RIETI Discussion Paper Series 15-E-035

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**March 2015**

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Abstract

In this study, we aim at quantifying the permanent socio-economic impacts of the Great Hanshin-Awaji (Kobe) Earthquake in 1995. We employ a large scale panel data of 1,719 wards (*shi, ku, cho, son*) from Japan over almost three decades. In order to overcome a fundamental difficulty of obtaining a clean control group, i.e., the Kobe economy without the earthquake, we adopt the synthetic control method of Abadie et al. (2010). Three important empirical findings emerged from our empirical analyses. First, the income level and the population size of the Kobe economy have been significantly lower than the counterfactual level without the earthquake over 15 years, indicating a significant permanent negative effect of the earthquake. Such a negative impact can be found especially in the central areas such as Chuo, Hyogo, and Nagata wards in Kobe, which are close to the epicenter. Second, the surrounding areas such as the city of Nishinomiya encountered positive permanent impacts with short-run negative effects of the earthquake. Third, the relatively outside areas such as the north (kita) wards of Kobe, the city of Akashi, and the city of Himeji seem to be insulated from the large direct and indirect impacts of the earthquake. In sum, there seem to be significant heterogeneities of the short-run and long-run losses caused by the earthquake even within the affected areas, suggesting that different market and non-market mechanisms function significantly to weather the impact of the earthquake spatially.

*Keywords*: Great Hanshin, Long-term impact, Synthetic control method, Ward-level data, Heterogeneities in damages

*JEL classification*: O11, Q54, R11



* This research is a part of the project "Post-disaster Recovery Policies and Insurance Mechanisms against Disasters: Case Studies on Earthquakes in Japan and Floods in Thailand" undertaken at the Research Institute of Economy, Trade & Industry (RIETI). The authors would like to thank RIETI for generous support for the project. The authors are also grateful for their helpful suggestions and comments from the seminar participants at RIETI – in particular, Atsushi Nakajima, Masahisa Fujita, Masayuki Morikawa and Hiroyuki Nakata. Noy's work was partly funded by a grant from the National Oceanic and Atmospheric Administration, Project R/IR-22, which is sponsored by the University of Hawaii Sea Grant College Program under Institutional Grant No.NA09OAR4170060. The opinions expressed and arguments employed in this paper are the sole responsibility of the authors and do not necessarily reflect those of RIETI or the Ministry of Economy, Trade and Industry of Japan or NOAA and any of its sub-agencies.

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## 1. Introduction

The Great Hanshin-Awaji earthquake (hereafter, the Kobe earthquake) struck at 5:46 a.m. on January 17, 1995, on Awaji Island offshore from the city of Kobe, affecting an area that was, at the time, home to 4 million people and that contained one of Japan's main industrial clusters. The earthquake, which had registered 7.3 on the Richter scale, cost 6,432 lives, resulted in 43,792 injured, and damaged 639,686 buildings, of which 104,906 were completely destroyed. The Kobe earthquake was responsible for one of the largest direct economic losses due to a natural hazard in recorded human history.[1] While we understand well the direct impact of the Kobe earthquake, we know much less about its impacts in the long-term. Surveys suggest that the people of Kobe experienced a prolonged and significant adverse impact on their well-being (1). However, did the Kobe earthquake in 1995 indeed cause permanent losses to the economies of Kobe and other surrounding areas in Japan? Or is the recorded sense of deteriorating well-being need to be explained through mechanisms other than a real decline in the economic circumstances of the region?

The received wisdom appears to be that the devastation wrought by the 1995 Kobe earthquake did not have any long-term impact on the Japanese economy, nor much impact on Kobe itself (2), though some recent work disputes these conclusions (e.g., 3). The answer to this question should be based on a comparison between the actual realized Kobe economy, and a counter-factual Kobe without the earthquake. The conventional approach has been to compare the development of post-quake Kobe with the trends observed in Japan (excluding Kobe; e.g., 4). However, such an approach raises questions about the arbitrariness of selection and the degree to which the comparison unit (Japan excluding Kobe) is indeed a credible proxy for the treatment unit's counterfactual (Kobe without an earthquake). This difficulty is compounded by the fact that the earthquake occurred a few years after Japan had already entered the "lost decade"— a prolonged recession following the collapse of the housing market circa 1990. The synthetic control method we adopt here, introduced by Abadie and Gardeazabal (6) and formalized in Abadie et al. (7 & 8 – henceforth ADH), overcomes these shortcomings by adopting a data-driven control-group selection procedure. The counter-factual observations are synthetically constructed as a weighted average of available control units that were not affected so that this synthetic control approximates the most relevant characteristics of the treated unit prior to the treatment.

