide a brief overview of the Kobe earthquake paying particular attention to the damage to infrastructure and economic activity against a background of a stagnating Japanese economy. In the ten years following the earthquake the Japanese economy grew very little and Kobe was already facing considerable challenges from a reliance on traditional industries such as steel and shipbuilding. Much of the factual information below emanates from Edgington (2010) who examines the reconstruction of Kobe and the geography of the crisis at a very detailed level, together the report of UNRCD (1995) entitled the "Comprehensive Study of the Great Hanshin Earthquake".

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 with a strength of 7.2 on the Richter scale. Kobe is located 430 km southwest of Tokyo and was an important port city with a population of close to 1.5 million and contributing around 10% of

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[6] There have also been a small number of case studies on US disasters such as Dorfman *et al.* (2007) who look at the employment and wage effects of Hurricane Katrina and Smith and McCarty (1996) who look at the demographic impact of Hurricane Andrew. In a related literature, Skoufias (2003) provides a survey of household coping strategies in the face of disasters and aggregate shocks. For example, Carter *et al.* (2007) consider poverty traps and natural disasters in Ethiopia and Honduras whilst Ferreira and Schady (2009) considers the impact aggregate shocks on child schooling and health.

Japan's total GDP (Orr 2007). The epicentre was 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. Because Kobe is an older city is had a very high population density with between 6,000 and 12,000 people per square kilometre (Orr 2007).[7]

The massive scale of the destruction was caused by two key factors in addition to the magnitude, depth and timing of the earthquake. 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]

Most importantly for this study, houses and commercial premises were destroyed and large parts of the city were affected by fires. 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).

Before we continue with our analysis it is useful to provide some background statistics on the magnitude of the earthquake. According to the City of Kobe (2012) statistics a total of 4,571 people lost their lives 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 crushing related injuries. By the end of the month there were nearly 600 shelters operating which were being used by at their peak by 236,899 individuals towards the end of January 1995. The damage to buildings was considerable. The number of fully collapsed buildings was 67,421 and partially collapsed 55,145. Fire damage

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[7] The housing in the older areas of Kobe tended to be constructed using heavy roof tiles and light frames and were designed to withstand storms but were not well suited to earthquakes (Orr 2007).

caused the complete destruction of 6,965 structures with 80 being half burned and a further 270 being partially burned (covering a total area of 819,108 m^2.) 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.[8]

Most importantly for this paper is the effect on industry. According to the City of Kobe (2012) report, 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 figures 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

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[8] In the data collected fully collapsed applies to buildings whose damage to principal supporting structures (walls, pillars, beams, roof and stairs) is more than 50% of the current value of the building. Partially collapsed is where the damage is between 20 and 50% of the value of the building. These definitions are discussed in more detail when we describe our damage indicators.

reconstruction.[9] 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).

One mitigating factor that helped the larger companies is 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 that were 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.

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.

Finally, it is important to discuss the reconstruction efforts that were implemented following the earthquake. Given the heterogeneous nature of the reconstruction expenditure both politically and geographically 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

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[9] 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.

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 available for rebuilding businesses and publically operated factories were also built that could be rented (1996-1999) and still housed 98 businesses in 2008. 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.[10]

In terms of utilities it is important to note 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.

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).

We now turn briefly to the economy of Japan. During the 1990s Japan was in a period of stagnation following the boom of the late 1980s. The country experienced relatively low growth up until 2004/2005 when the recovery picked up. 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

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[10] 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 figure although the total value of imports in 2007 was 106.4% of the 1994 value and exports were 95.3% of the 1994 value.

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 also took on considerable borrowings following the earthquake they too came under financial pressure due to the relative slow growth of the Japanese economy. Hence, the effects of natural disasters can be prolonged and affect the chances of plant survival long after the event itself.

3. Data

3.1 Plant level damage

We utilise the Japanese Manufacturing Census (Japanese Ministry of Economy, Trade and Industry) and the Establishment and Enterprise Census (Japanese Ministry of Internal Affairs and Communications) to create a database of 1,846 manufacturing plants in Kobe city from 1992. We then follow these plants until their death or until the end of our sample period in 2007. The Manufacturing Census and the Establishment and Enterprise Census are exhaustive and do not have a minimum size requirement for inclusion. As such, we do not have the problem of plants leaving the sample simply because their size has dropped below a minimum threshold. We are therefore able to identify precisely when a plant closed down in Kobe. One caveat is that although we know when a plant closes and reopens elsewhere in Kobe we cannot distinguish between those plants that closed permanently and those that moved elsewhere within Japan.

In order to identify accurately the level of damage suffered by 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 assign one of five colours to each building to categorise the damage incurred. More specifically, shortly after the earthquake each registered (prior to the earthquake) building was surveyed with respect to the damage incurred and then classified into one of five categories:

- Green: No damage, i.e. any damage was not more than 3 per cent of the building's total value.
- Yellow: Partially collapsed, i.e., damage was between 3-20% of the building's value.

- Orange: Half collapsed, i.e. damage was between 20-50% of the building's total value; typically this constituted damage to the principal structures (walls, pillars, beams, roof and stairs).
- Red: Fully collapsed, i.e. damage was between 50-100% of the building's total value; typically this constituted damage to the principal structures (walls, pillars, beams, roof and stairs)
- Pink: Fire damage, where damage was between 50-100% of the building's total value.

In practical terms the original maps provided by the sources above consisted of 111 individual tiles in jpeg format covering the Kobe area. These had to be geo-referenced and the buildings and their corresponding colours extracted and cleaned to generate a full set of building polygons with their damage colours. We depict an example of part of the original tiles and the extracted building polygons in Figures 2 and 3, respectively. Using the address of each plant we then identified the plant's location latitude and longitude and thus were able to allocate each plant to its respective building.

[Figures 2 and 3 about here]

To create a single damage index that varied between 0 and 1 we used the percentage loss of value associated with each colour to assign a numerical scale to each building by using the median between the category thresholds (i.e. 11.5% for yellow, 35% for orange, and 75% for red) except for green buildings which we assigned a loss of value of 0%. Throughout our analysis we also experimented with using the lower and upper threshold of the percentage loss values of each damage category in creating what is in essence a step function.[11]

From the original map the local authorities also created summary measures of damages by Chome-level.[12] More specifically, we have the number of buildings by damage colour per Chome. We thus created a Chome indicator of the loss in value using the following equation:

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[11] One could also use the individual categories on their own and create a set of corresponding dummy variables. We opt for ratio variable as our benchmark proxy for a number of reasons. Firstly, as will be seen, we will be experimenting with a large number of interactions in our analysis, making the interpretation of a single index more amenable in interpretation. Secondly, this allows us to have an index that is more comparable to our Chome-level damage index derived from a different data source (as described below).

[12] A Chome is a small administrative unit of which there are 3,179 in the Kobe-Hanshin area. One should note that in order to confirm the accuracy of our geo-referencing of buildings and their damage type we overlayed our building shape-file with a shape-file of the Chomes, calculated the number of buildings per se and per damage category per Chome and compared this to the official aggregated data available. There are 3,179 Chomes in total in the Kobe-Hanshin area.

