Spatial Reorganization in Urban Redevelopment: Evidence from an Earthquake in a Metropolitan Area

Xu, Hangtian

Hunan University

1 May 2017

Spatial Reorganization in Urban Redevelopment:

Evidence from an Earthquake in a Metropolitan Area

Hangtian Xu
School of Economics and Trade
Hunan University, P.R. China

May 2017

Abstract

This study provides a new lens to look at urban redevelopment by focusing on the spatial reorganization within the redeveloped area. We begin by presenting a toy model of residents' locational choice within a Metropolitan Area, which links crowded housing and market accessibility. A key ingredient in our model is the change in the location's population bearing capacity before and after the redevelopment. Dense and high market accessibility locations stagnated due to crowded housing before the redevelopment, allowing for the expansion of less dense and low market accessibility locations. Redevelopment increased the land-use efficiency and relieved dense locations from crowded housing, allowing them to be denser and enter into a new phase of growth, at the cost of less dense locations. The urban spatial structure is thus reorganized. We then document substantial variation in population growth across locations within a Metropolitan Area of Japan, which underwent intensive redevelopment due to a seismic earthquake. Using the variation of pre- and post-redevelopment periods, as well as dense and less dense locations, in population growth, we find strong empirical support for the model's predictions. Our results imply that urban redevelopment may be an appropriate strategy for developers to improve the spatial structure of a city, which is much needed for mega-cities.

Keywords: natural disaster; urban redevelopment; spatial organization

JEL classifications: R12; R23; O18

This is a rewritten version of a paper released in the MPRA paper series #75219. The former title was "Multiple Equilibria in the Urban Spatial Structure: Evidence from the Hanshin Earthquake." I am grateful to Kristian Behrens, Shihe Fu, John Komlos, Pinghan Liang, Ming Lu, Deming Luo, Zhao Rong, Jipeng Zhang, and Xiwei Zhu for kindly providing invaluable comments and suggestions.

E-mail: hangtianxu@gmail.com; Web: hangtianxu.weebly.com

1. Introduction

Development within a Metropolitan Area (MA) is usually not parallel across locations. Locations with high market accessibility (i.e., close to the central business district (CBD)) tend to develop more intensively, and their residential density tends to be higher. As the population size of an MA increases, the initial urban form and structure tend to be inefficient and cannot match with the increasing residential density, in particular, for high market accessibility locations. The urban form and housing stock designed for a less dense location may create land-use frictions as the location becomes increasingly dense. For example, *Si He Yuan* is a classical and representative architecture style of residential housing for Beijing citizens, which dates back to the Ming Dynasty and is widely distributed in the core districts of the city of Beijing. As a cultural symbol, however, land-use efficiency of *Si He Yuan* is pretty low compared with the modern residential houses, which caused frictions in land use in the dense core districts of Beijing (Xinhua Net, 2014).[1] The friction tends to become increasingly significant since the residential population of Beijing is rapidly growing, which has doubled from 10.9 to 21.7 million during the period 1990–2015 (National Bureau of Statistics of P.R. China, 2016).

However, non-malleable and durable housing and land-use externalities, which create land-use rigidity, and the interdependence of redevelopment decisions (Rosenthal and Ross, 2015) make redevelopment a costly endeavor and thus delay the process (Siodla, 2015). The loss in land-use efficiency due to non-malleable and durable housing can be substantial. Recent literature shows that

[1] The Floor Area Ratio (FAR) of *Si He Yuan* is usually less than 0.4, while that of a tower block (above 18 floors) is generally 2.4–4.5 in China (Ministry of Housing and Urban-Rural Development of P.R. China, 2007). In addition, *Si He Yuan* is typically an old housing stock, the room space use is not well matched with the modern living facilities, and thus unattractive to high-income residents. Although the land value of *Si He Yuan* is usually high because they are mostly located in the core districts of Beijing, tenants living in this area are usually low-income residents (Xinhua Net, 2014).

major disasters in urban areas created valuable redevelopment opportunities to mitigate urban land-use inefficiencies by clearing out the non-malleable housing. Studying the impact of the Great Boston Fire of 1872 on urban redevelopment, Hornbeck and Keniston (2017) find the land value gains from redevelopment in the burned area and its immediate neighborhoods to be as large as the value of all buildings lost in the fire. Siodla (2015) finds the long-term population growth of the burned areas of the 1906 San Francisco Fire is more significant than the case without the disaster.

In existing studies, long-term outcomes of a major disaster in the urban areas are basically estimated in average terms by taking the unaffected areas as the reference. This has raised several questions: Is the average treatment effect representative of all the locations within the area that experienced the disaster and the following redevelopment? In the case that locations within the destructed urban area are homogenous in damage intensity, should the long-term impacts of redevelopment then be homogenous across destructed locations? If the answer to the latter is "No," the question that directly follows is whether or not the initial density and market accessibility affect the outcomes of redevelopment, because denser urban areas with high market accessibility tend to be more sensitive to land-use efficiency, and thus benefit more from the clearing out of non-malleable housing stocks.

The current study utilizes the 1995 Great Hanshin Earthquake in Japan as a natural experiment to exploit the spatial reorganization dynamics of a destructed MA. The earthquake destructed dozens of municipalities in an MA with heterogenous population density and market accessibility, which provides an opportunity to test the within-variation of urban redevelopment. The earthquake mainly destroyed a major city (Kobe) in the Kyoto-Osaka-Kobe MA (hereafter, KOK MA) of Japan, leaving the remaining two major cities, Osaka and Kyoto, almostly unaffected. Within KOK

MA, Osaka, with a population of 2.60 million in 1990, is the unique core and the remaining two major cities are much smaller in population size and act as sub-cores. Within the quake-affected urban area, the part close to Osaka (therefore, has relatively higher market accessibility) was initially dense but stagnated (or slightly shrank) in population size, while the part relatively far away from Osaka was less dense and initially rapidly growing before the earthquake. Both parts suffered from seismic destruction and experienced intensive redevelopment since 1995. However, the stylized facts show that the initially stagnated part (close to Osaka) grows after the earthquake, while the initially growing part (far away from Osaka) stagnates. That is, the internal spatial organization is altered after the earthquake.

We established a simple conceptual framework to clarify the related channel. In our model, the quaked area constitutes two parts with different population density and market accessibility. The dense part (with high market accessibility) suffered from inefficient land-use and was restrained on the growth of residential density before the earthquake. That is, crowded housing caused low living quality and thus brought negative utility outcomes. The new residents migrating into this area thus chose to live in the less dense part at the expense of market accessibility, and the population size grew in the less dense part. The earthquake destruction cleared out the non-malleable housing stocks of the dense part, the following redevelopment increased its population bearing capacity, and allowed for making it denser. The less dense part, however, lost the opportunity to continuous growth due to the weakness in market accessibility.

The model predictions are supported by our empirical findings. We find that 16 years after the Great Hanshin Earthquake, the eastern part of the quaked area (initially dense area) gained 11 percent in residential population size, while the western part (initially less dense area) suffered a 10 percent drop, compared with the predicted population size following the pre-quake trend (i.e., the scenario in the absence of the earthquake). Our results are consolidated by incorporating additional control variables into regressions: house age and probability of a strong earthquake in the near future, among other factors. Moreover, we provide supporting evidence in terms of the pre- and post-redevelopment change in residential and commercial land prices, in addition to population growth dynamics.

Our study contributes to the aforementioned literature in three respects. First, our study adds to the literature strands that have analyzed urban renewal/redevelopment processes. To the best of our knowledge, we are the first to exploit the impacts of urban redevelopment on an urban area's internal spatial structure. Siodla (2015) and Hornbeck and Keniston (2017) estimate the average and net effects of a major disaster on the economic and social development of destructed urban areas (i.e., residential density, land value, GDP per capita, and so on). Collins and Shester (2013) and Ahlfeldt et al. (2017) estimate the effects of government-oriented urban renewal programs on the land value and residents' income level. Furthermore, Guerrieri et al. (2013) find that the gentrification could sometimes be endogenous but not necessarily be government-oriented. Most studies find positive urban renewal/redevelopment outcomes by comparing the performance of targeted areas with the controls in unaffected areas. Our study provides a new lens to look at the change in the internal spatial structure, rather than changes in totality (or, average level) of the targeted areas. We find the redeveloped urban areas are heterogeneously affected by the redevelopment progress.

Second, our analysis connects to the research strand that examines the post-Great Hanshin Earthquake economic dynamics in the city of Kobe (Horwich, 2000; Edgington, 2010; duPont and Noy, 2015). Kobe is a rare modern major city worldwide that suffered from an overwhelming destruction by a natural disaster; its experience on urban recovery is a novel case study to analyze the urban issues related to the occurrence of natural disaster.

Third, we provide new discussions on the determinants of economic locations regarding the fundamentals and path dependence, following Davis and Weinstein (2002; 2008), Bosker et al. (2007), and Bleakley and Lin (2012), among others, which are still not conclusive. The advantage of our study is that we focus on a local spatial scale, that is, within an MA. This setting enables us to have a clear observation of population dynamics and identification of exogenous shock, since a sudden event tends to have a more significant impact on local areas than on the entire nation (Barone and Mocetti, 2014).

The remainder of this paper is organized as follows. Section 2 introduces the background. Section 3 presents the conceptual framework. Section 4 details the empirical strategies and main findings. Section 5 provides additional extensions of the empirical findings and Section 6 concludes the study.

2. Background

KOK MA is the second largest MA of Japan, following the Tokyo MA. Broadly, it consists of five prefectures—OSAKA, KYOTO, HYOGO, NARA, and WAKAYAMA—with a total population size of 18.8 million in 2005 (Residential Population Survey, 2005).[2] There are three major cities in KOK MA—Kyoto (capital of KYOTO), Osaka (capital of OSAKA), and Kobe (capital of HYOGO)—within which Osaka is the unique core with a population of 2.68 million in 2005, while the remaining two have less than 1.50 million, thus performing as the sub-core of the MA (Residential

[2] To avoid confusion on the geographical scale, we indicate the name of a prefecture in capital letters. For example, Osaka refers to the city of Osaka, which includes 24 municipality-level districts, and OSAKA refers to Osaka prefecture, which includes 24 municipality-level districts (i.e., city of Osaka) as well as 32 municipality-level cities and 11 municipality-level towns or villages (as per the administrative division in 1990). This also holds for Kyoto/KYOTO, Nara/NARA, and Wakayama/WAKAYAMA.

Population Survey, 2005). These three cities are the designated cities of Japan,[3] which consist of several municipality-level districts, while the remaining cities in KOK MA are relatively small in size and classified as municipality-level cities.[4]

Osaka is located in the geographical center of KOK MA, with Kobe on the west side and Kyoto in the northeast (as shown in Figure 1). The population density in KOK MA is partly monocentric. As shown in Figure A.1, the population density dissipates significantly with the distance to core Osaka. Although the population densities are relative high in the core districts of Kobe and Kyoto (as shown in Figure A.1; the distance from the districts of these two major cities to core Osaka ranges between 30 and 50 kms), the related density and the number of dense districts are not comparable with Osaka.

On January 17, 1995, the southern part of HYOGO was destroyed by the Great Hanshin Earthquake, which was measured as level seven on the seismic intensity scale (based on the Japan Meteorological Agency). More specifically, Kobe, which is located 20 kms away from the epicenter, suffered maximum damage (Figure 2). Approximately 6,434 people lost their lives (final estimate as of 2005) in this earthquake, of whom about 4,600 were from Kobe (Kobe City Fire Bureau, 2006). On the other hand, Osaka, another major city close to the epicenter, was almost unaffected. In most areas of Osaka and its surroundings, the intensity scale was less than five.

After the earthquake, the government proposed a series of policies aiming to recover the quaked area. According to the City of Kobe (2010), the utilities in Kobe quickly recovered three months after the earthquake (communication, water, electricity, gas, and so on); the railways reopened

[3] The term "designated city" refers to the largest cities of Japan. One designated city consists of several municipality-level districts, and differs from the general municipality-level cities in the administrative division.
[4] The current study focuses on the redevelopment in urban areas. Therefore, we do not consider the rural areas (i.e., towns and villages) throughout the study.

in January 1996 (with some stations completely destroyed and being reconstructed); and roads and expressways were reopened in August 1996. As for housing reconstruction, “The Kobe City Emergency Three-Year Plan for Housing Reconstruction” was formulated, with a focus on early recovery from housing loss due to the earthquake. This project aimed at providing 82,000 new housing units by March 1998, and included various policies on rent reduction for public housing (City of Kobe, 2010). Consistent with the target of this project, we find in Figure 3 that intensive construction of dwellings started immediately after the earthquake (1995–1997).