[1] The total amount of loss caused by the Great East-Japan earthquake on March 11, 2011, seems to be the largest in human history (5).

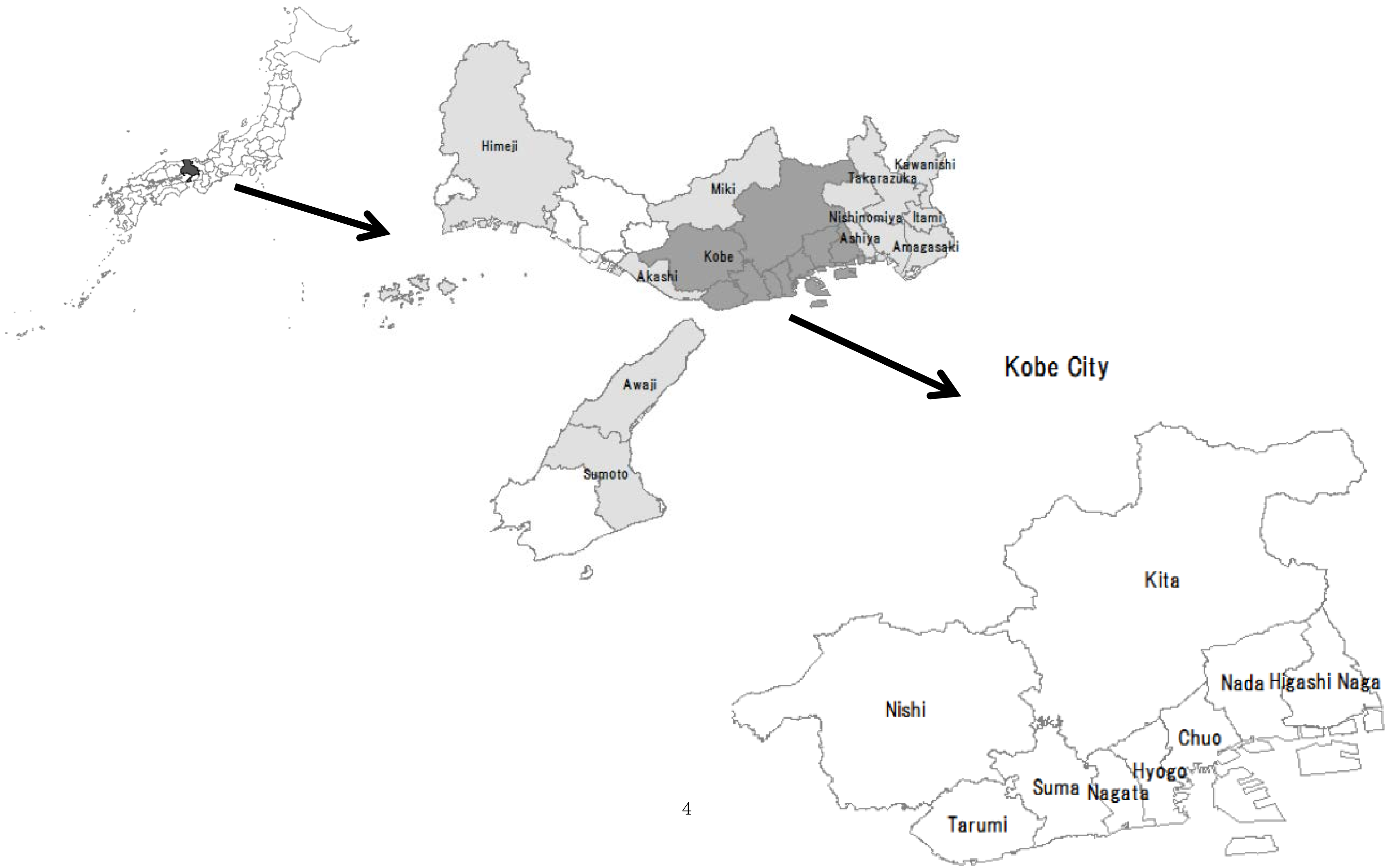
Recently, (9) and (10), using different methodologies and prefecture (province/state) level data, reach opposing conclusions. Neither, however, can explain their findings, as the analysis of prefecture level data masks dramatic heterogeneities in damages within Hyogo prefecture in the amount of direct losses with much of the prefecture unaffected but Kobe City and surrounding areas dramatically damaged. Equally, we would expect significant heterogeneities in the long-term indirect impacts. In order for us to adequately establish a counterfactual, provide details of the heterogeneous ways in which the economy of the region was impacted, and describe the mechanisms that led to these long-term effects, we employ a large panel data of Japanese wards (districts/counties) observed annually for over three decades (1980-2010). We conclude by putting our findings in the context of the (scant) literature on the long-term impact of environmental shocks and discusses the likely causal mechanisms.