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

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 colour, where we, as a benchmark point, assume that losses are the midway points between the thresholds (except for the green category where we assume no loss) as we did for our individual level damage indicator.

Local authorities also collected other 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. This helps address some of the potential endogeneity concerns that we now discuss in more detail.

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 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. However, as noted earlier, we do have aggregate data on the construction date of buildings within ten-year periods from 1945 onwards. In addition, our Chome-level data contains information on the number of buildings by building material type. We include these to control for building type at least at the Chome-level. It is worth noting that Chomes tended to be fairly 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 all buildings. 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.

As a next step we also proxied building-level damages using a shake-map of the earthquake. Specifically, we used the gridded shake map generated by Fujimoto and Midorikawa (2002) to allocate peak ground acceleration values to each plant's building which we present in Figure 4.[13] As can be seen, the degree of shaking differs widely across Kobe. One should note, however, that the grids of the shake-map are fairly large. If we overlay this with the building damage map data which we show in Figure 5 one notices immediately the extreme heterogeneity of damages even with shake-map cells.

[Figures 4 and 5 about here]

Another alternative may be to use the actual building damage information available at the Chome-level. Hence, we plot the distribution of our index from our Chome damage equation in Figure 6. Accordingly, there is a wide variation of damages across Chomes. Again, however, a closer look at individual Chome's as shown in Figure 7 reveals the wide heterogeneity of damage even within a Chome.

[Figures 6 and 7 about here]

3.2 Data descriptives

We now provide a brief description of our data. In Table 1 we provide a summary of the industrial structure in Kobe as well as estimates of the average plant level damage for each industry using the previously defined colours pink (fire), red (severe) and orange (moderate). The Yellow and Green categories are excluded for reasons of space.

[Table 1 about here]

Table 1 shows that rubber was the industry with the largest number of plants in Kobe, 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. We are reassured that these summary statistics match the anecdotal evidence and Kobe City statistics previously discussed.

In Table 2 we present 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. As previously discussed, the largest number of plants were located in the Nagata Ward which was home to the non-leather shoe industry. The Nagata Ward also experienced a high level of damage with over 42% of plants experiencing moderate to severe damage. Finally,

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[13] We assumed that the age of 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

in Figure 8 we provide a summary of plant closure over the period of our sample for the most severely damaged plants (pink and red). The immediate observation is that, perhaps unsurprisingly, the greater the damage to a plant the more likely that plant was to close in the years following the earthquake. However, this trend became less pronounced over time.

[Table 2 about here]

[Figure 8 about here]

In the next stage we examine the impact of the earthquake on plant survival using different econometric approaches. First, survival analysis and second panel data methods.

4. Methodology

4.1 Survival Analysis

To investigate the effect of earthquake damage on plant survival we first consider a simple nonparametric estimate of the survivor function *S(t)*, i.e. the probability of surviving beyond time *t*. The Kaplan-Meier function estimates the survivor function as follows:

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

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.

Figure 9 provides the estimates of the survivor functions for plants that were damaged by the earthquake and for those that were undamaged.[14] Analysis time refers to the number of years that the plant has been in the sample. As can be seen, the probability of survival is greatest for undamaged plants at all points in time.

[Figure 9 about here]

To examine the effect of earthquake damage on plant survival in more detail we estimate a Cox proportional hazards model (Cox 1972). 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. This can be expressed as:

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[14] Where a damaged plant is here defined as a plant that has experienced yellow, orange, red or pink damage.

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

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. A key feature of the Cox model is that the baseline hazard is given no particular parameterization and can be left un-estimated. However, the proportional hazards assumption requires that each plant's hazard is a constant multiplicative replica of another's. As equation (1) demonstrates, the effect of the function $exp(Z\beta)$ is to scale the baseline hazard function that is common to all units up or down. The implication of this is that the effect of covariates in proportional hazards models is assumed to be fixed over time. We test this assumption following Grambsch and Therneau (1994).

Vector Z contains our various earthquake damage variables as defined in the previous section and other variables likely to influence plant survival. A number of previous papers have examined the factors that influence the survival of plants. Key papers by Dunne *et al.* (1988, 1989) establish the important role played by plant age and size and most subsequent papers confirm these findings (for example Bernard *et al.* 2006). A variety of other factors have also been shown to be important. Bernard and Jensen (2007) find that multi-plant and multinational firms in the US have lower survival rates, while Gorg and Strobl (2003) find that Irish plants that are majority foreign owned also have lower survival rates. Disney *et al.* (2003) examine UK manufacturing plants and find that those that belong to a larger group are less likely to fail. Bridges and Guariglia (2008) examine the role played by financial variables and find that lower collateral and higher leverage result in lower survival probabilities for purely domestic firms than globally engaged firms, suggesting that global engagement may shield firms from financial constraints. Bernard *et al.* (2006) find that plant survival is negatively associated with industry exposure to low-wage country imports. This study, along with several others (e.g. Bernard and Jensen 2007) also emphasises the positive role played by productivity which is shown to increase survival rates. Neffke *et al.* (2012) examine the effect of agglomeration economies on plant survival and find that results differ depending on the type and age of the plant. Finally, in a related study, Falck (2007) finds that a new establishment has greater survival probabilities the greater the number of new businesses in the same region and same industry, a finding supported by Boschma and Wenting (2007).

While older plants are more likely to survive than younger plants we cannot directly include plant age in a Cox proportional hazards model as it would be collinear with the baseline hazard function. Instead we therefore include each plant's age in 1995 (*AGE*) as a time invariant measure of plant age. Since larger plants have been shown to be more likely to survive than smaller plants 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 the average wage within a plant (*WAGE*) as a proxy for the skill level of the workforce and also a measure of TFP on the basis that productive plants are more likely to survive than less productive plants. Since our dataset only provides a measure of capital stock for a subset of our sample, namely firms with over 30 workers, we follow Cui *et al.* (2012) and construct a measure of TFP that does not require a direct measure of capital. Details are provided in Appendix 1.

We also include dummy variables to capture whether the plant belongs to a multi-plant firm (*MULTI*), whether the plant moved location within Kobe city during the sample period (*MOVE*) and whether or not the plant is in a designated reconstruction priority zone (*RECON*) in which government assistance was provided and planning rules were relaxed.

Finally, 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 *ClusterFirms* which measures the number of firms within the same industry and same Chome (but not neighbouring Chomes). Our other three measures include *ClusterFirmsNb* 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.

Our survival estimations also include dummies for 162 industries, year dummies and dummies to capture the possible influence of being located in different wards within Kobe city. Finally, 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, defined as wooden, reinforced concrete, steel or brick. Table 3 provides definitions of all of our variables and Table 4 provides summary statistics.