3. Conceptual framework

3.1. A toy model of locational choice for residents

To examine the long-term impact of an earthquake (and the following redevelopment) on population dynamics within an MA, we set up a conceptual framework incorporating the features of non-malleable housing and market accessibility. We model the quaked area with two parts: western part and eastern part. They are identical in land size and located in the west and east side of a sub-CBD, respectively. There is a unique CBD in the east side of the quaked area (as shown in Figure 4).

We assume that the population size of the quaked area increases at an exogenously given rate (i.e., new inward migrants). The new migrants’ residential locational choice (i.e., eastern part or western part) is based on locational potential (LP), and the one with high LP is chosen. LP in our model is determined by two factors. The first is market accessibility (denoted as a), which is negatively correlated with the location’s weighted distance to CBDs (including CBD and sub-CBD) and positively correlated with the economic scale of CBDs, following Harris (1954). In our case, we have one CBD and one sub-CBD. The eastern part is closer to the CBD than the western part, although the distances to the sub-CBD are same for both. Therefore, the eastern part has relatively higher market accessibility. We assume the values of a for the two parts are constant over time in our study period.

The second factor is the intensity of crowded housing, which is co-determined by the population density and the location's population bearing capacity. High population density tends to create crowded housing, and thus decrease living quality; however, efficient land-use and housing structure may relieve the negative impacts of high density by increasing the location's population bearing capacity. LP is thus affected by the intensity of crowded housing (c; c = population density/population bearing capacity (per sq.km)), which represents the stress of housing capacity and living quality.

We assume that LP is not sensitive to c if the population density is lower than the population bearing capacity (i.e., $c<1$), since the housing capacity is not yet substantially stressed. However, LP tends to be negatively affected by c once c is greater than 1, because the stress of housing capacity brings negative utility outcomes to residents.[5] LP is thus set as:

$$LP = f(a,d),\ d = \max\{c,1\};\ \frac{\partial LP}{\partial a} > 0,\ \frac{\partial LP}{\partial d} < 0.$$

d is thus a centrifugal force of population growth. In the early stage of urban development (i.e., crowded housing has not yet become an issue), the eastern part has higher LP and is thus more attractive for residents than the western part. As the population density increases in the eastern part, c increases as well and exceeds one, following which LP decreases in the eastern part due to crowded housing. Once $LP_{west} > LP_{east}$ is satisfied, the residential density in the western part grows and that in the eastern part stagnates.

[5] LP could also be positively affected by c when c is still small and congestion has not yet become an issue. In such a circumstance, higher c leads to high density of the community, which makes it possible to provide more facilities like various restaurants (see Schiff, 2015). In the current framework, we assume that c is not correlated with LP when it is less than 1 to simplify the intuition of the theory.

In the absence of non-malleable housing, we would like to adjust the land use of the eastern part to make it denser. However, it is hard to do so since this requires assembling land parcels and tearing down existing structures, among others. Then, an earthquake hits this area (both eastern and western parts), which clears out the non-malleable housing and allows for optimal redevelopment at higher density. The destructed and redeveloped locations thus experience an increase in population bearing capacity (Figure 4). On the one hand, this implies that c decreases for the eastern part and it is possible for c to be less than 1 (i.e., $c_{east}^{prequake} > 1 > c_{east}^{postquake}$; $d_{east}^{prequake} > d_{east}^{postquake}$) again, implying $LP_{east}^{postquake} > LP_{east}^{prequake}$. On the other hand, the increased population bearing capacity by urban redevelopment did not increase the LP of the western part, since its pre-quake c was less than 1 (i.e., $d_{west}^{postquake} = d_{west}^{prequake}$; $LP_{west}^{postquake} = LP_{west}^{prequake}$). Once $LP_{east}^{postquake} > LP_{west}^{postquake}$ is satisfied (before the earthquake, we have $LP_{east}^{prequake} < LP_{west}^{prequake}$ due to crowded housing in the eastern part), we expect the inward migrants to the quaked area will choose the eastern part rather than the western part as the residential location.[6] The eastern part grows again, while the western part stagnates in population density. In addition, locations closest to the CBD tend to grow the most since they have the highest market accessibility among the locations in the quaked area, owing to the significantly higher economic scale of CBD compared to that of the sub-CBD (Figure 4).

3.2. Application of the model to the pre-earthquake facts

In this sub-section, we present descriptive evidence that the toy model works well regarding the growth dynamics of the quaked area in the case of the Great Hanshin Earthquake. First, we define the boundary of the quaked area and then divide it into two parts, eastern and western parts, as in the

[6] The incumbent residents might also relocate from the western area to the eastern area if the *LP* difference between the two parts can offset the moving cost; however, in the current framework, we do not consider the within-quaked area relocation to simplify the analysis.

model. We focus our study on the urban areas where the earthquake intensity was not less than five. Under this classification standard, 17 municipalities in HYOGO and six in OSAKA (Figure 5) are selected.[7] Population data for Yodogawa municipality (a quaked district of Osaka) are missing, and thus excluded from all our analysis. In total, there are 22 municipalities, of which 11 are municipality-level districts and the remaining 11 are municipality-level cities.[8]

According to the model, we set the core Osaka (i.e., Osaka station) as the CBD and core Kobe (i.e., Kobe station) as the sub-CBD. Quaked municipalities located in the east of sub-CBD are set as the eastern part, which are relatively closer to the CBD (i.e., core Osaka) than the remaining quaked municipalities. As the geographical distance between core Osaka and core Kobe is 30 kms, quaked municipalities within 30 kms away from core Osaka are classified into the eastern area, which include nine municipalities in HYOGO and five in OSAKA. The remaining quaked municipalities (i.e., more than 30 kms away from core Osaka) are classified as the western part, which include eight municipalities.

Prior to the empirical analysis on the causal effect of urban redevelopment on spatial reorganization, we first present some facts regarding the model predictions. Figure 6(a) plots the total population in the quaked area and Figure 6(b) plots the disaggregate population for the eastern and western parts during the period 1988–2010 (22 municipality-level disaggregate plots are shown in Figure A.2). We find the population growth trends as shown in Figure 6(b) are consistent with the setup in the model. Before the earthquake, the eastern part stagnated (slightly shrank), while the western part expanded solidly.

[7] We aggregated the earthquake intensity observations within a municipality: if the intensity scale of more than half the observations were not less than five, then we consider it as a quaked municipality. Based on the classification of the Japan Meteorological Agency (JMA) seismic intensity scale, an intensity scale of five means the earthquake is strong enough to generate cracks on both the wooden structure houses and reinforced concrete frame houses.

[8] Municipality-level district and municipality-level city are seen as equivalent in our study.

As shown in Figure 7, the quaked area is dense in population since a number of quaked municipalities have pretty high population density in 1988 (the first year in our longitudinal data, which is seven years before the earthquake). Within the 22 municipalities, the population densities for four are higher than 10,000 per sq.km, and for 14 are higher than 5,000 per sq.km. The population density is the highest in the areas closest to the CBD (i.e., core Osaka), and sub-CBD (i.e., core Kobe), and municipalities in the eastern part (i.e., distance to core Osaka < 30 kms) are generally denser in residential population. These stylized facts are consistent with the model setup (see Figure 4).

We then describe the correlation between population density and population growth rate by regressing the mean annual population growth rate in 1988–1994 with the initial population density in 1988 for 22 sample municipalities. Results of the cross-sectional estimation as shown in column 1 of Table 1 suggest that they are negatively correlated, implying that denser locations in 1988 tend to have lower annual population growth during the period 1988–1994, which is potentially caused by crowded housing in dense locations.

However, the negative correlation is also likely to be caused by other factors. The structure of house age may be an alternative factor affecting the residential location choice. People prefer new houses to old houses (see, e.g., Brueckner and Rosenthal, 2009). Municipalities with high market accessibility and density tend to be developed earlier, and thus, the housing tends to be older and unattractive to residents, which may be a confounding factor to crowded housing. By adding the conditions of housing age into the regression equation as per column 1 of Table 1, the results support our hypothesis that the degree of old housing stock negatively affects population growth. However, the coefficient of initial population density is still significant in column 2 of Table 1, and the magnitude is just slightly decreased. Then, to avoid estimation bias due to limited sample size, we regress the same equation with the municipality-level data (urban area only) for the whole of KOK MA, as well as nationwide Japan, and find that the results are essentially consistent (columns 3 and 4).

Furthermore, as we mentioned in the model, population density tends to negatively affect the population growth if and only if the current density exceeds the population bearing capacity. Therefore, we divide the nationwide municipality-level samples into two groups: one with population density not less than 5,000 per sq.km and other with population density less than 5,000 per sq.km. We find that population density negatively affects population growth only for dense areas, rather than less dense areas (columns 5–6 of Table 1),[9] which is again in line with our model assumption. In addition, we find old housing stock is negatively significant for both groups, suggesting that people prefer younger housing given that other conditions are the same, even for the cities relatively low in population density. Based on the estimates of column 6, we may infer that, for a municipality of Japan with a population density of 6,000 per sq.km in 1988, the mean annual population growth rate during the period 1988–1994 is on average 0.2 percent lower than that of a municipality with a density of 5,000 per sq.km in 1988.

In column 7 of Table 1, we regress the mean annual population growth rate of the quaked municipalities with the distance to core Osaka, and find that the coefficient is positively significant, implying that the population tends to move away from core Osaka, which is on the east of the quaked area. However, after controlling for the initial population density and degree of old housing stocks, we find that the related coefficient is no longer significant (column 8). This result suggests that the westward population growth pattern (i.e., the eastern part shrank while the western part grew) was mainly caused by the heterogeneity in initial population density and old housing conditions. The

[9] Regression results are essentially consistent even if the threshold population density is altered from 5,000 per sq.km to 4,000 and 6,000 per sq.km (results are available upon request).

preliminary empirical findings regarding the pre-earthquake demographical pattern in the quaked area are mostly in line with the model setup. We then empirically examine the post-earthquake population growth dynamics based on the model predictions.

4. Impact of earthquake (redevelopment) on spatial reorganization

As show in Figure 6(b), in the eastern part of the quaked area, population size stagnated before 1995, and suffered from a significant drop in 1995 and 1996. However, we find that this part showed considerable growth in population size shortly since 1997, the mean annual growth rate from 1997 is significantly higher than that in the pre-quake period. The population size of the eastern part quickly recovered to the 1994 level in 2000, and continuously expanded during the period 2000–2010. On the other hand, the initially expanding western part stagnated after the earthquake (Figure 6(b)). The facts clearly tell us that the population growth dynamics in both eastern and western parts were adjusted after the earthquake, which is in line with the predictions by the model.

We now formally examine the underlying mechanism of the observed population dynamics and spatial reorganization. First, we quantitatively estimate the change in the municipality-level population growth trend before and after the earthquake and redevelopment. Second, we test the related mechanisms as described in the model using the variations in locational potential, population growth, and house age, among others.

4.1. Estimated trend of population growth

Our baseline econometric equation allows changes in trends and intercepts of the municipality population index across areas and periods. In the quaked area, the short-term population dynamics after the earthquake is mainly caused by the housing destruction (i.e., migration due to homelessness), while the long-term population dynamics is expected to be affected by the redevelopment-related mechanisms. We thus divide our study period into three sub-periods: 1988–1994 is set as the pre-earthquake period; 1995–1997 is set as the short-term post-earthquake period experiencing population loss due to housing destruction and intensive reconstruction of infrastructures and new dwellings;[10] 1998–2010 is the long-term redevelopment period, the population dynamics of which is expected to be correlated with the mechanisms of long-term redevelopment, as proposed in the model.

The estimation equation is as follows:

$$\text{(R.1)} \quad Popindex_{it} = \sum_{a=1}^{2} \eta_{ap} + \sum_{a=1}^{2} \beta_{ap} time_t + \varepsilon_{it},$$

where a indexes areas (i.e., eastern part and western part), t denotes years, and p indicates periods. The dependent variable, $Popindex_{it}$, is the municipality-level population index (taking the population index of 1994 as the value of 1.00). The variable $time_t$ is a time variable considering the variations in period ($time_t = t - 1987$, for $1988 \le t \le 1994$; $time_t = t - 1994$, for $1995 \le t \le 1997$; $time_t = t - 1997$, for $1998 \le t \le 2010$). The parameters η_{ap} are a complete set of area-period fixed effects that allow changes in the mean population index for each area in the three time periods. The coefficients β_{ap} allow trends in population index for each area to vary by the three periods; ε_{it} is a stochastic error (similar application of the related econometric setup is seen in Redding et al., 2011).

