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"Transportation Performance, Disaster Vulnerability, and Long-Term Effects of Earthquakes"

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Abstract

This paper discusses the critical role of transportation systems in disaster recovery and the development of any long-term economic effects from earthquakes, based on insights from the Kobe earthquake and other disasters. The occurrence of long-term effects on regional economies has been controversial in the disaster literature and are for the most part ignored in earthquake loss estimation models. However, events such as the Kobe earthquake clearly demonstrate that certain kinds of long-term impacts do occur, at least in catastrophic disasters. Moreover, performance and recovery of transportation systems appear to play a major role in the development of long-term impacts. This arises in large part because transportation infrastructure often requires substantially lengthier repair times than other lifeline systems. Focusing primarily on the Kobe earthquake, this paper identifies two particularly significant examples of long-term effects of the disaster: loss of business at marine ports, and the development of striking intra-urban spatial differentials in disaster recovery. In both cases, this paper argues, transportation loss served to accentuate existing social and economic conditions of vulnerability, alter the competitiveness of places (whether globally or within a region), and thereby lead to long-term loss.

Introduction

In recent years, there has been much progress in the development of models of the economic impact of earthquakes. For example, FEMA's nationally applicable earthquake loss estimation model HAZUS includes a module that estimates regional economic impacts (Brookshire et al., 1997). Methodologies have been developed and demonstrated for estimating economic disruption from damage to lifeline systems such as electric power and transportation (Rose et al., 1997; Cho et al., 2000).

Despite methodological advances, however, in one important respect, all of these models suffer from a common limitation: they assume that economic disruption from disasters is a short-term phenomenon and that long-term effects do not occur. In other words, no changes in social or economic structure are anticipated, and losses are assumed to cease once physical restoration of damaged facilities has been completed or stabilized. Much of the previous literature has implied that economies are in fact quite resilient and long-term effects do not occur. This is supported by observations from moderate-sized disasters; in particular, the Northridge earthquake (Gordon and Richardson, 1995; Cochrane, 1996).

In the case of catastrophic disasters, however, the assumption of no long-term effects is no longer tenable, in view of insights from disasters such as, most notably, the 1995 Hyogoken Nambu (Kobe) earthquake. This paper presents empirical evidence indicating that in Kobe, at least two significant types of long-term loss occurred, both of which are related to transportation loss. The first pertains to business loss at the Port of Kobe, one of the largest container cargo ports in the world. The second relates to the development of spatial disparities in economic recovery within the disaster-impacted region which, this paper suggests, derived in part from differences in transportation accessibility after the earthquake. The premise of this paper is that transportation loss can serve to accentuate pre-existing conditions of disaster vulnerability and, in this way, lead to the development of long-term economic loss from earthquakes and other disasters.

The significance of transportation for the development of long-term economic impacts in disasters derives in part from its relatively long restoration times in comparison with other vital urban lifeline systems. After the 1989 Loma Prieta earthquake, damage to the Bay Bridge took one month to repair while the Cypress Viaduct was not rebuilt for several years. In the 1994 Northridge, power was restored within a couple of days while the last major highway bridge repair was completed about 10 months after the earthquake.

In Kobe, the earthquake wrought severe damage to the regional transportation system, including highways, regional railways, high-speed inter-regional rail, and seaport facilities. In this disaster, too, transport systems required much longer timeframes for repair than other urban lifeline systems. Figure 1 shows that while electric power and telecommunications were reestablished within the first couple of weeks, and water and natural gas within 3-4 months, the rail and highway networks were not completely restored until 7 and 21 months after the earthquake, respectively, and the Port of Kobe required somewhat over 2 years to complete repairs.