[Table 3 and Table 4 about here]

The average age of a plant is just over 18 years old. 14% of plants are part of a multi-plant firm and 17% of plants moved during this period. It is interesting to note that 40% of plants were in one of eight special reconstruction zones. Other interesting observations are that most firms were built between 1966 and 1975 and are fairly equally distributed between brick, wood, steel and reinforced concrete.

To further assess the robustness of our main results we also estimate three additional models. First we replace our main damage variable with separate dummy variables for the 3 most significant levels of damage (pink, red and orange). Second we estimate a Probit model with the probability of death as the dependent variable. Finally, we estimate a parametric survival model using the Gompertz distribution.[15]

In separate unreported estimations we also investigate the extent to which plant damage interacts with plant size, whether or not the plant is in a reconstruction zone, whether or not the firm moves within Kobe and the plant's wages. None of these interactions was consistently signed or statistically significant and hence for reasons of space they have not been reported.

4.2 The Impact of Damage on Employment, Value Added and Productivity

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:

$$E_{it} = \alpha_i + \gamma_t + X\delta + \varepsilon_{it} \qquad (3)$$

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.[16]

5. Results

Table 5 presents our main survival analysis results. 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

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[15] As already noted, a feature of the semi-parametric Cox model is that we do not need to make assumptions about the baseline hazard function ($\lambda_0(t)$ in equation 2). If such assumptions were wrong then our estimates of β might be misleading. However, if we did know the functional form of $\lambda_0(t)$ then our estimates of β would be more accurate than those from the Cox model. To find the most suitable parametric model we estimated models using a range of alternative distributions (Exponential, Weibull, log-logistic, log-normal, Gamma and Gompertz) and chose the distribution that provided the lowest Akaike information criterion. This was the Gompertz distribution.

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

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 5 about here]

Column (1) of Table 5 includes only our control variables. 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 more 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 more productive firms are more likely to survive. Finally, our measure of the degree of plant agglomeration (*ClusterFirms*) which measures the number of plants from the same 2-digit industry in a given Chome 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 concentration of plants from the same industry. 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 can be explained by the 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 although this *SHAKE* variable is not statistically significant (which is not surprising given figures 4 and 5). In column (4) we include the average building damage at the Chome-level (*CHOMEdamage*). As shown in Figure 5 there is considerable heterogeneity within any one Chome which may explain the lack of significance of *CHOMEdamage* is included by itself.

In Column (5) we include our building-level damage variable (*DAMAGE*). This variable is statistically significant with a hazard ratio of 1.56 suggesting that a 1 unit increase in damage leads to a 56% increase in the probability of plant closure. In Column (6) we also control for the average level of *CHOMEdamage* but this has little effect on the *DAMAGE* variable. In column (7) we interact our Chome-level 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 our Chome-level damage variables are significant. Both *DAMAGE* and *CHOMEdamage* hazard ratios are 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. This time effect is returned to below.

Table 6 provides some further sensitivity analyses to confirm the robustness of our primary finding, that plant damage significantly impacts upon plant survival. In model 1, *DAMAGE* is replaced by individual dummy variables for pink, red and orange levels of damage. Green (no damage) and yellow (superficial damage) are the omitted categories. While pink (fire) damage is not statistically significant, red and orange damage are both significant, with hazard ratios of 2.27 and 1.43, respectively. Model 2 replaces the Cox proportional hazards model with a Probit model which estimates the probability of plant death. *DAMAGE* is again shown to be a positive and statistically significant determinant of plant death. Finally, model 3 reports a parametric regression using the Gompertz distribution. This distribution provided the lowest Akaike Information Criterion (AIC) of all the distributions. *DAMAGE* is again positive and statistically significant, with a hazard ratio of 2.78. In each of these three models the sign and significance of the other control variables remains very similar to those in Table 5.

[Table 6 about here]

All three models in Table 6 also include *DAMAGE* interacted with time. In common with model 7 in Table 5, the time interaction is found to be negative, suggesting that the impact of earthquake damage on plant deaths declines over time. Figure 10 plots the damage hazard ratios over time for the Cox model estimation (model 7 in Table 5), the parametric model estimation (model 3 in Table 6) and, separately for the most significant individual level of damage, damage red (model 1 in Table 6). In each case the hazard ratio declines over time but remains above 1 thoughout the sample period. This indicates that damaged firms were more likely to die than non-damaged firms, even in 2007. Note that the possibility of a non-linear time interaction effect was also tested for each of these models but in all cases the quadratic *DAMAGE*time* variable was not statistically significant.

[Figure 10 about here]

Table 7 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 three out of the four being statistically significant. It would therefore appear that, other things being equal, belonging to a cluster in Kobe city was not good for plant survival. This perhaps reflects the increased local competition that results from clusters for firms who are predominantly serving the local market.[17] Table 7 also reports the hazard ratio on clusters interacted with *DAMAGE*. For the two clusters measured in terms of the number of nearby firms, damages interacted with clusters has a negative effect on plant deaths indicating that damaged firms who belonged to a cluster were less likely to die. The effect of the employment based clusters interacted with *DAMAGE* is not statistically significant.

[Table 7 about here]

In Table 8 we estimate a panel fixed-effects model to examine the impact of the earthquake on employment, value added, TFP and labour productivity. 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. The results for employment show that the more damaged a plant is, the greater the reduction in its employment. Chome level damage also reduces employment, perhaps reflecting the effect of local infrastructure damage on individual plants. 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*, and *ClusterFirms* all increase employment levels, while *WAGE* reduces employment.

[Table 8 about here]

Value added is negatively affected by plant and chome 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 labour productivity when we include time interaction terms, with the interaction

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[17] 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.

terms themselves being negative. This suggests that the earthquake had a positive effect on productivity although this increase reduces over time. This 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 labour inputs and output or an increase in output relative to capital and labour inputs. The precise mechanisms at work remain a topic for future research. 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.

6. 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. The majority of previous studies that have examined the impact of natural disasters have taken a macroeconomic approach looking at the impact of a natural disaster on economic growth at the country level. The results of these previous studies typically show that countries and larger regions recover quickly from a natural disaster.

In this paper we argue that a largely overlooked aspect of natural disasters is the local economic impact. 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 but that this effect falls over time. However, the effect appears to be longer lasting that the macroeconomic results suggest with plant deaths significantly impacted by the earthquake throughout our sample period of 1995-2007.

Our fixed-effects models also indicate that the earthquake had a significant negative impact reveal some evidence of creative destruction type behaviour among those plants that survived for our sample period. We find that productivity increased in the year following the earthquake although this increase in productivity decreased over time. 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).