In this equation, we allow both mean levels and trend rates of growth of population index to vary across areas and periods because it may take time for a new spatial organization pattern to emerge

[10] The damaged city of Kobe rapidly recovered its infrastructural facilities (see Section 2), and a number of new dwellings were built (Figure 3) in the first three years after the quake. This suggests that the first three years (1995–1997) after the quake could be taken as the period of short-term intensive reconstruction.

in response to an exogenous shock (Redding et al., 2011). As we find in Figure 6(b), the population growth trends in both areas are altered after the earthquake, for a specific area (either eastern or western part), β_{a3} is expected to be significantly different with the corresponding β_{a1}.

Related results are shown in Table 2; coefficients on the time trends in each area in each period capture mean annual rates of growth of population index (i.e., row 1 through row 6 of Table 2). We first consider the statistical significance of the difference in time trends between western and eastern parts within the pre-quake and long-term redevelopment periods. Panel A of Table 3 shows that during the pre-earthquake period, the difference in the mean annual rate of growth of population index was around 1.0 percent (insignificant), while for the redevelopment period, the related difference becomes -0.8 percent (significant; p-value<0.01). Then, panel B of Table 3 compares the time trends between the pre-quake (1988–1994) and redevelopment periods (1998–2010) for western and eastern parts (a difference within area across periods). The western part's mean rate of growth of population index declined by 0.8 percent per year (insignificant), while the eastern part's rose by 1.0 percent per year (significant; p-value<0.01). Finally, we consider the difference-in-difference by comparing the change in the western part's time trend between the pre-quake and redevelopment periods to that in the eastern part's time trend between the same time periods. Panel C of Table 3 shows that this difference-in-difference in mean annual population growth rates was 1.8 percent per year and was highly statistically significant.

By considering the estimated change in trends, we may calculate the quaked area's population size of 2010 in the scenario of absence of the earthquake. If we assume the population grew based on the trend of 1988–1994 for the period of 1995–2010, then, the population of the western part in 2010 is predicted at 1.608 million, and that of the eastern part at 1.842 million, with a total of 3.450

million. Compared with the real population data of the quaked area in 2010, we find the real total population (3.489 million) is just slightly different with the predicted case without the earthquake (1% higher than the scenario without earthquake). However, the internal structure is significantly altered. For the eastern part, the real population (2.043 million) is higher than the predicted population size for the non-quake scenario by 11% ($\approx$2.043/1.842-1). By contrast, for the western part, the real population in 2010 (1.445 million) is 10% ($\approx$1.445/1.608-1) lower than that for the non-quake scenario.

4.2. Controlling for the preference of new dwellings

The degree of housing destruction is heterogenous among the quaked municipalities. Municipalities that suffered maximum damage tend to reconstruct more new dwellings, and thus, the housing condition (in terms of average house age) tends to improve more than those that were less seriously destroyed. As people prefer new housing to old housing (see, e.g., Brueckner and Rosenthal, 2009, and the results of Table 1), the preference for new dwellings is thus an alternative channel affecting the location's attractiveness to residents, in addition to the channel we proposed in the model (i.e., more efficient land-use through redevelopment relieves the dense urban area from the crowded housing condition).

Figure 8 presents the conditions of average house age for the quaked municipalities and the remaining municipalities (unaffected by the earthquake) of KOK MA in 2003 (the latest data for related indicators are available for 2003). We find that the housing conditions of the two municipality groups are mainly different in the share of old dwellings (built no later than 1960) and new dwellings (built during the period 1996–2000, shortly after the earthquake). In 2003, on average, 10% of the dwellings are built no later than 1960 for the unaffected municipalities, while for the 22 quaked municipalities, this share is only 5% on average. On the other hand, the share of new dwellings (built during the period 1996–2000) in the quaked municipalities is 22%, while that in unaffected municipalities is just 15%. The shares of dwellings built in other periods (i.e., 1961–1995 and 2001–2003) are mostly comparable between these two municipality groups. This implies that the earthquake mainly destroyed the old houses (with poor seismic capacity), and they are replaced by new dwellings built shortly after the earthquake. Therefore, municipalities that suffered from stronger damage intensity in 1995 generally have a higher share of new dwellings (see Figure A.3).

The damage intensity thus has two effects on the residents' locational choice. First, high damage intensity may lead to high degree of redevelopment and thus make the municipality's land use more efficient to have a higher population bearing capacity. Second, higher damage intensity destroyed more old houses, consequently making the municipality younger and more attractive to residents. Both effects tend to increase the population size of a municipality. However, the effects of land-use efficiency change have different impacts on dense (with high market accessibility) and less dense (with low market accessibility) urban areas, while the effects of younger houses are homogenous for both dense and less dense urban areas (as shown in columns 5–6 of Table 1). As predicted by the model, in the case that both the eastern and western parts were damaged in the earthquake and redeveloped in the same intensity (with the same increase on population bearing capacity), the inward residents (new migrants to the quaked area) may choose to locate in the eastern part because it has higher market accessibility. That is, only the eastern part, rather than both parts, benefits from the redevelopment in terms of "higher land-use efficiency". These features allow us to distinguish between the "higher land-use efficiency effect" and the "younger house effect" of urban redevelopment.

Therefore, we test whether the post-quake tendency of eastward population growth (toward core Osaka) in the quaked area still exists after controlling for the change in house age condition. If "No," we may suppose that the results as shown in Table 2 are caused by the facts that the eastern part suffered from higher damage intensity and improved more on its housing condition (average house age), and it thus becomes more attractive to new residents than the western part. If "Yes," we then conclude that the results of Table 2 stem from the "higher land-use efficiency effect" which relieves the eastern part from crowded housing.

As our data on housing conditions (i.e., detailed housing structure in terms of house age) are only available for 2003, rather than at an annual frequency in the period of 1988–2010,[11] the related regression equation is set as follows:

(R.2) $\Delta PopG_i = \alpha_1 Dist_i + \alpha_2 \Delta Housing_i + \varepsilon_i$.[12]

$\Delta PopG_i$ is the difference of mean annual population growth rate during the period 1995–2010 and that during the period 1988–1994 for municipality i. $Dist_i$ is a municipality's distance to core Osaka (shorter for the municipalities in the eastern part). $\Delta Housing_i$ is the difference of mean housing condition during the period 1995–2010 and that during the period 1988–1994; we take the share of new dwellings (built during the period 1996–2003) in total dwellings in 2003 as the proxy. If a municipality has high share of new dwellings in 2003, this implies its housing condition was significantly improved after 1995. Then, the coefficient of α_1 captures the change in the population growth trend before and after the urban redevelopment regarding the municipality's proximity to core

[11] Related data are available for 1983–2003 in a five-year interval; however, the definitions of old and new dwellings are adjusted. Data among years are thus not comparable. See the details in Table A.1.

[12] When the number of periods of panel data is equal to two, first-differencing and fixed effect estimation produce identical estimates and inference (see Wooldridge, 2002). Therefore, Equation R.2 is equivalent to: $PopG_{it} = \alpha_1 Dist_i * postquake_t + \alpha_2 Housing_{it} + \delta_i + \gamma_t + \varepsilon_{it}$, that $t = 1$ (i.e., pre-quake, 1988–1994) or 2 (i.e., post-quake, 1995–2010). $PopG_{it}$ is the mean annual population growth rate for quaked municipality i in period t. $postquake_t$ is a dummy variable that takes the value of 1 for period 2 (post-quake) and 0 for period 1 (pre-quake). δ_i is the municipality fixed effect controlling for the all time-invariant differences between municipalities (e.g., initial population density). Year fixed effects (γ_t) control for time-variant changes that affect all quaked municipalities similarly.

Osaka, which is expected to be significantly negative, consistent with our model predictions.

Related estimations are shown in Table 4. Column 1 presents the estimations of Equation R.2, however, considering only the distance to core Osaka. Column 2 presents the estimations controlling for housing condition change. We find that in both estimates α_1 is significantly negative. Then, because the number of new dwellings may be endogenous to population growth, we use the number of dwellings damaged in the 1995 earthquake (over the population of a municipality in 1994) as an alternative measurement of the change in housing condition, which is exogenously determined by a municipality's average intensity scale in the 1995 earthquake. We find in Figure A.3 that these two indicators are highly correlated, and related results shown in column 3 of Table 4 are essentially unchanged in both significance and magnitude of α_1.

Moreover, as the regression sample size of Equation R.2 is limited (22 observations), our estimation results tend to be affected by outliers. Figure 9 thus presents the plot of related estimations as graphical evidence. First, the upper part of the graph presents two scatter plots of $\Delta PopG_i$ against $\Delta Housing_i$ for two measurements of $\Delta Housing_i$, respectively. Second, related residuals are obtained and the bottom part of the graph presents the scatter plots of the residuals against the distance to core Osaka. The related fitted lines of the scatter plots are partly affected by an outlier (i.e., Nishi municipality in the western part of the quaked area), as shown in Figure 9. However, regression results are essentially unchanged by excluding the data of Nishi (columns 4–5 of Table 4).

Based on the estimates of column 4 of Table 4, we may infer that, for a quaked municipality which is 20 kms away from core Osaka, the mean annual population growth during the period 1995–2010 is 0.3 (0.6) percent higher than that of a quaked municipality which is 40 (60) kms away from core Osaka (after subtracting the pre-quake population growth trend). Therefore, by considering the heterogeneity in the change of housing conditions (average house age), we find the distance to core Osaka is still a significant determinant affecting the pre- and post-1995 change in demographical pattern of the sample area, which is in line with the model predictions.

4.3. Controlling for the spatial dynamics of Kyoto-Osaka-Kobe MA

We question whether agglomerating with core Osaka was a trend in all municipalities in KOK MA since 1995. In this case, our previous estimates appear to be primarily driven by this trend rather than the impact of the earthquake. We thus examine the spatial reorganization pattern in the quaked area using the unaffected municipalities in KOK MA as the control variable. In doing so, the factor of overall trend impacting the baseline results is addressed.

As shown in Figure 1, Osaka is located in the geographical center of KOK MA, with Kobe in the west, Kyoto in the northeast, Sakai and Wakayama in the south, and Nara in the east.[13] By comparing the population dynamics in the Osaka-Kyoto area, Osaka-Sakai-Wakayama area, and Osaka-Nara area (see Figure 1) with the population growth pattern in the quaked municipalities that are located along the Osaka-Kobe area, we capture whether the other areas in KOK MA show a tendency to agglomerate with Osaka.

Therefore, we perform the estimation as shown in Equation R.3 considering the distance to Osaka, two time dummies for the time periods, and a dummy for quaked area:

$$\text{(R.3)} \quad \begin{aligned} PopG_{it} &= \alpha_1 Q_i \cdot y9597_t \cdot Dist_i + \alpha_2 Q_i \cdot y9803_t \cdot Dist_i + \alpha_3 Q_i \cdot y9597_t + \alpha_4 Q_i \cdot y9803_t \\ &+ \alpha_5 y9597_t \cdot Dist_i + \alpha_6 y9803_t \cdot Dist_i + \delta_i + \mu_t + \varepsilon_{it}. \end{aligned}$$

$PopG_{it}$ is the annual rate of population growth for municipality i and year t. Q is a dummy that

[13] Sakai, Wakayama, and Nara are also important cities of KOK MA, though their population sizes are much smaller than the top three major cities.

distinguishes between treatment (quaked) and control (unaffected) samples. There are two time dummies: *y*9597 (which takes that value of 1 for 1995–1997, and 0 otherwise) and *y*9803 (which takes that value of 1 for 1998–2003, and 0 otherwise).[14] They separately capture the short-term (due to homelessness shortly after the earthquake) and long-term impact (due to the change in locational potential; as the *LP* in the model) of the earthquake and redevelopment. We insert interaction terms among *Q,* a time dummy, and distance to core Osaka (*Dist*). Municipality and year fixed effects are controlled for by δ_i and μ_t. α_2 is thus the key coefficient. If the population growth pattern (as shown in Figures 6(b) and 9) is not driven by the overall agglomeration trend (toward core Osaka) in KOK MA, then α_2 is expected to be negative, that is, compared to the other municipalities in KOK MA, the quaked municipalities show a significantly higher gradient of population growth in terms of proximity to core Osaka. Since α_1 is mixed with the temporary population loss due to shelter seeking by the homeless, it is not necessary for it to be related to the distance to core Osaka, and thus, the sign is expected to be undetermined.