## 2. Data & Method

For all Japanese wards, we obtain information on 67 variables, so that our dataset is constructed from 1,763,153 observations.[2] The synthetic control methodology requires that each predictor variable have at least one observation associated with each control unit during the pretreatment period. The methodology requires that each unit of observation in the pool of possible controls be unaffected by the treatment. We removed all cities, towns, and wards in both Hyogo and Osaka Prefectures so that all wards in all other prefectures are used as potential counterfactual controls. Between 1980 and 2010 there were 719 mergers between cities, towns, and wards. This, together with missing observations, reduced our sample to 1719 wards.

[2] "Basic Data of Cities, Towns, and Villages (shi ku cho son kiso data) of Statistics Bureau, Ministry of Internal Affairs and Communications, available at: http://www.stat.go.jp/english/data/ssds/outline.htm. For the full list of variables used in this paper, please see Appendix A. 16 of these variables, have issues with missing data, such as Product Shipments, and could not be used as predictor variables. The remaining 51 variables both served as predictor variables, as well as potential variables to check for impact.

Figure 1: Wards in Hyogo Prefecture Selected for Analysis



We employ the synthetic control methodology to quantify the impact of the Kobe earthquake by constructing a counterfactual from other Japanese wards that were subject to the same external shocks and institutional and legal frameworks but have not directly experienced the earthquake. Let $Y_{it}$ be the outcome variable for ward $i$, where we set $i$=1 for the treated wards and $i$>1 for the other Japanese wards unaffected directly by the earthquake, at time $t$ (=1, …, $T_0$, …, $T$) where $T_0$=1994. $Y_{it}^{I}$ is the outcome variable in the presence of the earthquake and $Y_{it}^{N}$ is the outcome variable had the earthquake not occurred.[5] The model requires the assumption that the event had no effect on the outcome variable before it occurred at time $T_0+1$ $(Y_{it}^{I}=Y_{it}^{N} \forall t \leq T_0)$. Although this last assumption is unjustified in cases where disaster impact is frequent and therefore expected, Kobe had not experienced a similar event, and was widely perceived in Japan as a low-earthquake-risk region.

The observed outcome is defined by $Y_{it}=Y_{it}^{N}+\alpha_{it}D_{it}$ where $\alpha_{it}$ is the effect of the disaster on the variable of interest $(Y_{it}^{I}-Y_{it}^{N})$ and $D_{it}$ is the binary indicator denoting the event occurrence ($D_{it}$=1 for $t>T_0$ and $i=1$; and $D_{it}$=0 otherwise). The aim is to estimate $\alpha_{it}$ for all $t>T_0$ for the affected wards/cities ($i$=1). The estimation problem is that for all $t>T_0$ it is not possible to observe $Y_{1t}^{N}$ (the counterfactual) but only $Y_{1t}^{I}$.

Following ADH, suppose that $Y_{it}^{N}$ can be given by the following factor model:

$Y_{it}^{N}=\delta_t+\theta_t Z_i+\lambda_t\mu_i+\varepsilon_{it}$, where $Z_i$ is a vector of observed covariates (variables such as regional product per capita, population, etc.)[6] and $\mu_i$ is a vector of unknown factor loadings.

[5] This description is a modified version of (7). To simplify comparison, we follow their notation where $I$ denotes intervention (event occurring) and $N$ denotes non-intervention (event not occurring).
[6] A full list of the additional variables we use can be found in the data appendix.

Let $W = (\omega_2, ..., \omega_{J+1})'$ be a vector of weights allocated to the different (unaffected) ward/city observations such that $w_j \geq 0$ for $j = 2, ..., J+1$ and $\sum_{j=2}^{J+1} \omega_j = 1$. A synthetic control is a weighted combination of the controls such that it replicates a treated unit as if the treatment had not occurred. Thus the outcome variable for each synthetic control can be written

$$\sum_{j=2}^{J+1} \omega_j Y_{jt} = \delta_t + \theta_t \sum_{j=2}^{J+1} \omega_j Z_j + \lambda_t \sum_{j=2}^{J+1} \omega_j \mu_j + \sum_{j=2}^{J+1} \omega_j \varepsilon_{jt} \qquad (1)$$

Suppose there is a set of estimated weights $(\hat{\omega}_2, ..., \hat{\omega}_{J+1})$ that can accurately replicate the treated unit's pre-treatment observations in the following manner

$$\sum_{j=2}^{J+1} \hat{\omega}_j Y_{j1} = Y_{11}, \ldots, \sum_{j=2}^{J+1} \hat{\omega}_j Y_{jT_0} = Y_{1T_0} \quad \text{and} \quad \sum_{j=2}^{J+1} \hat{\omega}_j Z_j = Z_1 \qquad (2)$$