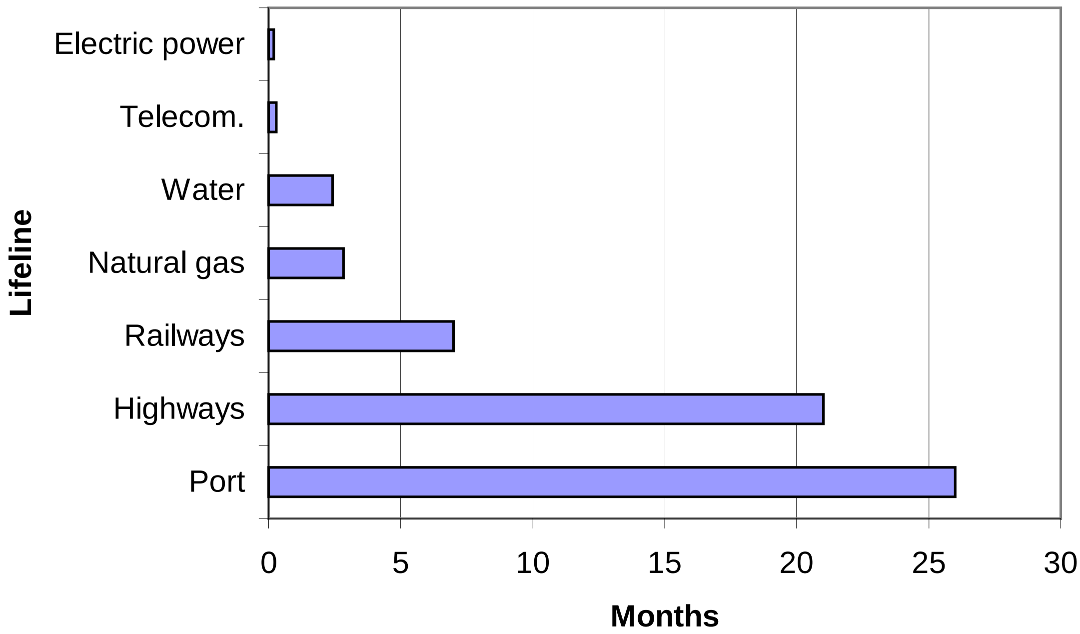

Figure 1. Lifeline Restoration Timeframes in the Kobe Earthquake

Subsequent sections of this paper focus on the development of long-term loss at the Port of Kobe and the emergence of spatial disparities in disaster recovery and its linkage to urban transportation accessibility loss. The paper concludes with implications for other seismically vulnerable urban areas and topics for further research.

Long-Term Loss at the Port of Kobe

There can be no doubt that the earthquake causes substantial loss of business at the Port of Kobe. In 1994, prior to the earthquake, the Port of Kobe was the world's sixth largest container port in terms of cargo throughput; in 1997, after repairs had been completed, it ranked seventeenth (Chang, 2000). Figure 2 shows container cargo traffic through the Port of Kobe before and after the earthquake, where values have been normalized against 1990 levels. Even in 1998, 3 years after the disaster, cargo traffic remained at roughly half of pre-disaster levels. As shown in the figure, the trend is especially striking in the case of transshipment cargo, or cargo that is moved from one vessel to another at Kobe (e.g., from a feeder boat to a large ship for ocean crossing) but that originates from and is destined for other regions. Kajitani et al. (2000) have established that the discontinuities in pre- and post-earthquake traffic at the Port are statistically significant, and that changes in long-term trends did occur.

Chang (2000) found that the loss of business differed according to the various types of traffic and their geographic relationship to the Port of Kobe. Much import/export cargo, that is cargo originating from or destined for Japan, was temporarily lost to competing ports in the country. However, as shown in Figure 3, the vast majority of it was regained after a few months, once repairs at Kobe had made substantial progress. Note that perhaps a quarter of Kobe's market share in this arena does appear, however, to have been permanently lost to competing ports in Japan.

Figure 4, on the other hand, shows that long-term loss for transshipment cargo was much more severe. In addition to total transshipment cargo, the figure shows trends for the North America-China and North America-Korea routes, which together comprised nearly 70 percent of transshipment traffic through Kobe before the earthquake. Note that in the case of North America-Korea traffic, the 1998 level was even lower than that in 1995, the year of the earthquake. In the transshipment cargo market, Kobe competes with other Asian ports such as Busan, Kaohsiung, and emerging mainland Chinese container ports. This cargo need not go through Kobe, and indeed, transport costs using Kobe as the transshipment center are known to be higher for some routes than using alternative ports such as Busan. Thus even before the earthquake, this type of cargo was particularly vulnerable to foreign competition. Once shippers were forced to invest in setting up operations elsewhere while Kobe was repairing its earthquake damage, they seem in many cases not to have returned.