For the treatment samples, we include the 20 quaked municipalities (17 municipalities in HYOGO and three municipality-level cities in OSAKA. Two quaked municipality-level districts in Osaka are excluded from the estimate because population of Osaka is confounded, as it is correlated to the population dynamics of both the treatment and control samples. Control samples include the municipalities in the four prefectures' urban area (i.e., OSAKA (except Osaka), KYOTO, WAKAYAMA, and NARA). In total, there are 64 control municipalities (Table A.1 presents the data

[14] In this estimation, our data are for the period of 1988–2003 rather than 1988–2010. During the period of 2003–2006, Japan experienced large-scale municipality amalgamation, and thus, the number of municipalities in Japan was reduced from 3212 to 1821 (Yodomichi, 2007). Although the quaked area (22 municipalities) was not affected by the merger, a number of other municipalities in KOK MA were merged during the period 2003–2006. Therefore, their population data before and after 2003 are not comparable. However, our baseline estimation is not likely to be affected by the time period change. For the estimation of Equation R.1, the results are essentially unchanged by using the data for 1988–2003 instead of those for 1988–2010 (results are available upon request).

summary).

Figure A.4 presents the population growth for control municipalities during 1994−2003 by the distance to core Osaka (the trend of population growth in 1988−1994 is subtracted); unlike the trend in the treatment group, there is no significant downward sloping on the fitted line of the control group (Figure A.4). Column 1 of Table 5 provides the relevant estimates of Equation R.3. α_2 is significantly negative at -0.07 and α_4 is significantly positive at 2.46, suggesting that quaked municipalities within 35 kms (≈2.46/0.07) to core Osaka experience higher population growth than the related control municipalities in 1998−2003, while the remaining quaked areas suffer from population loss during this period. The estimated threshold of distance (i.e., 35 kms) is highly consistent with the cutoff distance range that we set in the estimation of Equation R.1 (i.e., 30 kms). Column 2 presents the results by controlling for prefecture-year and municipality fixed effects, which clears out the disturbance from the prefecture-year level macro shock. α_2 is still significant at -0.09. In column 3, we include only the overlapped distance samples to ensure treatment and control samples drop in the same distance range on the proximity to core Osaka, and the result is almost unchanged.

Finally, as suggested by Scawthorn (1982), given the possible awareness of a natural hazard within an urban area, a residential location is generally selected on the basis of its proximity to high-risk areas. Relevant empirical evidences are shown in Nakagawa et al. (2007) and Naoi et al. (2009). Given the advancement on earthquake prediction, the possibility of an earthquake in the near future tends to affect residential location choice. In column 4, we control for the possibility of a strong earthquake (≥6 on the intensity scale) in the period 2005–2035, and the result is consistent with the baseline estimates.[15]

[15] Data on the possibility of a strong earthquake are only available for the period of 2005–2035.

5. Further discussion

5.1. Cross-prefecture employment

One additional possibility of rapid population growth in the eastern part of the quaked area is the expansion of Osaka. More specifically, this refers to the increased employment demand in OSAKA by residents in the eastern part of the quaked area (of HYOGO), since the commuting time between core Osaka and core Kobe is less than 30 minutes by rail.

However, the data shown in Figure 10 suggest the opposite. Although the cross-prefecture employment in the eastern part of the quaked area (of HYOGO) is high among the share of total residents (15% in 1990), the ratio did not increase after the earthquake. By 2000, the eastern part's population had already recovered to the pre-quake condition (Figure 6(b)). However, the cross-prefecture employment remained significantly lower than that before the quake (1990).[16] Since the average employment-to-population ratio is relatively stable within this period (51% in both 1990 and 2000; Data source: Japan Statistical Yearbooks), the hypothesis that the rapid population growth in the eastern part of quaked HYOGO can be attributed to the inward flow of Osaka's commuting population is partially rejected.

5.2. Land price

We utilize the land price to provide additional evidence concerning the channel of post-quake population dynamics. We suppose the change in land price could be seen as a proxy of change in the locational potential; municipalities with increasing (relatively) locational potential tend to have high

[16] Data on cross-prefecture employment are from the National Census by the Statistics Bureau, Ministry of Internal Affairs and Communications (released in a five-year interval).

growth rate in land price. Residential and commercial land price data are available annually since 1993; thus, we have data for two years before the earthquake. Table 6 presents the results obtained using the specification of Equation R.3 (by replacing the dependent variable with the growth rate of land price), which are consistent with the estimates for residential population (Table 5).

We first estimate the impact of the earthquake (and redevelopment) on residential land price. Column 1 of Table 6 suggests that the residential land market in the quaked area has similar growth pattern with residential population size. This result is robust when the overlapped distance is accounted for (column 2). Then, because of the burst of the economic bubble at the beginning of the 1990s, residential land price dramatically dropped, especially in Metropolitan Areas. We thus separately estimated the redevelopment impact for municipality-level districts (i.e., Kobe) and municipality-level cities (i.e., other quaked municipalities except for Kobe), since major cities have a significantly higher land price. We find that there is a significant difference in the magnitude of estimated coefficients between district samples and municipality-level city samples; however, the pattern is similar (columns 3–4). Finally, column 5 presents the estimates for commercial land price, and the results are found to be similar with those of residential land price.

6. Concluding remarks

In this study, we examined the long-term consequence of the Great Hanshin Earthquake on the urban spatial structure of the quaked area. The results revealed the following: first, the natural disaster does not have a considerable persistent impact on the total population of the quaked area; and second, the internal residential distribution significantly changed. Population tended to agglomerate toward locations with high market accessibility, since urban redevelopment improved the land-use efficiency and thus allowed for the high market accessibility and dense locations to be denser.

Existing empirical studies on the impact evaluation of urban redevelopment mainly consider the United States as the base, whose major cities are much less dense than the major cities in Asia (such as Tokyo, Shanghai, and Mumbai). That is, the capacity constraint in U.S. cities is not as serious as that in the Asian major cities. The impact of urban redevelopment on increasing a city’s population bearing capacity is thus not sufficiently discussed in the existing literature. By focusing on a super MA of Asia, we find that redevelopment may allow the dense urban areas to be denser by improving the land-use efficiency and thus reorganize the spatial structure of an MA. These findings shed new light on the heterogeneity in the impacts of urban redevelopment across locations and suggest that researchers should focus more attention on the case-to-case outcomes of redevelopment, rather than the average outcomes.

References

Ahlfeldt, G.M., W. Maennig, and F.J. Richter (2017) Urban renewal after the Berlin Wall: A place-based policy evaluation, *Journal of Economic Geography*, 17: 129–156.

Barone, G. and S. Mocetti (2014) Natural disasters, growth and institutions: A tale of two earthquakes, *Journal of Urban Economics*, 84: 52–66.

Bleakley, H. and J. Lin (2012) Portage and path dependence, *Quarterly Journal of Economics*, 127: 587–644.

Bosker, M., S. Brakman, H. Garretsen, and M. Schramm (2007) Looking for multiple equilibria when geography matters: German city growth and the WWII shock, *Journal of Urban Economics*, 61: 152–169.

Brueckner, J.K. and S.S. Rosenthal (2009) Gentrification and neighborhood housing cycles: Will America's future downtowns be rich? *The Review of Economics and Statistics*, 91: 725–743.

City of Kobe (2010) Comprehensive strategy for recovery from the Great Hanshin-Awaji Earthquake. (http://www.city.kobe.lg.jp/safety/hanshinawaji/revival/promote/img/English.pdf)

City of Kobe (2011) The Great Hanshin-Awaji Earthquake: Statistics and restoration progress.

Collins, W.J. and K.L. Shester (2013) Slum clearance and urban renewal in the United States. *American Economic Journal: Applied Economics*, 5: 239–293.

Davis, D.R. and D.E. Weinstein (2002) Bones, bombs, and break points: The geography of economic activity, *American Economic Review*, 92: 1269–1289.

Davis, D.R. and D.E. Weinstein (2008) A search for multiple equilibria in urban industrial structure, *Journal of Regional Science*, 48: 29–65.

duPont, W. and I. Noy (2015) What happened to Kobe? A reassessment of the impact of the 1995 earthquake in Japan, *Economic Development and Culture Change*, 63: 777–812.

Edgington, D.W. (2010) *Reconstructing Kobe: The geography of crisis and opportunity.* Vancouver: UBC Press.

Guerrieri, V., D. Hartley, and E. Hurst (2013) Endogenous gentrification and housing price dynamics, *Journal of Public Economics*, 100: 45–60.

Harris, C. D. (1954) The market as a factor in the localization of industry in the United States, *Annals of the Association of American Geographers*, 44: 315–348.

Hornbeck, R. and D. Keniston (2017) Creative destruction: Barriers to urban growth and the Great Boston Fire of 1872, *American Economic Review*, forthcoming.

Horwich, G. (2000) Economic lessons of the Kobe Earthquake, *Economic Development and Culture Change*, 48: 521–542.

Kobe City Fire Bureau (2006) Situation of damage and victims: Hanshin-Awaji Earthquake (in Japanese). Retrieved May 25, 2008.

Ministry of Housing and Urban-Rural Development of P.R. China (2007) Urban and Rural Planning Law of People's Republic of China (in Chinese).

Nakagawa, M., M. Saito, and H. Yamaga (2007) Earthquake risk and housing rents: Evidence from the Tokyo Metropolitan Area, *Regional Science and Urban Economics*, 37: 87–99.

National Bureau of Statistics of P.R. China (2016) *China Statistical Yearbook*. Beijing: China Statistics Press.

Naoi, M., M. Seko, and K. Sumita (2009) Earthquake risk and housing price in Japan: Evidence before and after massive earthquake, *Regional Science and Urban Economics*, 39: 658–669.

Redding, S.J., D.M. Sturm, and N. Wolf (2011) History and industry location: Evidence from German airport, *The Review of Economics and Statistics*, 93: 814–831.

Residential Population Survey (various years) Local Administration Bureau, Japan Ministry of Internal Affairs and Communications, Tokyo.

Rosenthal, S.S. and S.L. Ross (2015) Change and persistence in the economic status of neighborhoods and cities. In G. Duranton, J.V. Henderson, and W.C. Strange (eds), *Handbook of Regional and Urban Economics*, Vol. 5, Elsevier.

Scawthorn, C., H. Iemura, and Y. Yamada (1982) The influence of natural hazards on urban housing location, *Journal of Urban Economics*, 11: 242–251.

Schiff, N. (2015) Cities and product variety: Evidence from restaurants, *Journal of Economic Geography*, 15: 1085–1123.

Siodla, J. (2015) Razing San Francisco: The 1906 disaster as a natural experiment in urban redevelopment, *Journal of Urban Economics*, 89: 48–61.

Wooldridge, J.M. (2002) *Econometric Analysis of Cross Section and Panel Data*. Cambridge: The MIT Press.

Xinhua Net (2014) Thousands of *Si He Yuan* in Beijing become dilapidated tenements (in Chinese). 2014.05.12.

Yodomichi, K. (2007) The development of municipal mergers in Japan (in Japanese), COSLOG Up-to-Date Documents on Local Autonomy in Japan, No.1, pp.1–22.