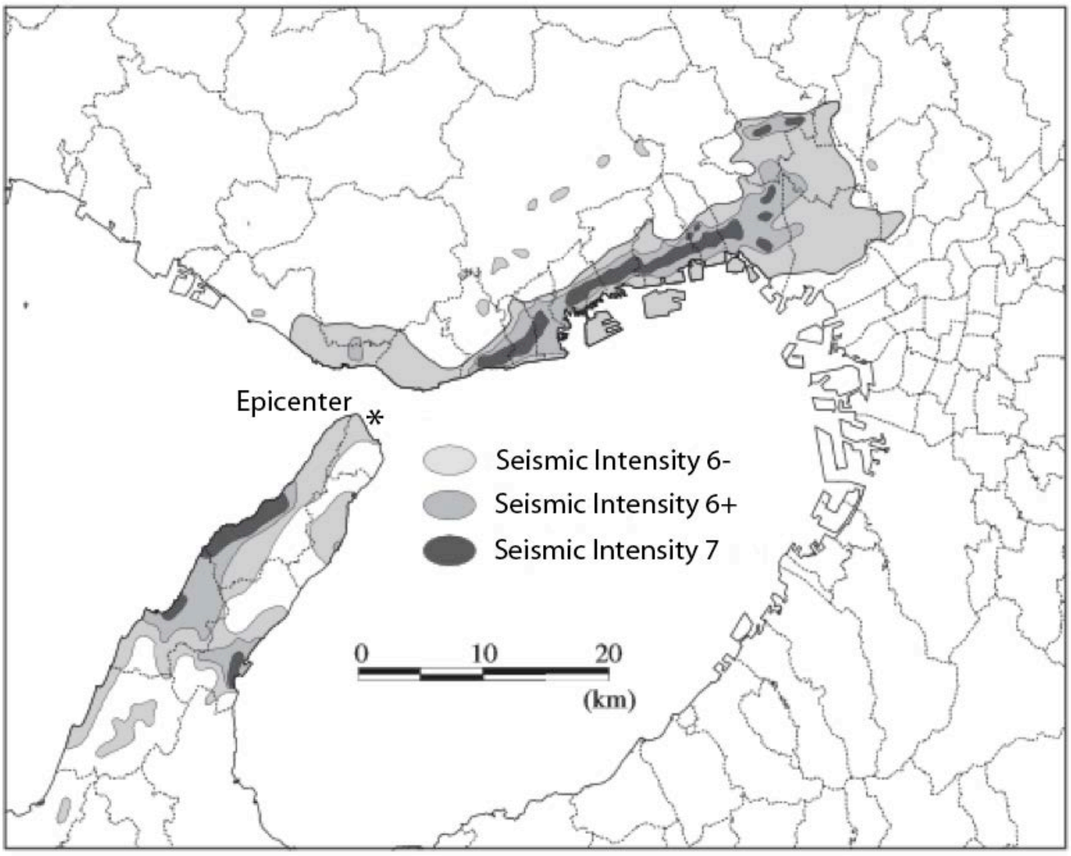


Figure 2: Example of building level damage in Kobe (raw data).

Figure 3: Example of building level damaged (cleaned)

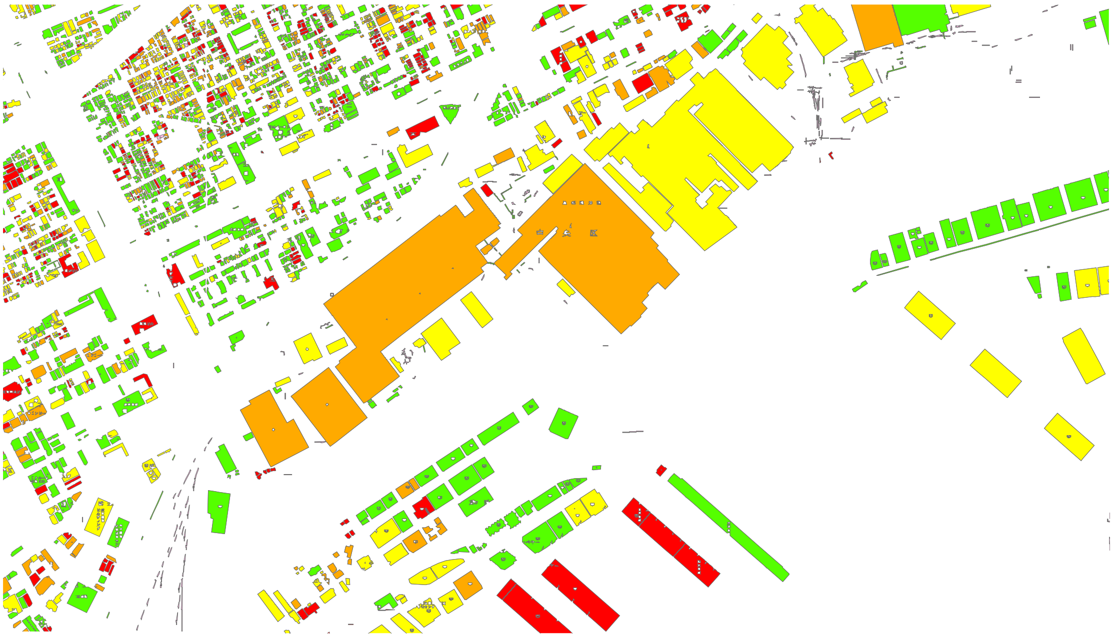


Figure 4: Shake-map of Kobe.

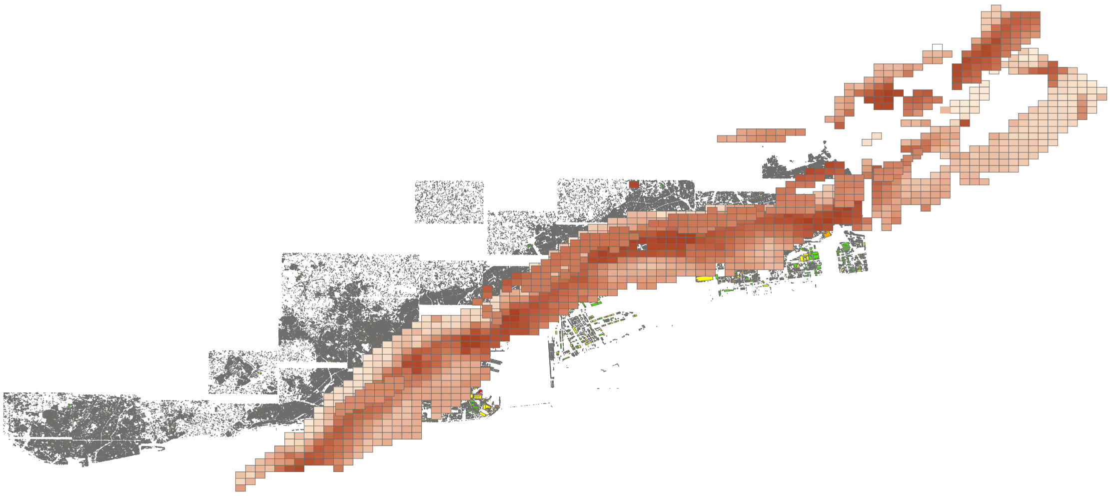


Figure 5: Shake-map showing building heterogeneity.