Anecdotally, and from trends as shown in Figure 5, Busan has been frequently cited as a major gainer from Kobe's loss. Prior to the disaster, Busan had been climbing in the world container port rankings while Kobe had been gradually dropping. In the years immediately preceding the disaster, Busan had just overtaken Kobe in container traffic. It can be said, therefore, that the Port of Kobe had been quite vulnerable to business loss from Asian port competition when the earthquake hit, and because of this condition of vulnerability, the damage caused by the disaster brought about long-term loss of business.

Ports appear to be particularly vulnerable to long-term loss from disasters because they generally face strong competition for key types of business from competitors that are located outside the disaster area. The Port of Kobe case, while striking, was not unprecedented. Dacy and Kunreuther (1969) found that in the 1964 Great Alaska earthquake, substantial shifts in regional marine traffic were sustained. Figure 6 shows that the Port of Seward, which was devastated in the disaster, permanently lost substantial traffic to the Port of Anchorage, which had escaped relatively unscathed. Apparently, Seward had previously been considered the only year-round ice-free port in that region of Alaska, but the need to find alternatives after the earthquake caused ship operators to discover that the winter ice at Anchorage could, in fact, be broken. While these ports were much smaller than Kobe and its competitors, the parallels are striking.

Certainly the occurrence of long-term impacts, at ports and in general, depends upon the scale of damage sustained. Determining the critical threshold, or otherwise characterizing the process more rigorously, is difficult because of the paucity of examples. It is interesting to note, however, that in the 1989 Loma Prieta earthquake, the Port of Oakland appears to have experienced no long-term and virtually no short-term impacts, despite having suffered damage at 3 of its 11 main berths. Through quick response and flexible operations, it was able to double-up service at the remaining functional berths. Reportedly, only one ship turned away because of the earthquake damage (Port of Oakland, 1999).