Table 1: Cross-sectional estimates with pre-earthquake data

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Mean annual pop. growth in 1988–1994 (expressed as a percentage)							
ln(population per sq.km in 1988)	-1.330**	-1.194**	-0.539***	-0.282***	-0.105	-1.135***	--	-1.089**
	(0.538)	(0.512)	(0.157)	(0.078)	(0.116)	(0.189)		(0.470)
Share of old dwellings in 1988	--	-9.877*	-8.182***	-10.118***	-9.221***	-4.953***	--	-9.778*
		(5.221)	(1.205)	(0.802)	(1.292)	(1.473)		(5.734)
Distance to core Osaka (km)	--	--	--	--	--	--	0.048*	0.013
							(0.025)	(0.013)
Constant	1.207*	10.853**	5.251***	0.783	-0.229	10.983***	-1.100**	9.616**
	(0.691)	(4.516)	(1.406)	(0.521)	(0.670)	(1.686)	(0.401)	(3.970)
Sample	Quaked area	Quaked area	KOK MA	Nationwide	Nationwide (pop. dens. <5000)	Nationwide (pop. dens. ≥5000)	Quaked area	Quaked area
Prefecture dummies	--	--	--	X	X	X	--	--
N	22	22	118	766	611	155	22	22
R^2	0.179	0.532	0.293	0.327	0.346	0.532	0.183	0.542

Notes: See Table A.1 for the details of the variables. For columns 3–6, we include all the municipality-level cities and districts (i.e., urban areas) in KOK MA and nationwide, respectively; municipality-level towns and villages (i.e., rural areas) are not included. We insert prefecture dummies in the estimation with nationwide data to control for prefecture-level variations on population growth. Heteroskedasticity robust standard errors are in parentheses.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 2: Estimated trends for the pre-quake, reconstruction, and long-term redevelopment periods

	Population index (pop. in 1994=1.00000)
(1) D[West(dist.≥30km)] * Trend[1988–1994]	0.00794 (0.00773)
(2) D[West(dist.≥30km)] * Trend[1995–1997]	-0.00194 (0.01002)
(3) D[West(dist.≥30km)] * Trend[1998–2010]	-0.00031 (0.00151)
(4) D[East(dist.<30km)] * Trend[1988–1994]	-0.00280** (0.00117)
(5) D[East(dist.<30km)] * Trend[1995–1997]	-0.00366 (0.00292)
(6) D[East(dist.<30km)] * Trend[1998–2010]	0.00737*** (0.00156)
(7) D[West(dist.≥30km)] * D[1988–1994]	0.94344*** (0.05365)
(8) D[West(dist.≥30km)] * D[1995–1997]	0.99615*** (0.00396)
(9) D[West(dist.≥30km)] * D[1998–2010]	0.99016*** (0.03709)
(10) D[East(dist.<30km)] * D[1988–1994]	1.0207*** (0.00851)
(11) D[East(dist.<30km)] * D[1995–1997]	0.98369*** (0.00479)
(12) D[East(dist.<30km)] * D[1998–2010]	0.97958*** (0.01110)
Time period	1988–2010
N	506
R^2	0.995

Notes: There is no constant term in this regression. West (dist.≥30km) refers to the eight municipalities in the western part of the quaked area, they are not less than 30 kms away from core Osaka. East (dist.<30km) refers to the 14 municipalities in the eastern part of the quaked area, they are less than 30 kms away from core Osaka. D[-] refers to dummy variables as described in the bracket. Trend[-] refers to time trend variables for different periods. For example, Trend[1988–1994], Trend[1995–1997], and Trend[1998–2010] are equal to 0, 0, and 3, respectively for year 2000, since 2000 is not dropped in the periods [1988–1994] and [1995–1997], and it is the third year of the period [1998–2010]. **(-)** in the front of the name of coefficients refers to coding numbers for the data calculation of Table 3. Heteroskedasticity robust standard errors (clustered at the municipality level) are in parentheses.

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 3: Estimated differences in time trends

Panel A: Within period difference (Diff. b/w West & East)	
Period 1988–1994 [= **(1)**–**(4)**]	Period 1998–2010 [= **(3)**–**(6)**]
0.01073 (0.00785)	-0.00768*** (0.00214)
Panel B: Between period difference (Diff. b/w 1988–1994 & 1998–2010)	
West [= **(1)**–**(3)**]	East [= **(4)**–**(6)**]
-0.00825 (0.00663)	0.01017*** (0.00228)
Panel C: Difference-in-difference	
[= ((**1**)–(**4**))–((**3**)–(**6**))]	
0.01842** (0.00698)	

Notes: The coefficients are obtained from the estimates of Table 2, **(1)**–**(6)** refer to row 1 through row 6 of the related estimates in Table 2. Heteroskedasticity robust standard errors (clustered at the municipality level) are in parentheses.

* $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$

Table 4: First-differencing estimations

	(1)	(2)	(3)	(4)	(5)
	Diff. in mean annual pop. growth (before & after the earthquake in 1995) (expressed as a percentage)				
Distance to core Osaka (km)	-0.026***	-0.023**	-0.023**	-0.015***	-0.015***
	(0.009)	(0.009)	(0.010)	(0.004)	(0.003)
Share of new dwellings (built in 1996–2003) in 2003	--	2.452***	--	2.681***	--
		(0.906)		(0.798)	
Num. of dwellings damaged in the earthquake/Population in 1994	--	--	7.753**	--	5.469**
			(3.532)		(2.505)
Constant	0.716***	-0.022	0.381*	-0.209	0.318**
	(0.177)	(0.316)	(0.200)	(0.264)	(0.138)
N	22	22	17	21	16
R^2	0.381	0.449	0.464	0.625	0.566

Notes: The dependent variable is calculated by: [(ln(pop,2010)–ln(pop,1994))/16–(ln(pop,1994)–ln(pop,1988))/6]*100, at the municipality level. See Table A.1 for the details of the variables. For columns 3 and 5, data for five municipalities in OSAKA are missing. For columns 4 and 5, data for Nishi municipality are excluded as an outlier. Heteroskedasticity robust standard errors are in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 5: Estimations with the data of the whole of KOK MA

	(1)	(2)	(3)	(4)
	Annual rate of population growth (expressed as a percentage)			
D[Quaked area] * D[1995–1997] * Dist._Osaka	-0.021	-0.012	-0.034	-0.020
	(0.017)	(0.019)	(0.024)	(0.026)
D[Quaked area] * D[1998–2003] * Dist._Osaka	-0.071^{***}	-0.091^{***}	-0.098^{***}	-0.099^{***}
	(0.027)	(0.033)	(0.035)	(0.033)
D[Quaked area] * D[1995–1997]	-0.649	0.049	-0.369	-1.201
	(0.513)	(0.438)	(0.659)	(1.638)
D[Quaked area] * D[1998–2003]	2.459^{***}	1.853^{***}	3.206^{***}	3.428^{*}
	(0.647)	(0.493)	(0.848)	(1.972)
D[Quaked area] * D[1995–1997] * Quake possibilities	--	--	--	0.334
				(0.532)
D[Quaked area] * D[1998–2003] * Quake possibilities	--	--	--	-0.072
				(0.634)
Constant	-0.030	-0.548^{**}	0.028	0.028
	(0.217)	(0.237)	(0.261)	(0.262)
Municipality fixed effect	X	X	X	X
Year fixed effect	X	--	X	X
Pref * Year fixed effect	--	X	--	--
Period * Dist_Osaka	X	X	X	X
Period * Quake possibilities	--	--	--	X
Overlap on the distance to core Osaka	--	--	X	X
Num. of treatment/control municipalities	20/64	20/64	20/48	20/48
N	1,344	1,344	1,088	1,088
R^2	0.121	0.243	0.134	0.139

Notes: See Table A.1 for the details of the variables. Time period is 1988–2003. Control sample includes urban municipalities (cities and districts) in OSAKA (excluding Osaka), NARA, KYOTO, and WAKAYAMA. Heteroskedasticity robust standard errors (clustered at the municipality level) are in parentheses.

* $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$

Table 6: Estimations on land price

	(1)	(2)	(3)	(4)	(5)
	Annual rate of land price growth (expressed as a percentage)				
	residential	residential	residential	residential	commercial
D[Quaked area] * D[1995–1997] * Dist._Osaka	-0.067	-0.192***	-1.049***	-0.124*	0.008
	(0.048)	(0.064)	(0.208)	(0.061)	(0.095)
D[Quaked area] * D[1998–2003] * Dist._Osaka	-0.201***	-0.362***	-1.182***	-0.232***	-0.335***
	(0.047)	(0.068)	(0.183)	(0.053)	(0.123)
D[Quaked area] * D[1995–1997]	5.276***	8.515***	41.452***	5.290***	2.199
	(1.790)	(2.201)	(7.436)	(1.823)	(3.151)
D[Quaked area] * D[1998–2003]	8.518***	12.840***	42.692***	8.400***	11.456***
	(1.698)	(2.278)	(5.976)	(1.691)	(3.887)
Constant	-2.862***	-5.004***	-19.906**	-2.747***	-11.453***
	(0.229)	(1.033)	(7.779)	(0.223)	(2.074)
Municipality and year fixed effects	X	X	X	X	X
Period * Dist_Osaka	X	X	X	X	X
Overlap_dist_Osaka	--	X	X	X	X
Sample	All	All	District	City	All
Num. of treatment/control municipalities	20/64	20/48	9/9	11/38	20/48
N	924	748	198	539	731
R^2	0.683	0.723	0.779	0.762	0.509

Notes: See Table A.1 for the details of the variables. Time period is 1993–2003. Heteroskedasticity robust standard errors (clustered at the municipality level) are in parentheses.

* $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$

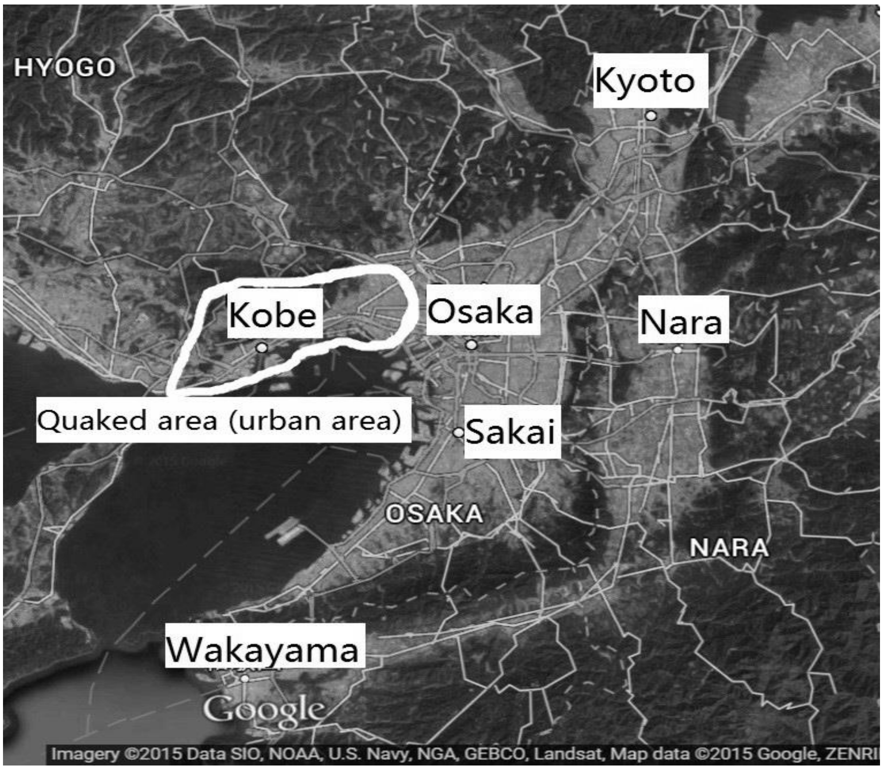


Figure 1: Topography of the Kyoto-Osaka-Kobe MA

Notes: Area encircled is the quaked urban area in the 1995 Great Hanshin Earthquake.

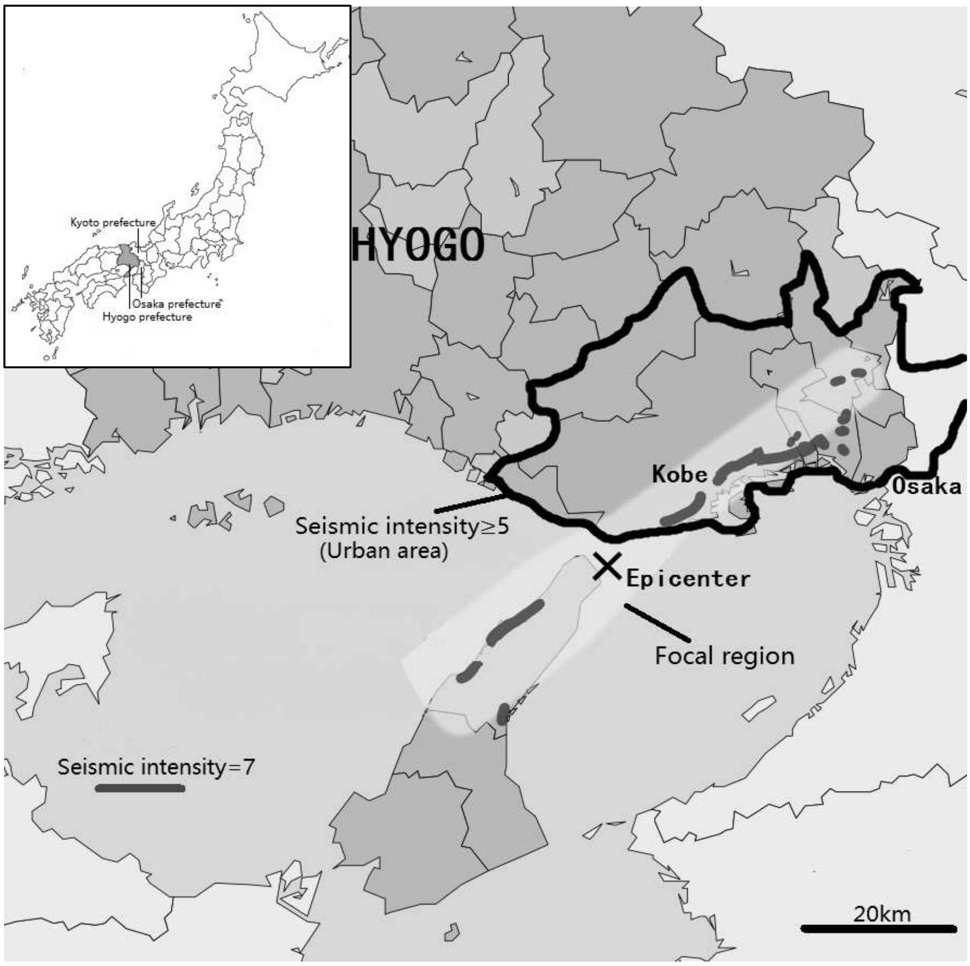


Figure 2: Locations of epicenter and major destroyed areas

Notes: The southwest part of the focal region is the Awaji island; we exclude this island from the analysis since it is a rural area (the island comprised towns and villages, not cities and districts). The bold line encircles municipality-level cities and districts suffered an earthquake that was ≥5 on the intensity scale (more than half of the intensity scale observations within the area are not less than five) (Data source: Japan Seismic Hazard Information Station). Although the epicenter is in the west of Kobe city, owing to the spread of the earthquake wave, the distribution of a seismic intensity of seven is not absolutely restricted to areas close to the epicenter. Takarazuka, which is 35 kms away from the epicenter, also suffered the earthquake measuring seven on the intensity scale.