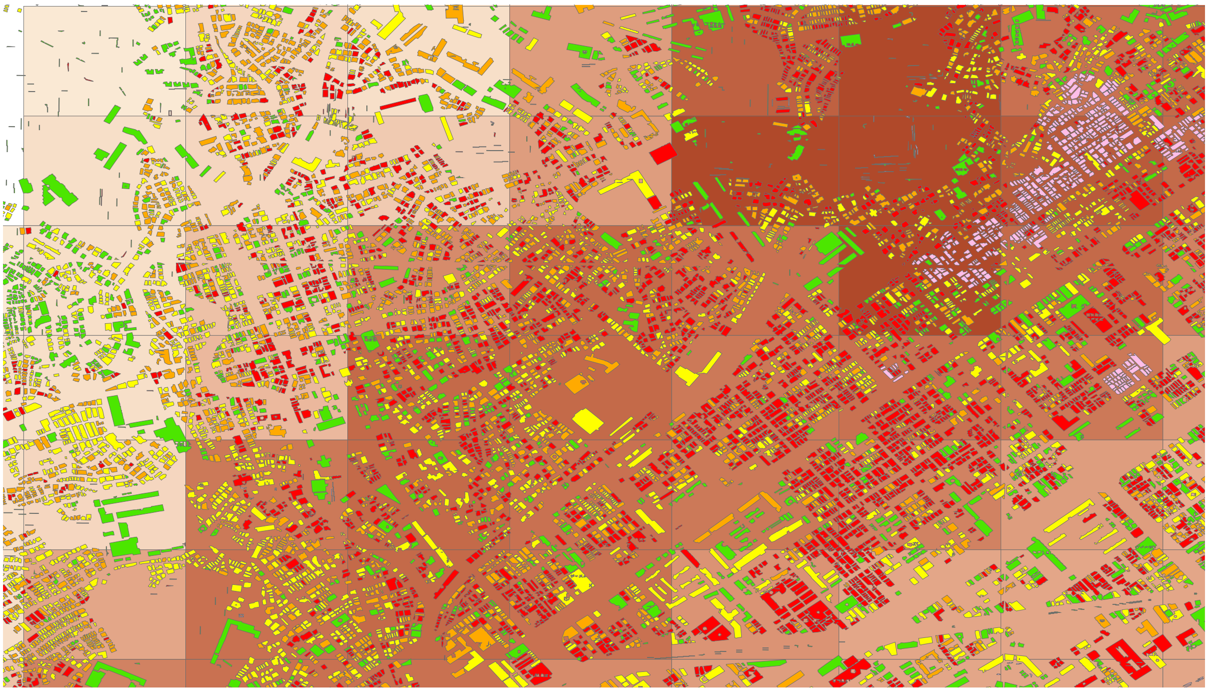


Figure 6: Chome-level damages.

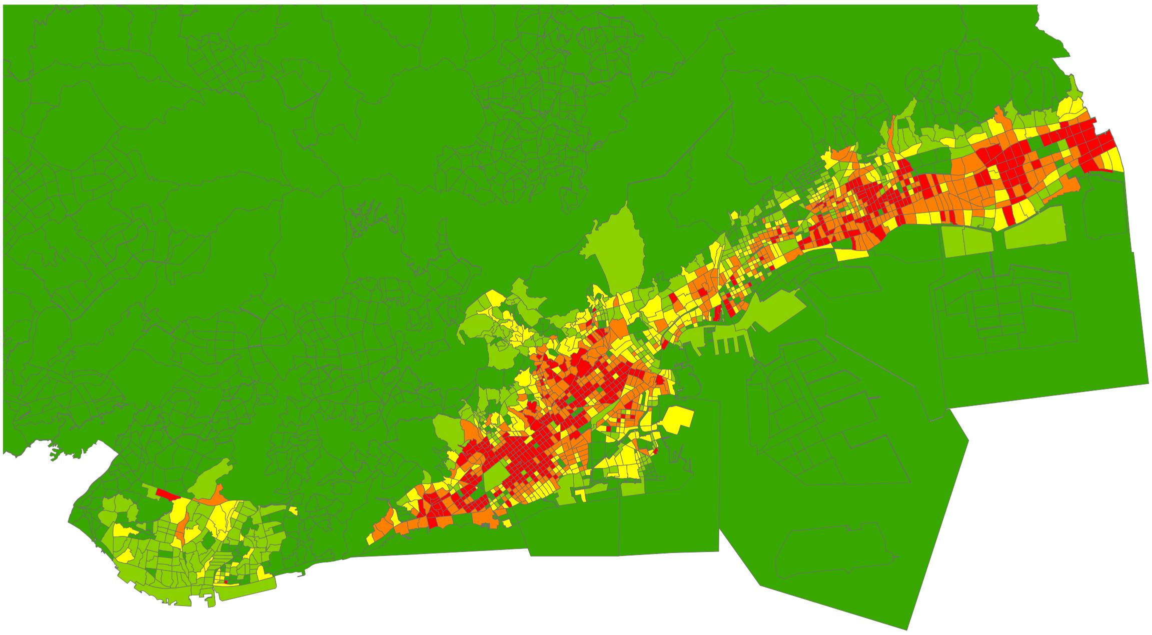
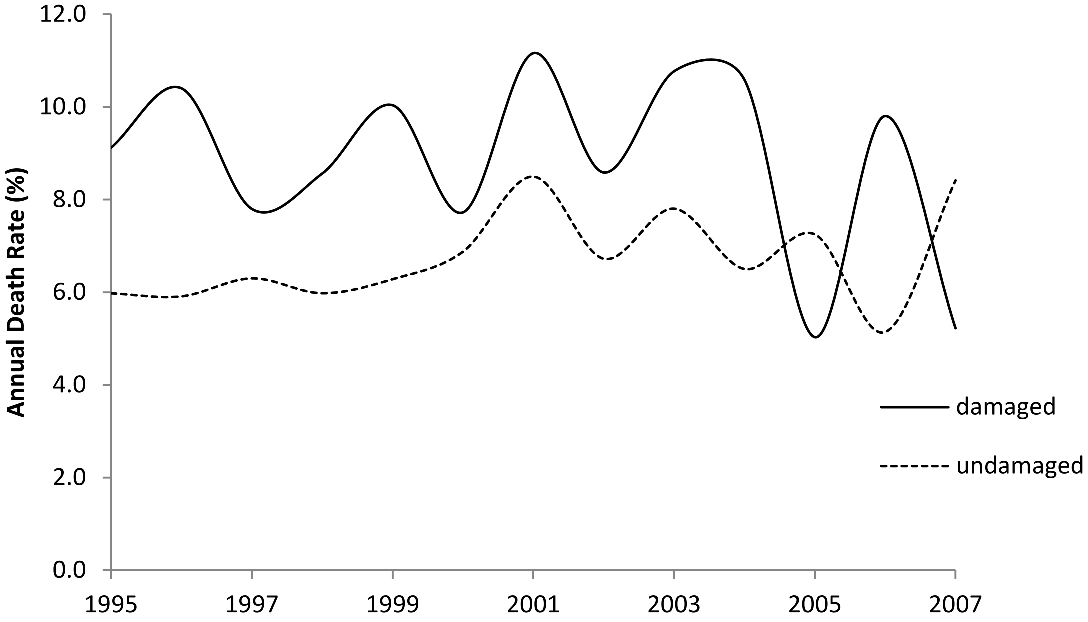