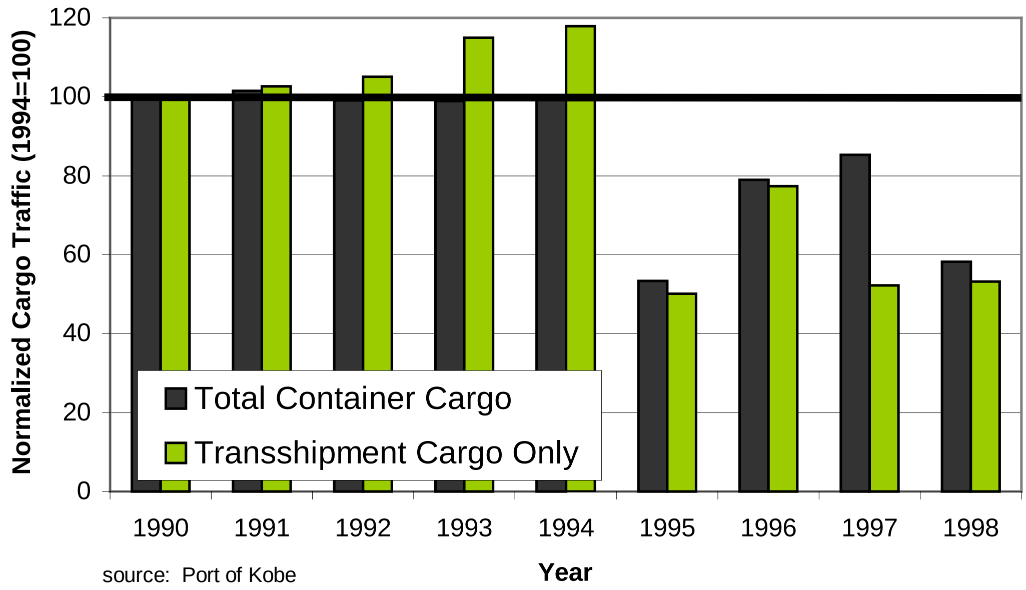

Figure 2. Container Traffic Through the Port of Kobe, 1990-98

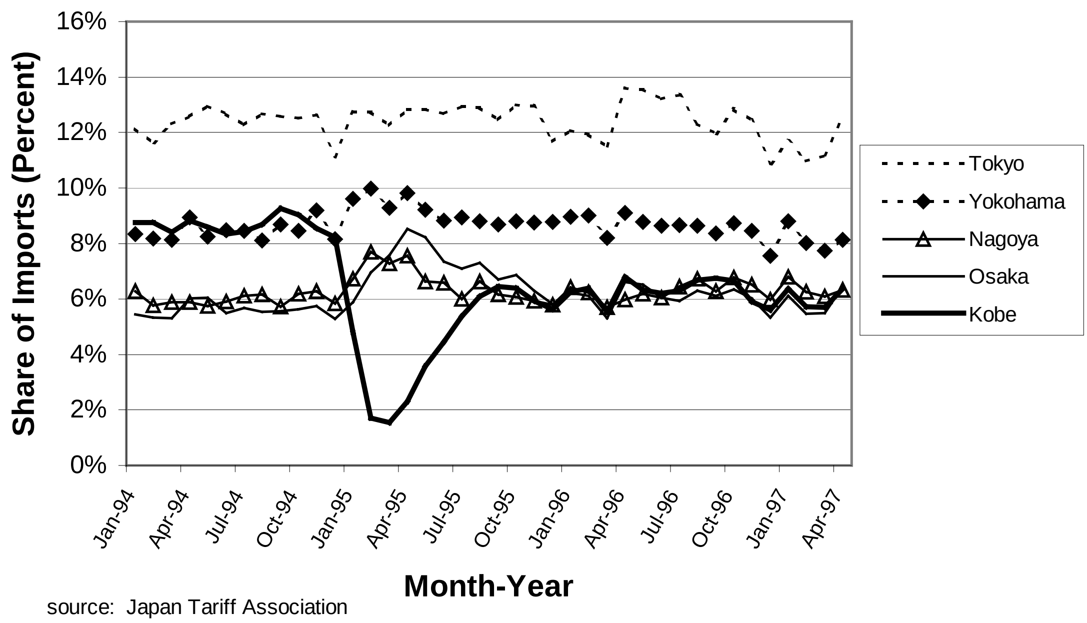

Figure 3. Major Ports' Shares of Japan's Import Trade, Jan. 1994-April 1997

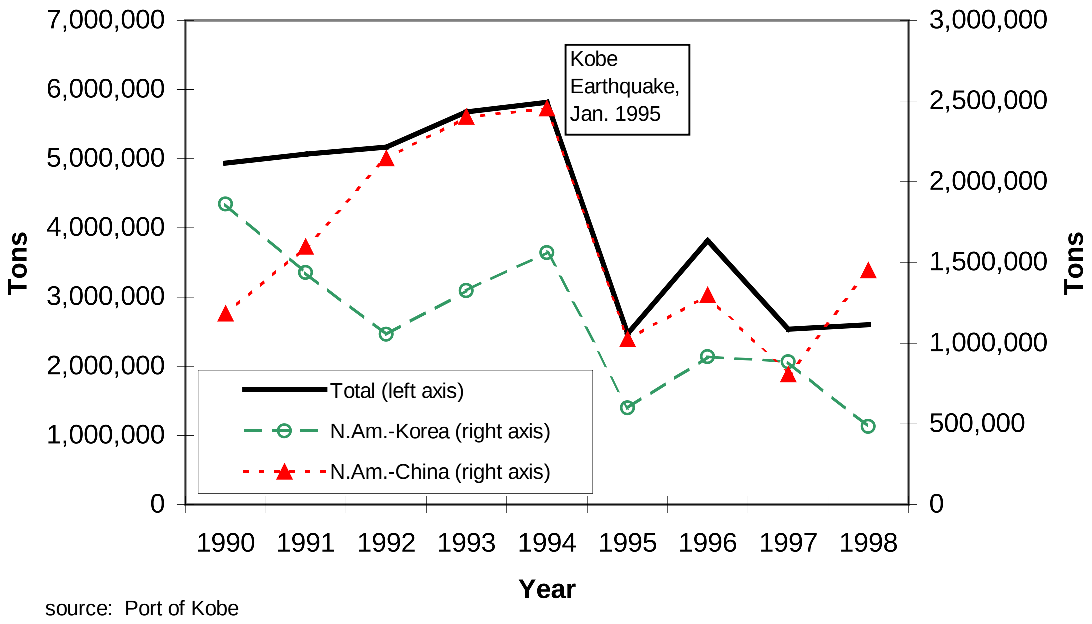

Figure 4. Transshipment Cargo Through the Port of Kobe, 1990-98

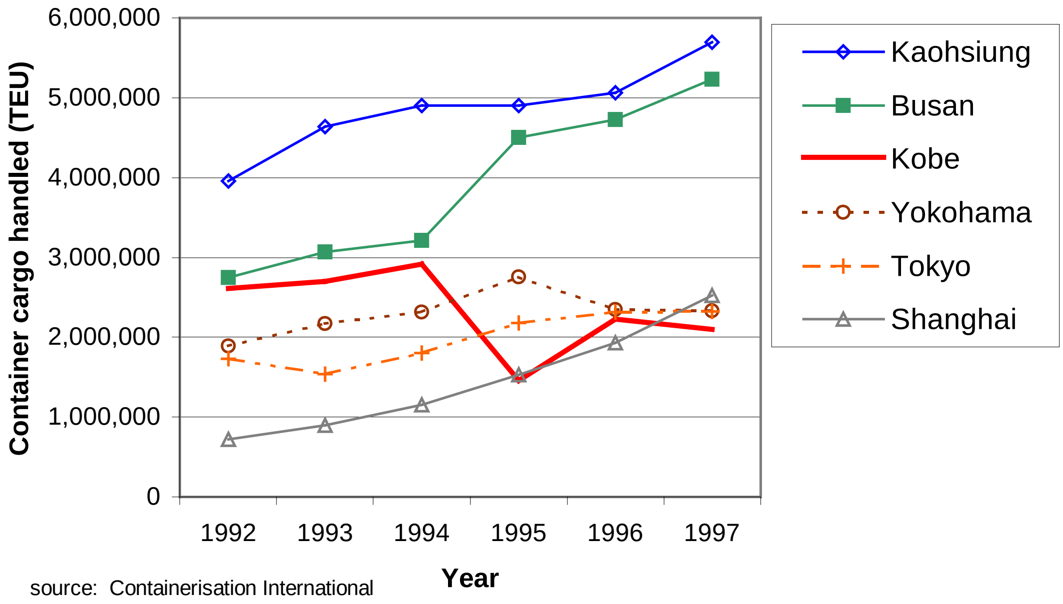

Figure 5. Container Traffic at Selected Asian Ports, 1992-1997

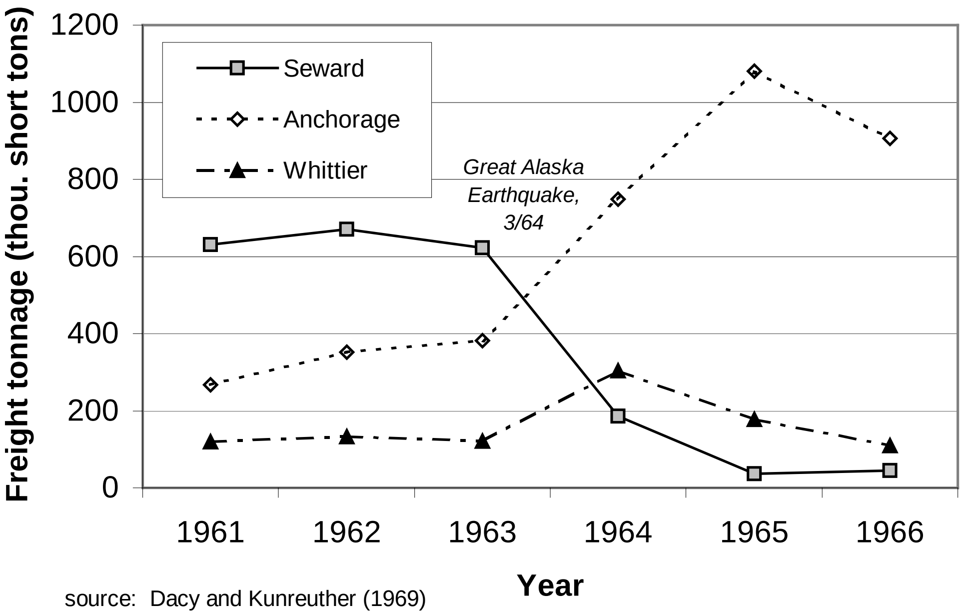

Figure 6. Cargo Traffic Through Alaska Ports Before and After the 1964 Earthquake

Development of Spatial Disparities in Kobe's Recovery

The second example of long-term effects in the Kobe case consists of the development of spatial differences in recovery rates across the urban space. A rigorous investigation of the causes of these disparities is beyond the scope of this paper. However, it is argued here that patterns in the loss and restoration of urban transportation service have likely contributed to this phenomenon.