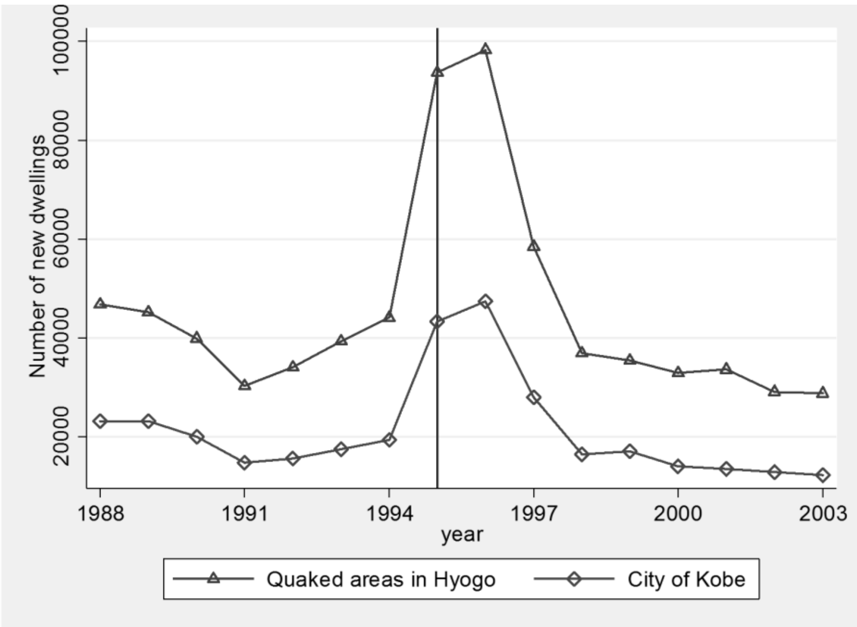


Figure 3: Number of new dwellings (time point of construction beginning)

Notes: Data refer to the number of new residential dwellings starting construction in a specific year. Quaked areas in HYOGO contain 17 municipalities in HYOGO (including nine municipality-level districts of Kobe) suffered an earthquake that was ≥5 on the intensity scale (Data source: Japan Seismic Hazard Information Station). Related data for the quaked municipalities in OSAKA are not available. Data are from the Annual Report of Construction Statistics, annually released by the Section of Information Management, Policy Bureau, Ministry of Land, Infrastructure, Transport and Tourism.

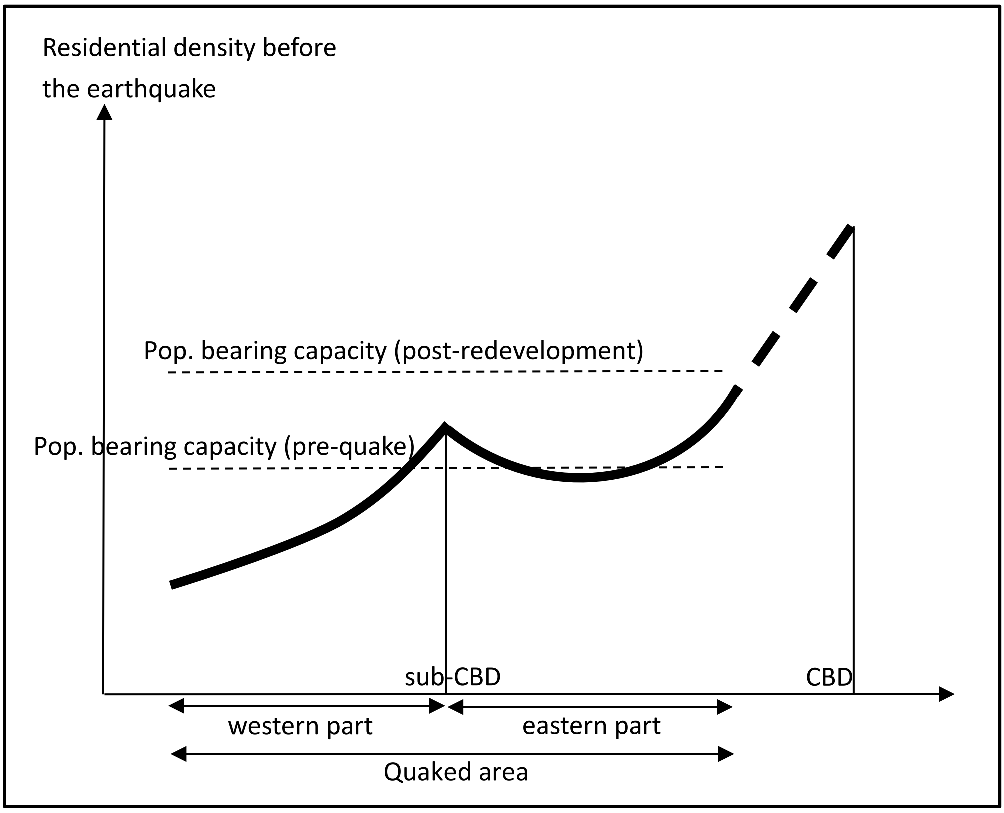


Figure 4: The pre-quake residential density in the quaked area

Notes: The quaked area refers to the sum of western and eastern parts. The CBD is not affected by the earthquake. The population bearing capacity refers to the threshold of population density that leading to a crowded housing; any population density higher than the population bearing capacity will negatively affect residents' living quality, as set in the model. Before the earthquake, the population densities in the locations of eastern part are mostly approaching or passing the population bearing capacity, while for the western part, the population density is not yet stressed. Urban redevelopment increased the population bearing capacity for both parts.

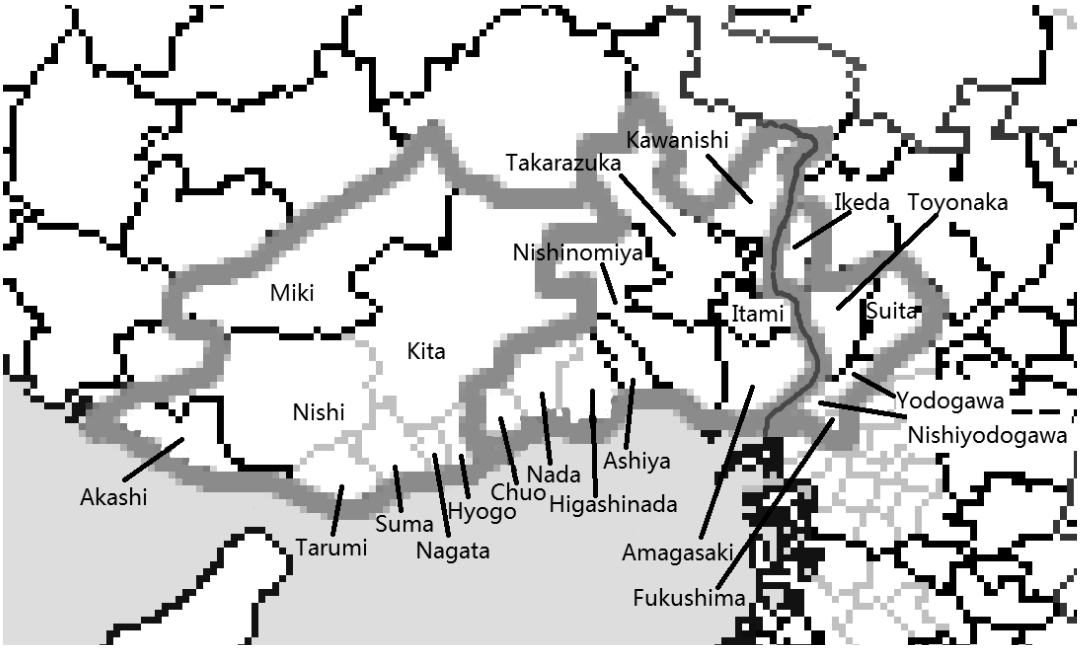
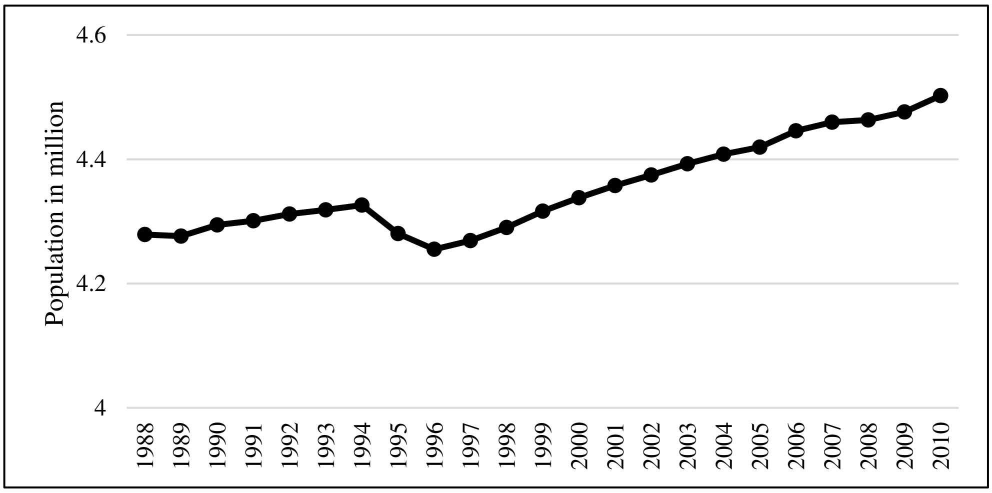
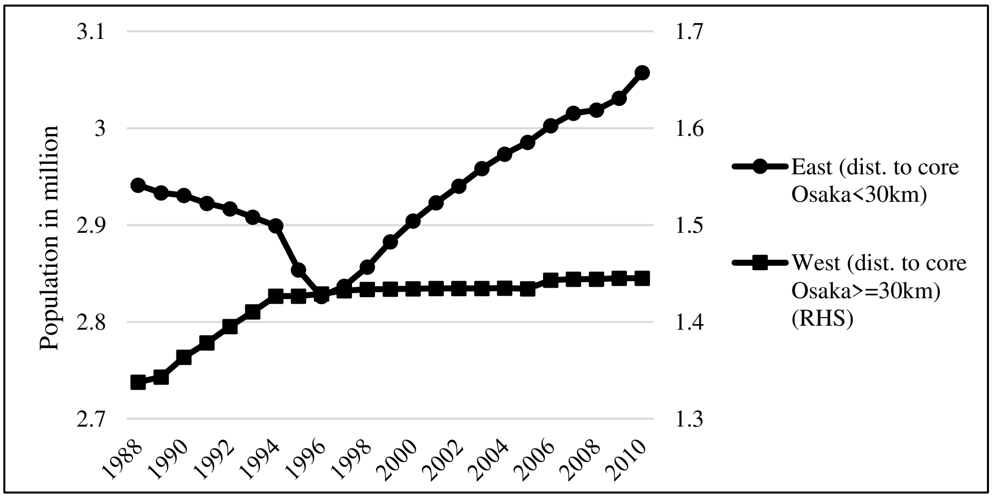


Figure 5: Municipalities in the quaked area

Notes: The area encircled by bold line consists of 23 municipalities (consistent with that of Figure 2). The left-hand side (eight municipalities) is the western part of the quaked area in HYOGO, the middle (nine municipalities) is the eastern part of the quaked area in HYOGO, and the right-hand side (six municipalities) is the quaked area in OSAKA. Population data for Yodogawa (municipality-level district) in OSAKA are missing, and thus, Yodogawa is excluded from all the analysis. All municipalities suffered an earthquake that was ≥5 on the intensity scale (more than half of the intensity scale observations within the area are not less than five) (Data source: Japan Seismic Hazard Information Station). The total land size of the 22 sample municipalities is 1,172 sq.km, of which 631 sq.km is the western part of HYOGO, 427 sq.km is the eastern part of HYOGO, and 114 sq.km in OSAKA.