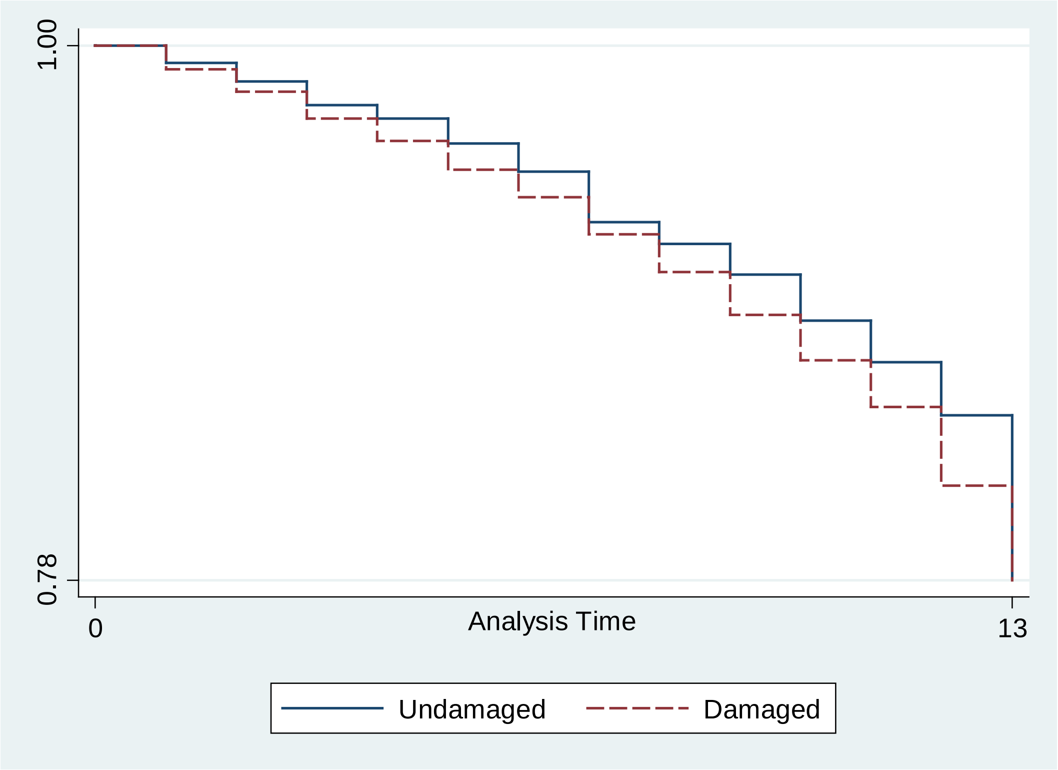
Figure 7: Building damage heterogeneity with Chome-level demarcations.

Figure 8: Annual Death Rate of Severely Damaged and Undamaged Plants



where damage = Pink + Red

Figure 9. Kaplan-Meier Survival Curves for Damaged and Undamaged Plants



Where damage = Pink + Red + Orange + Yellow

Figure 10. Damage Hazard Ratios Over Time (from Table 5 (model 7) and Table 6 (models 1 and 3))

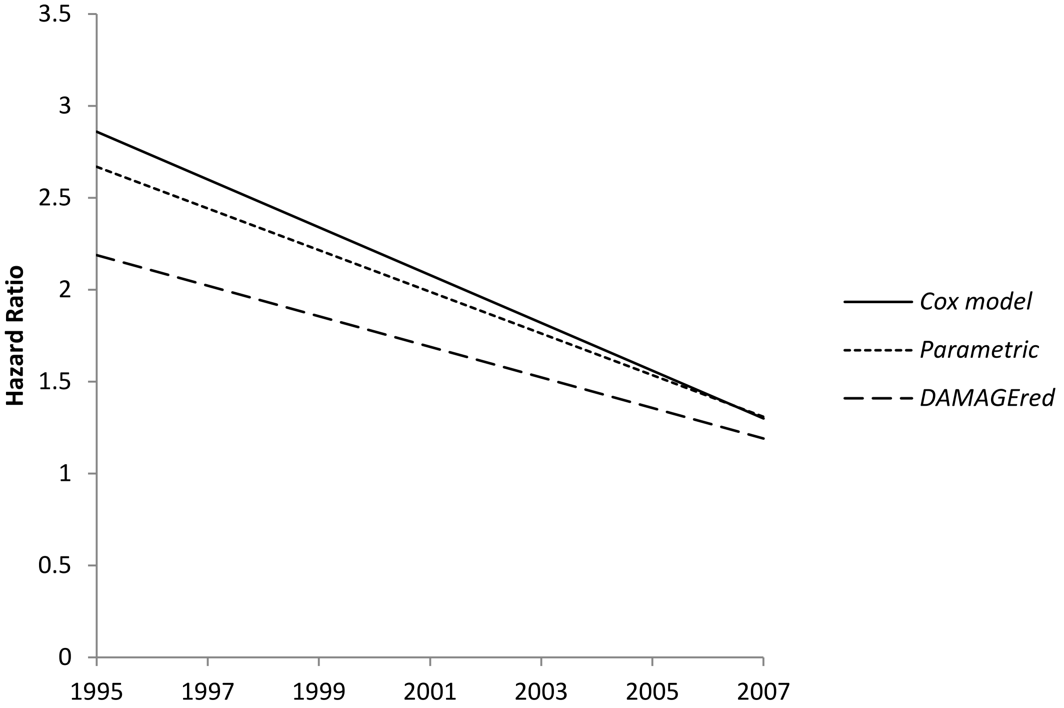


Table 1. Damage by Industry (ranked by *Pink* + *Red* + *Orange* damage)