Figure 7 shows the 9 wards comprising Kobe city, together with the regional rail network. As suggested by the location of the rail lines, which are the major form of commuting in the region, the coastal wards are most densely populated. Downtown is located in Chuo ward. Damage was most severe in the coastal wards. Nishi and Kita wards, which are mountainous and contain many new towns, suffered comparatively little damage.

Changes in total employment provide a useful indicator of economic impact and recovery. The second column of Table 1 shows the change in number of jobs in Kobe city and each of its constituent wards between 1991 and 1996. These data derive from the national censuses of establishments taken in October every five years. The 1996 employment data therefore refer to the situation nearly 2 years after the earthquake. Total employment grew by some 2 percent for the city as a whole, but this varied widely across space, ranging from a decrease of 21 percent in Nagata ward to an increase of 27 and 24 percent in Nishi and Kita wards, respectively. Total employment in Kobe in 1996 was 789,000 persons.

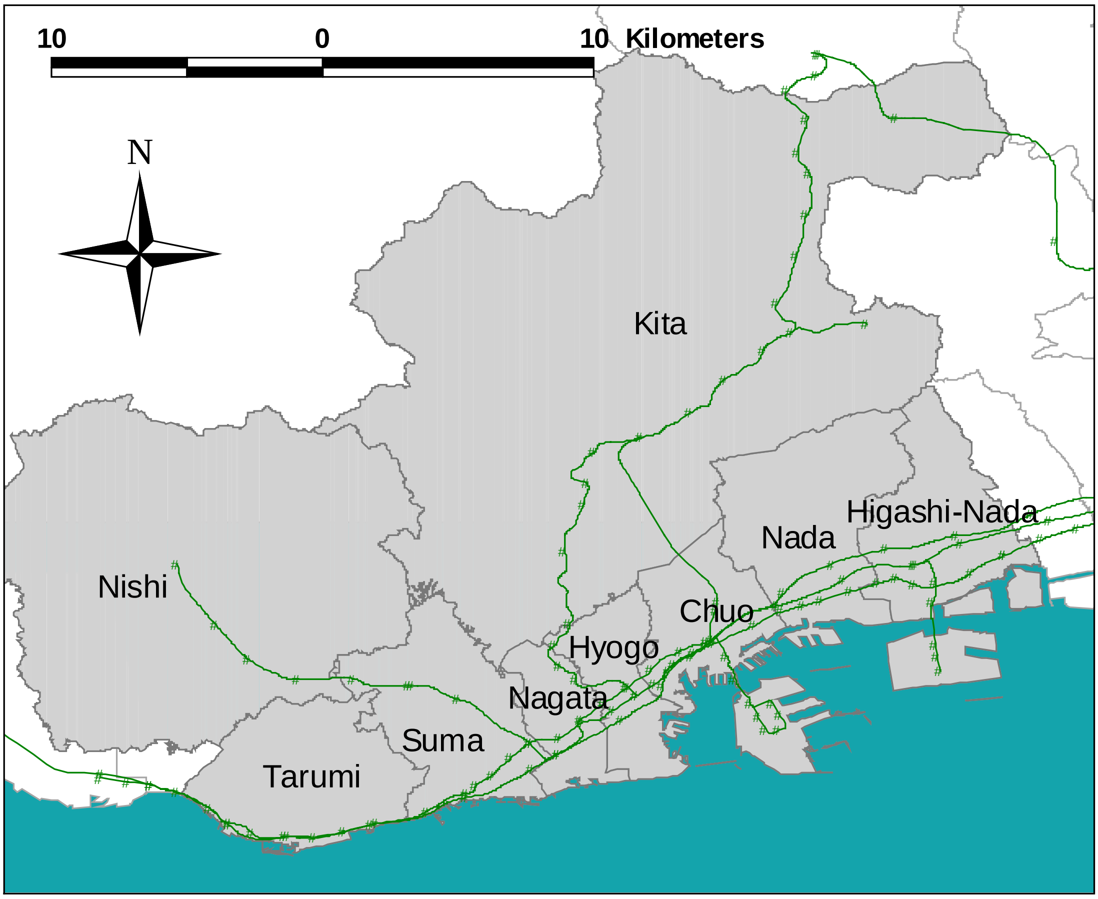

Figure 7. Kobe City Wards and Rail Network

Table 1. Measures of Loss and Vulnerability by Ward(1)