(a) total population in the quaked area (22 municipalities)



(b) population growth dynamics within the quaked area

Figure 6: Population growth in the quaked area

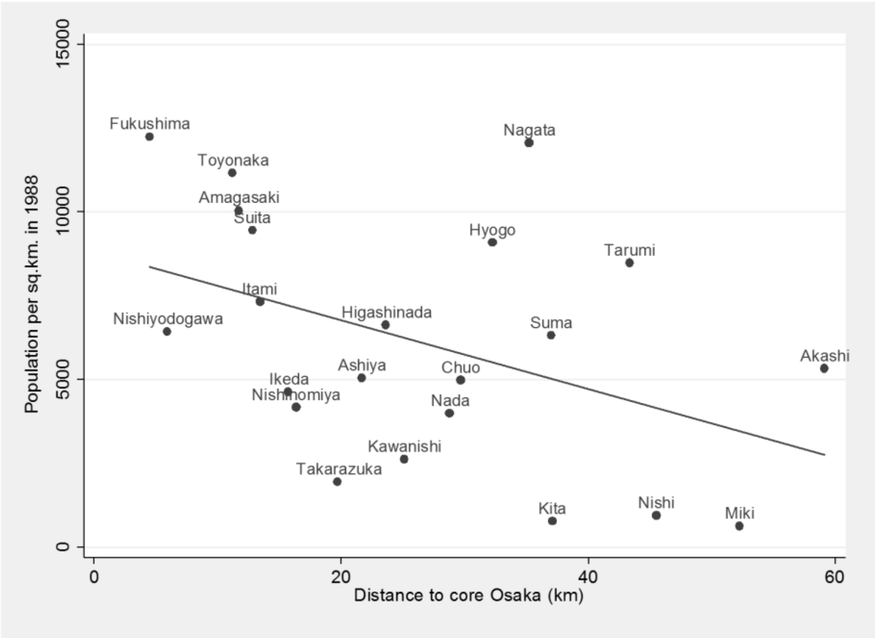


Figure 7: The relationship between the distance to core Osaka and the population density in 1988

Notes: See Table A.1 for the details of the variables.

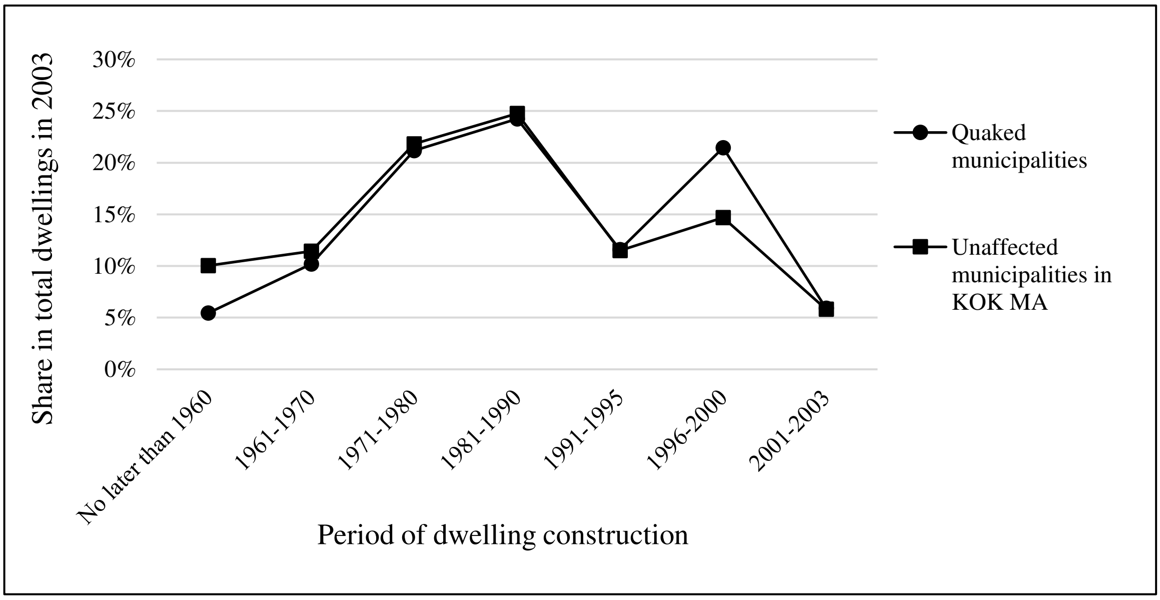


Figure 8: House age in 2003 (time point of construction completions)

Notes: See Table A.1 for the details of the variables. The period of dwelling construction refers to the time point of construction completions, rather than the time of beginning (as in Figure 3). A number of new dwellings in the quaked area started building in 1995 (as in Figure 3) but completed the constructions in the next years.

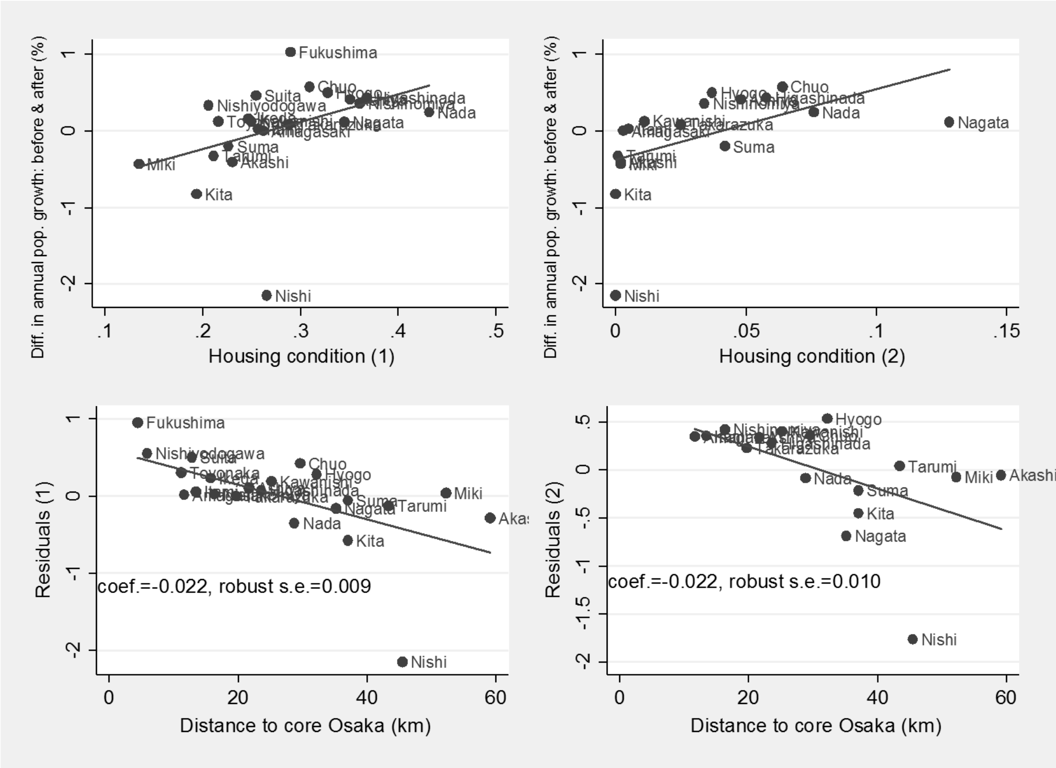


Figure 9: Graphical evidence of Table 4

Notes: See Table A.1 for the details of the variables. *Housing condition (1)*: Share of new dwellings (built in 1996–2003) in 2003; *Housing condition (2)*: Num. of dwellings damaged in the earthquake/Population in 1994. For *Housing condition (2)*, related data for the five quaked municipalities in OSAKA are missing, therefore, the sample size is reduced to 17.

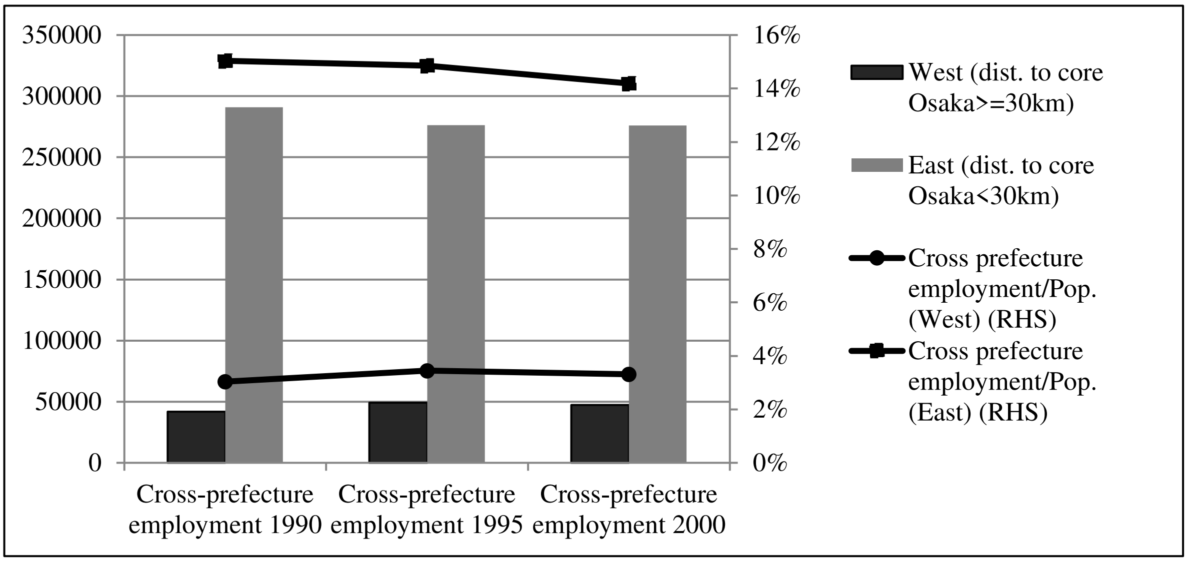


Figure 10: Cross-prefecture employment in the quaked area

Notes: Cross-prefecture employment: Number of residents in the quaked area of HYOGO who work in OSAKA. Data on cross-prefecture employment are from National Census by the Statistics Bureau, Ministry of Internal Affairs and Communications. The data refers to 17 quaked municipalities in HYOGO (with eight in the western part and nine in the eastern part).

Appendix

Table A.1: Data summary

Panel A: Data summary for the within-quaked area estimations					
Indicator	Obs.	Mean	Std.Dev.	Min.	Max.
Residential population (1988–2010)	506	198,045	116,847	53,682	497,212
Population index (1988–2010) (pop. index in 1994=1.00)	506	1.01	0.08	0.68	1.29
Mean annual pop. growth in 1988–1994 (%)	22	-0.07	1.69	-2.07	5.96
Mean annual pop. growth in 1994–2010 (%)	22	-0.04	1.16	-1.95	3.81
Population per sq.km in 1988	22	6,133	3,638	619	12,954
Distance to core Osaka (km)	22	26.45	15.02	4.49	59.13
Share of old dwellings (built before 1946) in 1988	22	0.05	0.04	0.00	0.17
Share of new dwellings (built in 1996–2003) in 2003	22	0.27	0.07	0.14	0.43
Num. of dwellings damaged in the earthquake/Population in 1994	17	0.03	0.04	0.00	0.13

Panel B: Data summary for the estimations taking the unaffected municipalities in KOK MA as the control			
Number of sample municipalities		Treatment (20 muni.)	Control (64 muni.)
Indicator	Year	Mean	Mean
	1988–1994	0.33	0.15
Annual population growth (%)	1995–1997	-0.73	0.36
	1998–2003	0.49	-0.05
	1988–1994	-9.95/-17.01	-6.04/-13.11
Annual growth on residential/commercial land price (%)	1995–1997	-2.65/-9.06	-2.36/-8.49
	1998–2003	-7.11/-9.83	-5.94/-9.34
Distance to core Osaka (km)	--	28.57	36.95
Strong (≥6 intensity) earthquake possibility (before 2035)	--	2.01	4.04

Notes: Some of the data were taken for the fiscal year, which runs in Japan from April 1, therefore, the earthquake (January, 1995) was recorded as occurred in the fiscal year of 1994. For such cases, we set the data of fiscal year t as the data for t+1. Data sources: 1) Data for residential population and population density are from the Residential Population Survey, Ministry of Internal Affairs and Communications (released annually); 2) House age data are from the Housing and Land Survey, Ministry of Internal Affairs and Communications (released in a five-year interval). For the Housing and Land Survey (1988–1998), the house age data are divided by two categories (after 1945 or not, i.e., taking the ending of World War II as a threshold). In the Housing and Land Survey (2003), however, the house age data are divided by a ten or five year interval (i.e., ~1960, 1961–1970, 1971–1980, 1981–1990, 1990–1995, 1996–2000, and 2001–2003). Therefore, data of 2003 are not comparable with that of earlier volumes of the survey; 3) House destruction data (Num. of dwellings damaged in the earthquake/Population in 1994) for the 17 quaked municipalities in HYOGO are from Edgington (2010); 4) Data on the possibility of a strong earthquake are from the Japan Seismic Hazard Information Station. The data are from January 1, 2005, and refer to the possibility of ≥6 intensity earthquake during 2005–2035. The possibility is counted in 1–5 by the quake probability: 0–0.1%, 1; 0.1–3%, 2; 3–6%, 3; 6–26%, 4; 25–100%, 5; 5) Longitude and latitude data (geo-code) for each municipality are obtained from the Center for Spatial Information Science, The University of Tokyo (CSV Address Matching Service), using which we calculate a municipality's distance to core Osaka (the distance between the core area of a municipality to the core Osaka); 6) Data on the growth rate of residential/commercial land price are from the prefectural statistics by Prefectural Statistical Bureau (released annually).