Industry	% of Sample	PINK/RED /ORANGE	PINK	RED	ORANGE
Non-Ferrous Metals	0.6	54.2	0	15.6	38.5
Rubber	17.0	46.1	5.5	24.8	15.8
Leather and Fur	6.8	44.0	7.5	19.8	16.8
Information & Communication Machinery	0.4	41.9	0	33.8	8.1
Pulp, Paper	2.5	41.6	3.4	16.5	21.7
Furniture	1.4	40.3	0	16.9	23.5
Chemicals	1.2	36.9	13.1	19.2	4.6
Textiles	4.8	36.8	0	17.4	19.5
Printing	10.5	36.5	0.9	16.5	19.1
Wood Lumber	1.8	33.3	0	16.0	17.3
Plastic Products	1.8	32.6	0	14.9	17.6
Electronic Devices & Semi-Conductors	0.6	32.3	0	8.3	24.0
Metal Products	8.6	31.6	1.9	11.2	18.5
Transport Machinery	5.1	30.5	1.8	8.1	20.7
Porcelain and Pottery	1.3	30.2	6.1	18.1	6.1
Industrial Machinery	6.0	29.6	0.6	14.1	14.9
Electronic Machinery	3.0	26.5	3.6	10.1	12.7
Food	12.3	24.5	1.6	9.4	13.5
General Machinery	4.6	23.0	1.2	10.4	11.4
Beverages and Tobacco	2.1	22.1	0	9.1	13.0
Iron and Steel	1.3	19.3	0	16.5	2.8
Oil and Coal Products	0.5	17.3	16.1	0.0	1.2
Other Manufacturing	4.6	15.4	0.7	4.9	9.8
Household Machinery	0.8	14.5	0	8.4	6.1
Newspapers	0.6	9.8	0	7.8	2.0

Table 2. Damage by Ward (ranked by *Pink* + *Red* + *Orange*) (*Percentage of Firms in Each Ward That Were Damaged)*

	% of sample	*PINK+RED+ ORANGE*	*PINK*	*RED*	*ORANGE*
Suma	6.4	44.1	14.4	11.9	17.8
Nagata	38.7	42.8	3.5	21.3	18.1
Nada	5.5	32.3	1.4	20.4	10.4
Higashi Nada	14.5	27.9	0.86	14.5	12.5
Hyogo	20.4	27.7	0.23	11.1	16.4
Tarumi	2.1	18.1	0	0	18.1
Chuo	12.4	16.3	0.63	3.9	11.8

Table 3. 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
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
ClusterFirms	The number of plants belonging to the same 2 digit industry as the plant in question and within the same chome
ClusterFirmsNb	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).

Table 4. 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
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
ClusterFirms	1.5	3.0	0	20
ClusterFirmsNb	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

Table 5. Main Results of Survival Analysis (Cox proportional hazard)

	1	2	3	4	5	6	7
DISTEPI		1.01***					
		(4.1)					
SHAKE			0.99				
			(-0.27)				
CHOMEdamage				1.12		1.06	1.77***
				(1.3)		(0.7)	(6.7)
DAMAGE					1.59***	1.56***	2.99***
					(4.0)	(3.8)	(5.7)
CHOMEdamage* Time							0.87***
							(-5.9)
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	2.21***	2.21***	2.21***	2.21***	2.19***	2.20***	2.19***
	(10.6)	(10.6)	(10.6)	(10.6)	(10.6)	(10.6)	(10.4)
SIZE3	0.79**	0.79***	0.77***	0.79***	0.80***	0.80***	0.80***
	(-2.7)	(-2.8)	(-2.7)	(-2.6)	(-2.6)	(-2.5)	(-2.6)
SIZE4	0.94***	0.94***	0.94***	0.94***	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)	(-5.0)	(-5.1)	(-5.1)	(-5.2)
TFP	0.90**	0.89**	0.90**	0.89**	0.90**	0.90**	0.91**
	(-2.2)	(-2.3)	(-2.1)	(-2.3)	(-2.1)	(-2.1)	(-1.9)
MULTI	1.59***	1.59***	1.58***	1.61***	1.57***	1.59***	1.60***
	(4.3)	(4.3)	(4.2)	(4.3)	(4.2)	(4.3)	(4.4)
MOVE	0.76***	0.75***	0.76***	0.76***	0.74***	0.74***	0.78***
	(-3.3)	(-3.4)	(-3.3)	(-3.4)	(-3.6)	(-3.6)	(-3.2)
RECON	1.002	1.001	1.002	1.001	0.99	0.99	1.001
	(0.2)	(0.1)	(0.3)	(0.1)	(-0.2)	(-0.3)	(0.1)
ClusterFirms	1.02	1.02	1.02	1.02*	1.02**	1.02**	1.03***
	(1.6)	(1.6)	(1.6)	(1.7)	(2.0)	(2.0)	(2.3)
observations	16,658	16,658	16,658	16,658	16,658	16,658	16,658
Wald	304828***	329924***	319115***	358224***	303195***	337831***	372465***

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

Table 6. Sensitivity Results

	1	2	3
DAMAGEpink	1.33		
	(0.84)		
DAMAGEred	2.27***		
	(5.2)		
DAMAGEorange	1.43**		
	(2.2)		
*DAMAGEpink*Time*	1.012		
	(0.2)		
*DAMAGEred*Time*	0.92***		
	(-3.7)		
*DAMAGEorange*Time*	0.96*		
	(-1.7)		
DAMAGE		0.19**	2.78***
		(2.0)	(5.1)
*DAMAGE*time*		-0.016	0.89***
		(-1.0)	(-3.7)
CHOMEdamage	1.87***	0.13**	1.86***
	(7.3)	(2.4)	(6.9)
*CHOMEdamage*time*	0.86***	-0.029***	0.85***
	(-6.3)	(-2.8)	(-6.3)
AGE	0.99**	-0.0017	0.99**
	(-2.1)	(-1.5)	(-2.0)
SIZE1	2.20***	0.37***	2.25***
	(10.4)	(8.8)	(10.2)
SIZE3	0.80**	-0.13**	0.78***
	(-2.6)	(-2.8)	(-2.6)
SIZE4	0.94***	-0.21***	0.69***
	(-3.7)	(-3.6)	(-3.1)
WAGE	0.99***	0.00049***	0.99***
	(-5.1)	(-3.3)	(-4.4)
TFP	0.91**	-0.059**	0.90**
	(-2.1)	(-2.2)	(-2.0)
MULTI	1.60***	0.25***	1.58***
	(4.4)	(4.5)	(4.1)
MOVE	0.77***	-0.22***	0.79***
	(-3.2)	(-5.0)	(-2.8)
RECON	0.99	0.024	1.010
	(-0.1)	(0.6)	(0.1)
ClusterFirms	1.03**	0.010***	1.03
	(2.2)	(4.5)	(2.2)
observations	16,658	16,658	16,658
Wald	370956***	624.5***	77654***
Pseudo R^2		0.080	

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

Model 1 uses separate dummies for the 3 most significant levels of damage
Model 2 uses a Probit estimation
Model 3 uses a parametric estimation using the Gompertz distribution