Abadie et al. (2010) show that under acceptable assumptions, combining the previous equations yields the following: $Y_{1t}^N = \sum_{j=2}^{J+1} \hat{\omega}_j Y_{jt}$. Furthermore they prove that this equality will hold for all $t$ provided the number of pre-intervention periods is large enough.[7] In our case we have 15 periods of pre-disaster data, which is comparable to (7) and (8) using this method. We obtain an estimate of the impact of treatment (the earthquake) as:

$$\hat{\alpha}_{1t} = Y_{1t} - \sum_{j=2}^{J+1} \hat{\omega}_j Y_{jt} \qquad \text{for} \quad t > T_0 \qquad (3)$$

Our goal is to select a set of weights for which (2) holds approximately. We determine the appropriate weights by examining the goodness of fit over the pre-treatment period as well as the predictor balance for all of the variables in $Z_1$. The set of weights $W$ is selected to minimize the distance between the predictor variables for the treated prefecture ($X_1$) and those of the synthetic control ($X_0 W$) during the pretreatment period. We choose $W$ such that the following equation is minimized:

[7] For the complete proof see (7) Appendix B.

$$\|X_1 - X_0W\|_V = \sqrt{(X_1 - X_0W)' V (X_1 - X_0W)} \quad (4)$$

where $V$ is some $(k \times k)$ symmetric and positive semi-definite matrix. In this particular case $k$ is the number of explanatory variables. $V$ is used to place weights on the predictor variables such that the difference between the variable of interest for the treated prefecture ($Y_1$) and that of the synthetic control ($Y_0W$) is minimized during the pre-treatment period. We use the Synth Package for R to obtain $V$ such that the root mean squared prediction error (RMSPE) is minimized for the period prior to the earthquake. For robustness, we use two different initial values to obtain $V$ and then use the best result as our final value.[8] We only present, and map, results for which the RMSPE $\leq 10\%$.[9] The motivation for the strict adherence to this condition is that this tight fit establishes the robustness of our results. Our success (or lack thereof) in establishing a counterfactual that successfully tracks the actual observations for the treated units in the pre-treatment period is our main yardstick.

An alternative approach is to examine placebo impacts (impact assessment for geographical units that did not, in reality, experienced the disaster – similarly to the placebo effect in medical studies). This approach is, however, difficult in our case, given the very large dataset we are using (much bigger than what was used in the previously cited papers by Abadie and co-authors). The placebos we estimate are generally estimated fairly inaccurately (their pre-event fit is low). We nevertheless include placebo results for our main variables of interest in the attached appendix and discuss them in the text.

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[8] The R ‘synth’ package uses two starting values for the weights and then utilizes the Nelder-Mead and BFGS algorithms to minimize the distance.

[9] RMSPE $\equiv \sqrt{\frac{\sum_t \left(\frac{y_t - \hat{y}_t}{\hat{y}_t} \times 100\right)^2 \times 1_{\{t<1994\}}}{\sum_t 1_{\{t<1994\}}}}$. We use t<1994 rather than t<1995 since the Earthquake occurred on Jan.7, 1995 (fiscal year 1994).

## 3. Results

We start by showing a few illustrative examples of the results we obtain, and follow with a set of maps that summarize our results more comprehensively. In figures 2 and 3, we show the impact of the earthquake on the population of Kobe City (aggregated over its wards), and for another nearby city to the East of Kobe, Nishinomiya. These two figures show both the actual observations for Kobe and Nishinomiya (black lines) over the whole sample period (1980-2010) and the calculated synthetic counterfactual (grey line). The distance between the two lines is the calculated impact of the earthquake ($\hat{\propto}_{1t}$).

For Kobe City, we find permanent negative but small impact on total population: around 2% decline in population 15 years after the earthquake, after an initial larger decline in the immediate few years of the disaster's aftermath (Figure 2). While we do not show these figures separately, the permanent loss of population in Kobe City can be found for both males and females. Nishinomiya, shown in figure 3, provides an illuminating contrast. After a sharp decline in the immediate aftermath of the earthquake, a decline that was bigger than that experienced in Kobe City, Nishinomiya ended up with population gain; the population 15 years after the earthquake has increased by 10% relative to what it would have been had the earthquake not occurred (Figure 3).