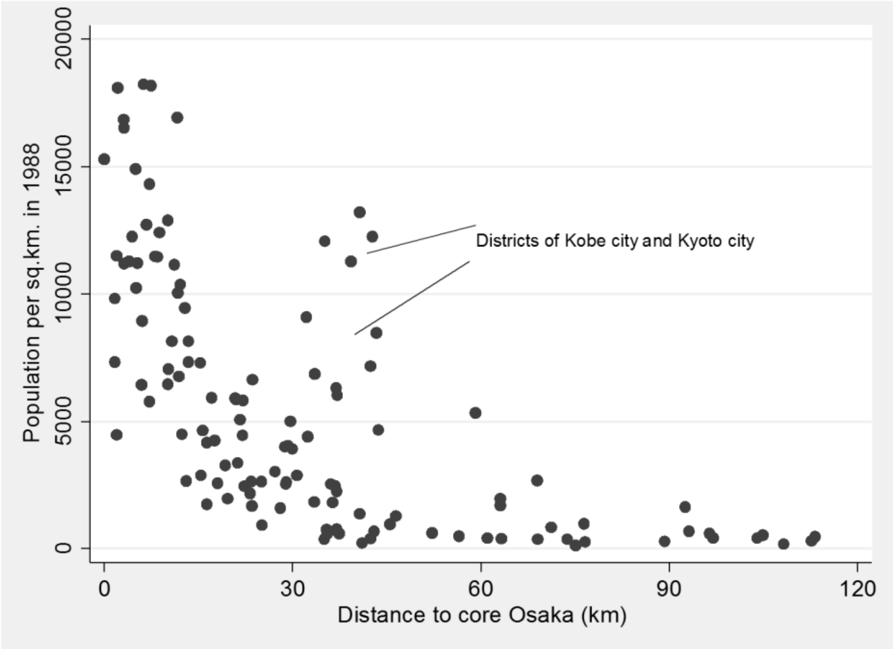


Figure A.1: Municipality-level population density in the Kyoto-Osaka-Kobe MA

Notes: The data include municipality-level cities and municipality-level districts of KOK MA, rural municipalities are excluded. Population data for Yodogawa (municipality-level district) of Osaka are missing. In the distance range of [30, 50] kms to core Osaka, there are several municipalities with population density higher than 6000 per sq.km, which are the districts of Kobe city and Kobe city (i.e., the sub-cores of the KOK MA).

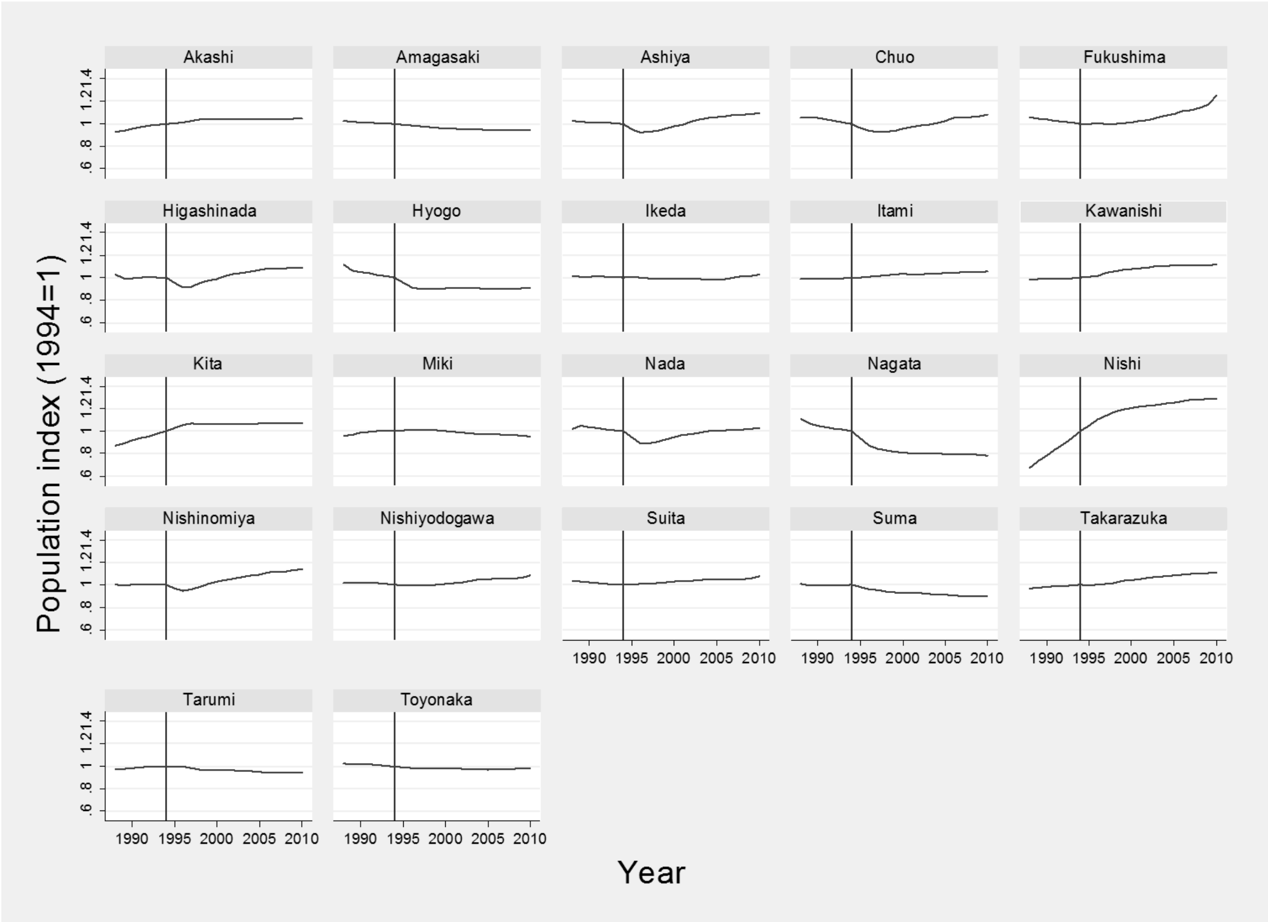


Figure A.2: Population index of the quaked municipalities

Notes: Time period is 1988–2010. Population index of 1994 is set as the value of 1.00. The vertical reference line is for 1994. On October 24, 2005, the town of Yokawa was merged into Miki city, thus the population data of Miki before and after 2005 are not comparable. To keep the population data comparable, we adjust the population of Miki city by: $Pop\_adjusted_t = Pop_t - Pop_{Yokawa\_in\_2004}$ for year t in the period 2005–2010.

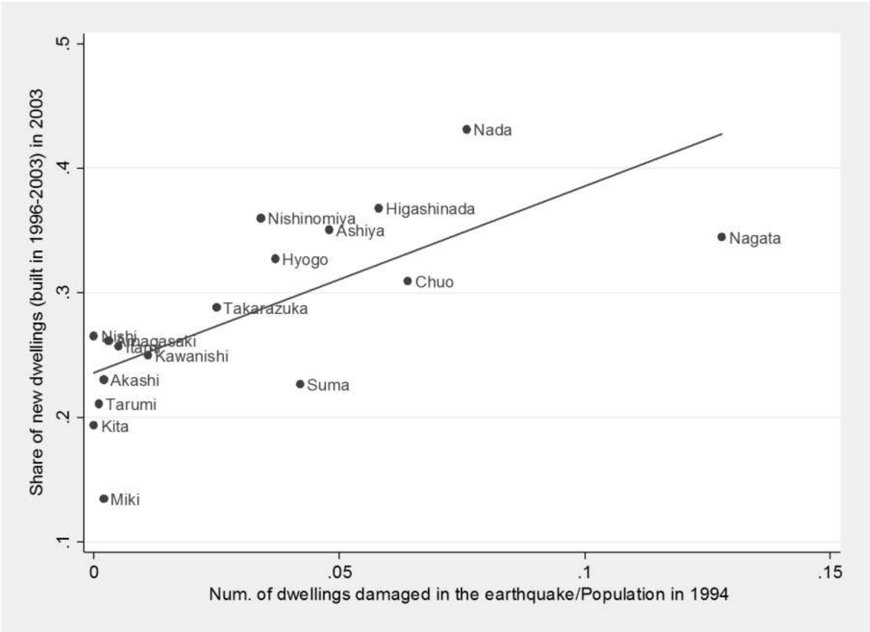


Figure A.3: Relationship between the damage intensity and the condition of house age in 2003

Notes: See Table A.1 for the details of the variables. Data of "Num. of dwellings damaged in the earthquake/Population in 1994" for the five quaked municipalities of OSAKA are missing.

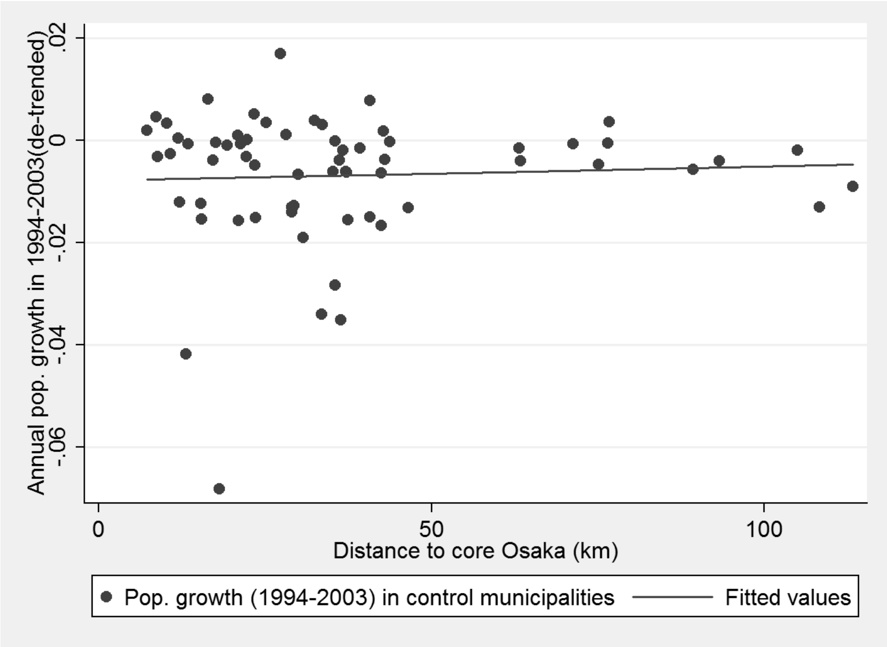


Figure A.4: Population dynamics in control municipalities of the Kyoto-Osaka-Kobe MA

Notes: Control municipalities refer to 64 municipalities as in the regression of Equation R.3. Mean annual population growth is calculated as (ln(pop,2003)–ln(pop,1994))/9. The population data in 2003 are de-trended using the data of 1988–1994. That is, we construct the pre-1995 linear trend of municipality-level population growth by using population data in 1988–1994 and then de-trend the original population data in 2003 by subtracting them with the population increase implied by pre-1995 trend.