Table 7. Clustering Results

	1	2	3	4
DAMAGE	3.34***	3.86***	2.82***	2.95***
	(5.7)	(6.2)	(5.2)	(5.4)
*DAMAGE*Time*	0.86***	0.86***	0.87***	0.87***
	(-4.5)	(-4.6)	(-4.3)	(-4.3)
CHOMEdamage	1.75***	1.78***	1.76***	1.75***
	(6.5)	(6.5)	(6.6)	(6.6)
*CHOMEdamage*Time*	0.87***	0.87***	0.87***	0.87***
	(-5.8)	(-5.8)	(-5.9)	(-5.8)
ClusterFirms	1.04***			
	(2.7)			
ClusterFirmsNb		1.03***		
		(5.0)		
ClusterEmp			1.0001	
			(1.5)	
ClusterEmpNb				1.0001*
				(1.9)
*DAMAGE*Cluster*	0.95	0.97***	1.0025	1.0001
	(-1.5)	(-2.6)	(1.5)	(0.3)
AGE	0.99**	0.99**	0.99**	0.99**
	(-2.1)	(-2.1)	(-2.1)	(-2.2)
SIZE1	2.19***	2.18***	2.18***	2.17***
	(10.4)	(10.3)	(10.3)	(10.3)
SIZE3	0.80***	0.79***	0.80***	0.80***
	(-2.6)	(-2.7)	(-2.6)	(-2.6)
SIZE4	0.94***	0.94***	0.94***	0.94***
	(-3.7)	(-3.8)	(-3.6)	(3.6)
WAGE	0.99***	0.99***	0.99***	0.99***
	(-5.2)	(-5.3)	(-5.2)	(-5.2)
TFP	0.91*	0.90**	0.91**	0.91*
	(-1.9)	(-2.1)	(-2.0)	(-1.9)
MULTI	1.60***	1.62***	1.59***	1.58***
	(4.3)	(4.5)	(4.3)	(4.3)
MOVE	0.77***	0.75***	0.77***	0.77***
	(-3.2)	(-3.4)	(-3.3)	(-3.2)
RECON	1.001	0.99	1.001	1.001
	(0.1)	(-0.04)	(0.1)	(-0.1)
observations	16,658	16,658	16,658	16,658
Wald	312095***	329219***	323270***	305422***

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

Table 8. Determinants of Value Added, Employment, TFP and Labour Productivity 1992-2008 (Fixed Effects Panel)

	logEMP	logEMP	logVA	logVA	TFP	TFP	logLabProd	logLabProd
DAMAGE	-0.063***	-0.068***	-0.043*	0.34	0.021	0.11***	0.016	0.098***
	(-8.9)	(-5.6)	(-1.7)	(0.8)	(0.8)	(4.0)	(0.7)	(2.8)
*DAMAGE*Time*		0.00067		-0.011**		-0.010***		-0.012***
		(0.3)		(-2.2)		(-5.9)		(-3.5)
CHOMEdamage	-0.042***	-0.030***	-0.037**	-0.045**	-0.0050	0.00007	0.0044	-0.015
	(-8.0)	(-3.9)	(-2.7)	(-2.9)	(-0.6)	(-0.01)	(0.3)	(1.3)
*CHOMEdamage*Time*		-0.0017*		0.0011		-0.0029		0.0027*
		(-1.8)		(0.5)		(-0.7)		(1.7)
Time		-0.18***		-0.52***		0.038***		-0.34***
		(-137.1)		(-116.1)		(7.4)		(-95.3)
AGE	0.083***	0.15***	0.26***	0.46***	-0.019***	-0.033***	0.18***	0.31***
	(160.2)	(167.3)	(172.9)	(143.6)	(-16.8)	(-12.7)	(140.5)	(119.1)
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)	(12.6)
MULTI	0.051**	0.051**	-0.029**	-0.029**	-0.058***	-0.058***	-0.078***	-0.078***
	(2.3)	(2.3)	(-2.0)	(-2.1)	(-3.8)	(-3.7)	(-3.4)	(-3.4)
MOVE	0.012	0.012	0.019	0.019	-0.0072	-0.0073	-0.0082	-0.0082
	(1.5)	(1.5)	(1.1)	(1.1)	(-0.5)	(-0.5)	(-0.7)	(-0.7)
RECON	0.011	0.009	0.048***	0.048***	0.070***	0.066***	0.038***	0.038***
	(1.1)	(1.1)	(3.7)	(3.7)	(6.5)	(5.0)	(3.8)	(3.8)
ClusterFirms	0.0023***	0.0023***	0.0017	0.0016	-0.0018	-0.0020	-0.0006	-0.0007
	(2.8)	(2.8)	(0.9)	(0.8)	(-0.8)	(-0.9)	(-0.3)	(-0.4)
observations	11,688	11,688	11,616	11,616	11,616	11,616	11,616	11,616
R^2	0.11	0.11	0.15	0.15	0.10	0.11	0.14	0.14

Each model contains plant fixed effects.

***, **, * denote statistical significance at 99%, 95% and 90% confidence levels, respectively

Appendix 1: Estimating TFP

A feature of our data is that information on capital stocks is collected only for plants with 30 employees or more. Such plants form a minority of our sample implying that conventional measures of TFP are therefore not available to us. To overcome this problem we follow Cui *et al.* (2012) and estimate a measure of plant level TFP that does not require information on capital stocks. We assume that all plants in the same industry use the same technology and that this technology can be represented by a homogenous production function, written as:

$$V_{ijt} = \theta_{ijt} p_j\left(l_{ijt}, z_{ijt}\right) \qquad \text{(A1)}$$

where V_{ijt} is value added in plant i, industry j and year t, l_{ijt} is the labour force, z_{ijt} is a vector of all other inputs and θ_{ijt} represents plant level productivity, measured as the deviation from the industry average productivity. If we assume that the production function is homogenous of degree α_j then equation (1) can be rewritten as:

$$V_{ijt} = \theta_{ijt}\left(l_{ijt}\right)^{\alpha_j} p_j\left(1, \frac{z_{ijt}}{l_{ijt}}\right) \qquad \text{(A2)}$$

where the degree of homogeneity of the production function captures the industry-specific degrees of returns to scale.

As Cui *et al.* (2012) point out, expressing the production function in this way allows us to separate the plant level labour input l_{ijt} from the input ratios z_{ijt}/l_{ijt} which are not observable in our data. If we continue to assume that plants within the same industry possess the same production function (aside from the plant specific productivity parameter) and also assume that all plants in the same industry are subject to the same input prices, then all plants within the same industry should select the same input ratios z_{ijt}/l_{ijt} due to cost minimisation. This implies that p_j (1, z_{ijt}/l_{ijt}) from equation (2) can be captured by industry-by-year-specific variables. We therefore estimate the following:

$$log\left(V_{ijt}\right) = \sum_j \delta_j IND_j + \sum_j \alpha_j IND_j * log\left(l_{ijt}\right) + \lambda_{jt} + \epsilon_{ijt} \qquad \text{(A3)}$$

where IND_j represents dummies for our 162 three-digit industries. The error term ε_{ijt} includes the plant specific productivity parameter θ_{ijt} which captures the deviation of each plant's productivity from the industry average. This can be expressed as:

$$\log\left(\theta_{ijt}\right) \equiv log\left(V_{ijt}\right) - \sum_j \delta_j IND_j - \sum_j \alpha_j IND_j * log\left(l_{ijt}\right) - \lambda_{jt} \qquad \text{(A4)}$$

Figure A1. Histogram of Industry Returns to Scale Coefficients (α_j from equation 4)