Figure 2: The Impact of the Earthquake on Population of Kobe City

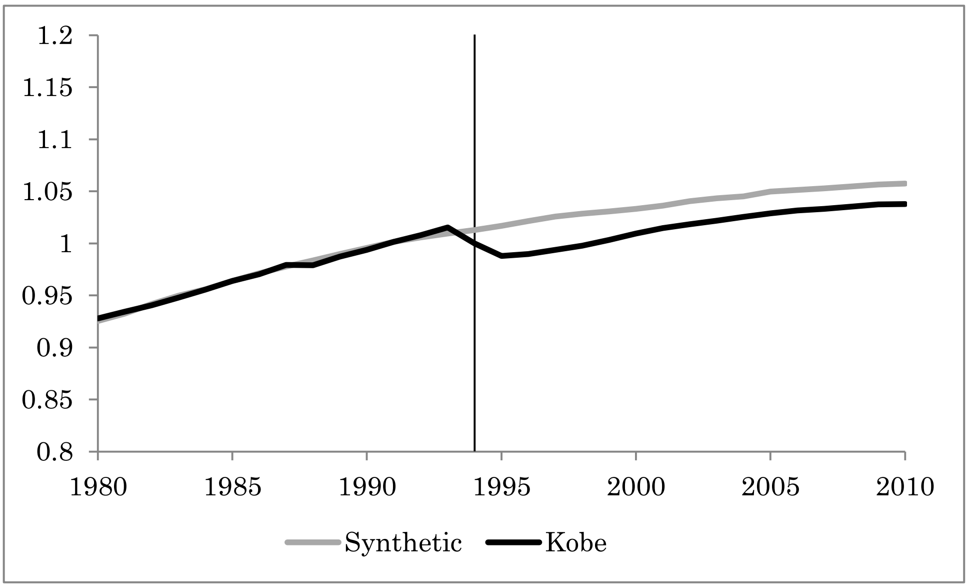
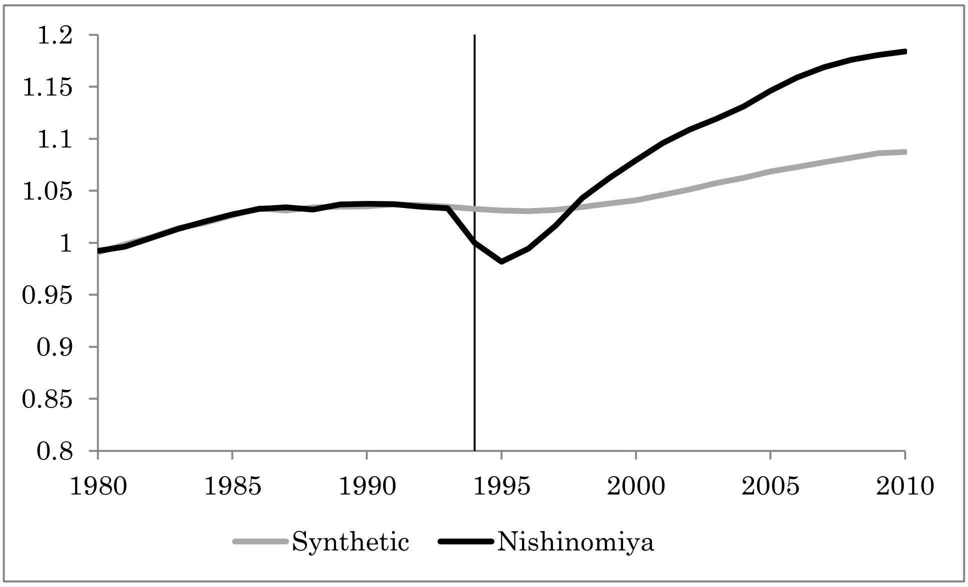



Figure 3: The Impact of the Earthquake on Population of Nishinomiya City




For Kobe's population estimate, we make two observations from the placebo results: First, the goodness-of-fit for Kobe's population estimates pre-event is better than for most other cities in our dataset. Second, the post-event trajectory of Kobe is not significantly outside the range of estimates for other regions. This second observation suggests that the small identified impact on

Kobe's population may not be statistically robust.

Figures 2 and 3 show the impact of the earthquake for only two geographical units. In order to summarize the information included in the results for every impacted ward/town/city in the region, we plot these on a map. We color every geographical unit with the estimated impact on the variable of interest, calculated as the difference between the synthetic and the actual observation for that region (as the distance between the two lines in figures 2 and 3, expressed in percent); blue colors denote decreases and the reds denote increase. Only those results for which the pre-event fit is sufficient (RMSPE<10; see footnote 7) are presented. These maps allow us to observe more clearly the spatial patterns we found. In all figures, the top panel presents our estimates using the city-level data. Thus, the impact plotted for Kobe City is estimated for the city as a whole, using a control group composed of other Japanese cities. The bottom panel provides more detail by focusing on differential impacts across the nine wards of Kobe City; these impacts are estimated using the ward-level dataset.[10]

During the first year after the earthquake, there was a short-term dip in population across the whole area nearest to the epicenter, and including the urban Eastern corridor toward Osaka. In the longer-run, however, we observe heterogeneities in permanent population trends. Figures available in the appendix present the population impact maps for the aggregate figures, and disaggregated by gender and age and using several population measures from different sources. In figure 4, we observe a pattern of movement away from the most severely affected areas. However, regions to the east, that were also seriously impacted initially, seem to gain in long

[10] In principle, the results presented in the top panel for Kobe City (city-level) can be thought of as a weighted-average of the results from the bottom panel of each map (ward-level) – weighted by the relative size of each ward. However, this is not exactly the case as the synthetic is estimated using a different set of controls.