	Employment Change, 1996-91 (2)	Competitive-ness Change Index (3)	Relative Damage Index (4)	Vulner-ability Index (5)	Accessibility Index (6)
Kobe City	2 %	-4 %	1.00	0.31	Not applicable
Wards: Higashi-Nada	8 %	3 %	**1.20**	0.25	0.65
Nada Ward	**-13 %**	**-22 %**	**1.78**	**0.38**	**0.53**
Chuo Ward	**1 %**	**-5 %**	**1.37**	0.27	**0.52**
Hyogo Ward	**-1 %**	**-6 %**	**1.85**	0.31	**0.50**
Nagata Ward	**-21 %**	**-31 %**	**2.57**	**0.43**	**0.50**
Suma Ward	2 %	-4 %	0.85	**0.37**	**0.50**
Tarumi Ward	9 %	1 %	0.50	**0.46**	0.61
Nishi Ward	27 %	18 %	0.18	0.22	0.74
Kita Ward	24 %	12 %	0.22	**0.35**	0.76

Notes: (1) Figures in **boldface** indicate relatively severe loss or potential for loss; (2) change in total number of jobs in ward between the 1996 and 1991 censuses; (3) residual of shift-share analysis, as defined in text; (4) as defined in text; (5) Percent of jobs found in small businesses (10 or fewer employees); (6) highway transportation accessibility as defined in text, for Jan. 1996.

For purposes of analysis, it is helpful to separate out earthquake-related from non-earthquake related trends, to the extent possible. The latter includes such effects as pre-earthquake employment growth/decline and the distribution of employment among sectors that generally experienced differential growth rates over this period. A simple shift-share analysis was conducted to evaluate employment change net of these effects. The reference data for normalization consisted of industry employment growth rates for Hyogo Prefecture as a whole, of which Kobe comprised just over 30 percent in 1996. The third column of Table 1, labeled "competitiveness change index," shows the unexplained residual from the shift-share analysis normalized to 1996 employment, or what is typically referred to as the change in competitiveness for the locality. Note that while total employment grew by 2 percent in this period, this growth is actually 4 percent less than expected if it had followed industry growth rates for the prefecture as a whole. That is, Kobe city became less competitive over this period. Nonetheless, the same pattern of spatial differentials can be seen with the competitiveness change index as with the raw employment change figures. Four wards showed particularly high loss of competitiveness within the city: Nagata (31 percent loss), Nada (22 percent loss), and Hyogo and Chuo (6 and 5 percent loss, respectively). On the other hand, Kita and Nishi wards gained substantially.

How can these remarkable spatial disparities be explained? Based on theory and prior research, attention was focused in the current preliminary analysis on three main types of causes: physical damage, economic vulnerability, and transportation accessibility (the final three columns in Table 1). The intent was to gain insights from an overview of available data that could help in developing more rigorous explanatory models in further work.

A measure of relative damage severity for each ward was constructed as follows:

$$D_k = \left(\frac{N_k}{P_k} \right) \Big/ \left(\frac{N_C}{P_C} \right) \qquad (1)$$

where D_k is the damage index for area k, N is the number of damaged buildings, P is the resident population, and subscript C indicates figures for all of Kobe City. The table indicates that five of the coastal wards, from Higashi-Nada westward to Nagata, suffered relatively high damage compared to the city as a whole. Of these, Nagata ward had the greatest damage, while the indices for Hyogo and Nada wards are also very high. Nishi and Kita wards experienced much less damage in comparison.

Relative damage density thus goes a long way to explaining spatial differences in competitiveness change index. This is especially true at the extremes, that is, Nagata on the one hand and Nishi and Kita on the other. However, the correspondence is not exact, and the deviations from this correlation are particularly interesting. Damage is not a good predictor of economic loss – either employment change or competitiveness loss – in the middle range. For example, Nada ward suffered slightly less damage than did Hyogo ward, yet it experienced much more severe economic loss. Higashi-Nada ward suffered slightly less damage than did Chuo ward, but it performed much better economically after the disaster.