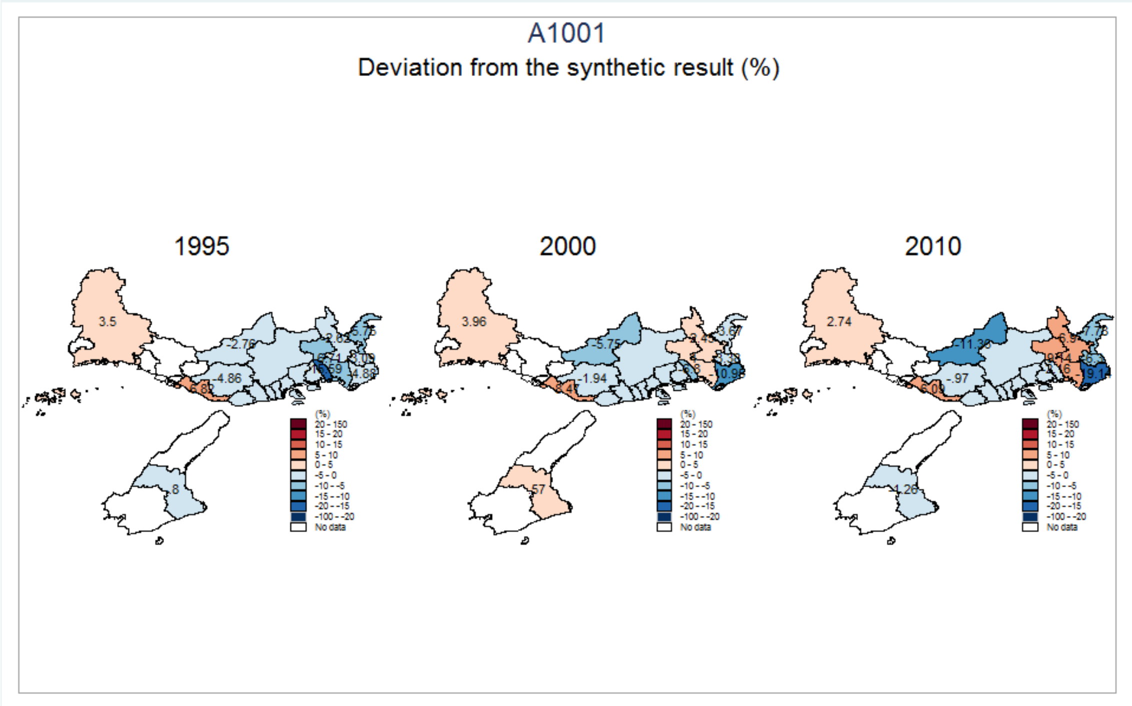
run, suggesting that proximity to Osaka may be a driver of population recovery. These patterns are not uniform; Sumoto city, for example, which is located near the epicenter, has been largely unaffected, implying that the community and industry employment characteristics matter as well.

Figure 5 includes an examination of the day-time population of the area we examine. These estimates suggest that there is a uniform and persistent decline of population even in the longer-term. This decline in daytime population is even observed for these towns to the East, for which we observed population increases in figure 4. This suggests that the increase in population observed to the East of Kobe City is driven by people who have moved to these areas from the devastated center, but have also switched their location of employment eastward to Osaka.

Another intriguing trend, presented in figure 6, is the increase in the number of people over the age of 65. When compared with other geographical units in Japan (the synthetic control), Kobe City seemed to have gained more. While we do not know the exact reasons for this shift, we can speculate that it may be associated with either people returning to their cultural roots (as the impact of the earthquake leads to shifts in preferences), or that over-65, living mostly on fixed incomes, are moving to a place where living costs are lower (both because of the relative economic decline of the region and the generous government support).

For income, as we can see from Figure 7, Kobe City partially bounced back after the earthquake, but there still appears to be a permanent loss in income. Again, we find intra-regional heterogeneous variations in income recovery. While the areas East of Kobe seem to gain in long run, other parts closer to central Kobe lost substantial amount of income, suggesting once more that the proximity to Osaka as a new provider of employment and income may be a driver of the (partial) economic recovery in Kobe's Eastern region.