Pre-existing conditions of economic vulnerability are posed as the second major explanatory factor for the spatial differentials in recovery. For present purposes, a simple index of vulnerability is defined in terms of the preponderance of small businesses prior to the disaster. This is based on the premise, suggested in the literature, that small businesses tend to suffer more in and have a harder time recovering from disasters. The index is defined as the percentage of jobs that are found in firms employing 10 or fewer persons, according to the 1991 census. Vulnerability can help explain the differential experiences of Hyogo and Nada wards, where physical damage levels had been similar. As seen in Table 1, Nada ward had much higher pre-earthquake vulnerability than Hyogo and, after the disaster, suffered much higher economic loss.

Even damage and vulnerability together do not explain the case of Chuo and Higashi-Nada wards, however. Both of these suffered similar levels of destruction and could be characterized by relatively low vulnerability (more large businesses) compared to the city as a whole. Nevertheless, Chuo ward suffered a 5 percent loss of competitiveness, as defined above, while Higashi-Nada ward enjoyed a 3 percent gain. The key difference in this case appears to be conditions of transportation accessibility following the disaster.

A transportation accessibility index α for ward k at time t after the disaster is defined as follows (for further details, see Chang and Nojima, 2000):

$$\alpha_k(t) = \frac{f - A_k(t)}{f - 1} \tag{2}$$

$$A_k(t) = \frac{1}{n_k} \sum_{i \in N_i} A_i(t) \tag{3}$$

$$A_i(t) = \frac{\sum_{j \neq i} w_{ij} d_{ij}(t)}{\sum_{j \neq i} w_{ij} d_{ij}^*} \tag{4}$$

where $A_k(t)$ is an accessibility ratio, f is a constant, subscript i indicates a node on the transport network, n_k is the number of nodes in k, N_k is the set of nodes in k, d_{ij} is the minimum distance on the damaged network from node i to node j, d^* is the minimum distance on the intact network, and w_{ij} is the destination weight for node j for commuters originating from node i. The index α ranges from 0 (complete accessibility loss) to 1 (no loss). Table 1 shows the accessibility index for railways for January 1996, one year after the earthquake. Accessibility is seen to be poor in the central coastal wards, but better in the outer coastal and especially the interior wards.

Returning to the comparison of Chuo and Higashi-Nada wards, the principal difference in the explanatory factors shown in Table 1 concerns transportation accessibility. Although damage and vulnerability were similar, Higashi-Nada benefited from much better transport accessibility following the disaster, which could explain why it showed much stronger economic recovery than Chuo ward and Kobe City as a whole. Transportation access thus appears to be not the primary factor in explaining recovery differentials, but an important one nonetheless.

Conclusions

This paper has discussed the occurrence of long-term economic impacts in major disasters. Using examples primarily from the Kobe earthquake, it has shown that long-term impacts do occur, and that transportation loss figures importantly in the development of these impacts. Moreover, the findings suggest the reason why transportation is so significant: because its restoration times are typically long (on the order of months or years), transportation disruption reduces the *competitiveness of places*, whether within regions (as in the case of the spatial recovery differentials) or between regions (as in the case of the Port of Kobe). In this sense, it is not necessarily transportation loss itself that leads to long-term impacts, but the accentuation of pre-existing conditions of vulnerability by transportation disruption that leads to loss of competitiveness and the occurrence of long-term impacts. This effect appears to depend also on the magnitude of the disaster and may not be evident in smaller events. By implication, risk analysis for other seismically vulnerable areas should pay particular attention to the potential performance of the transportation system as well as its interaction with pre-existing conditions of economic vulnerability.

These findings suggest several areas for further research. In particular, the causal mechanisms for the development of long-term impacts should be investigated through theoretical development and more rigorous empirical analysis and modeling. The occurrence of long-term impacts should be studied in other recent catastrophic disasters such as the 1999 Kocaeli, Turkey, earthquake. In addition, more sophisticated characterizations of spatial vulnerability conditions should be developed and investigated as factors in modeling the economic impact of earthquake disasters.

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