Figure 4: Total population



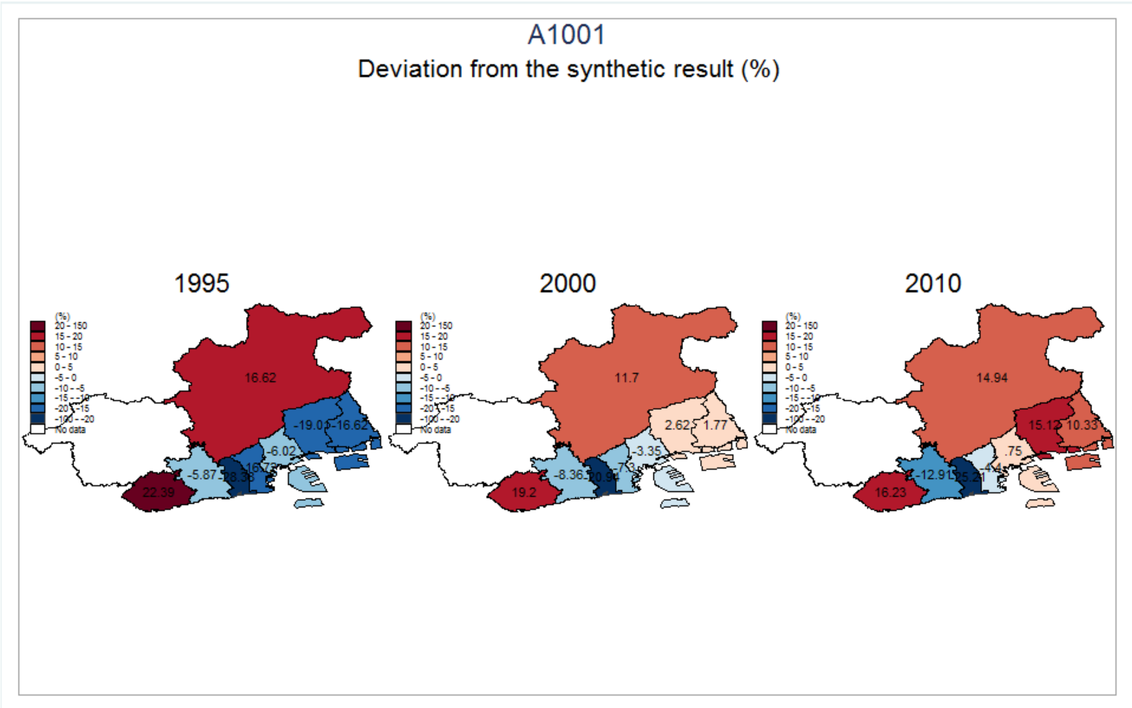



Figure 5: Daytime population

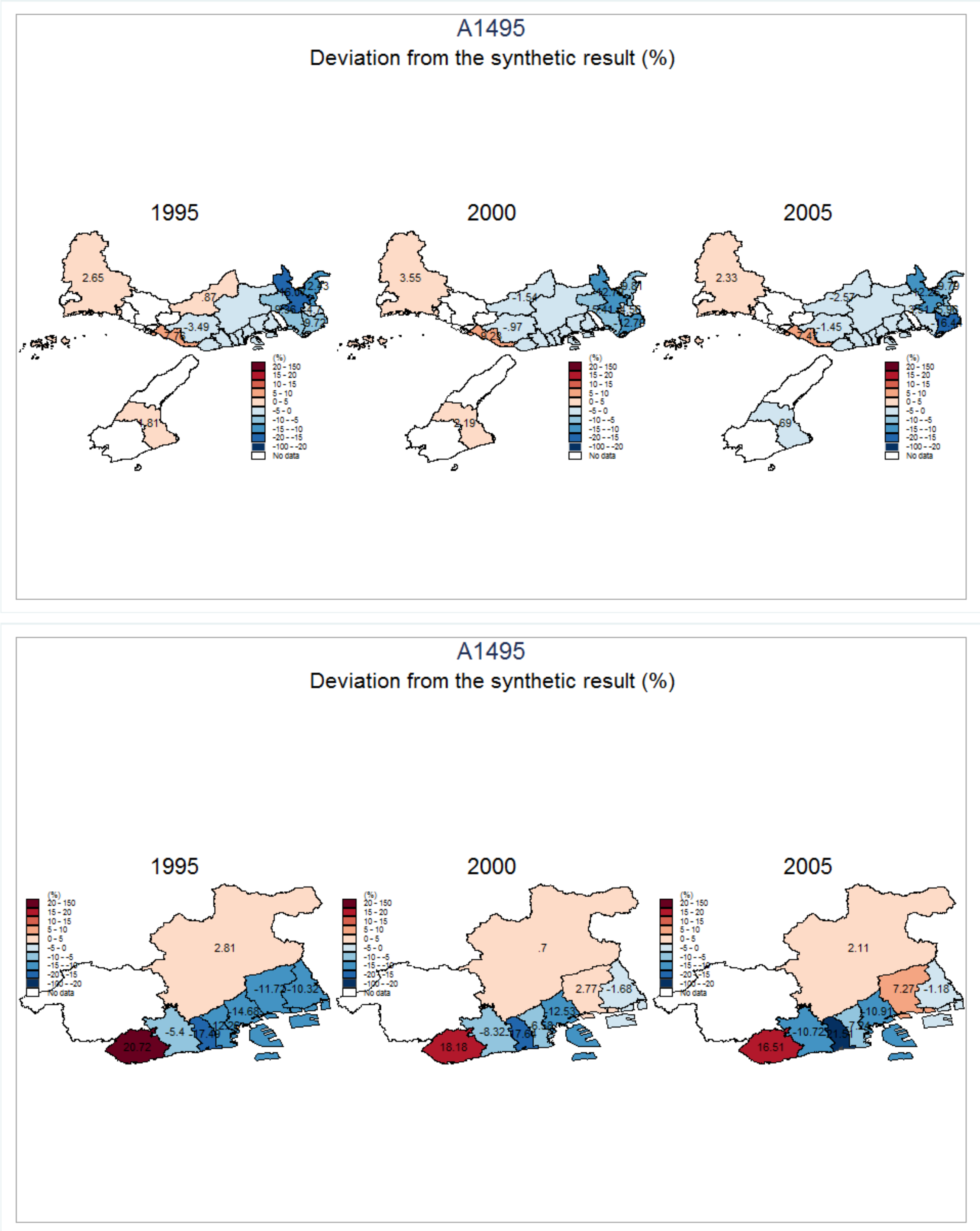


Figure 6: More than 65 year-old population

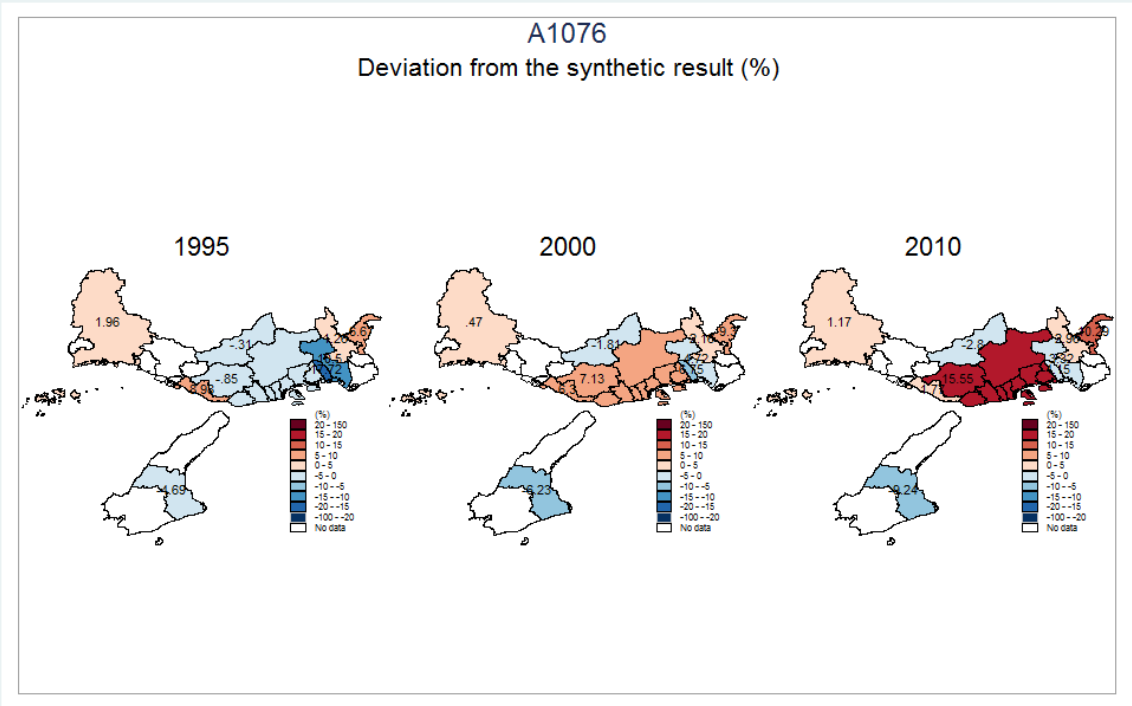
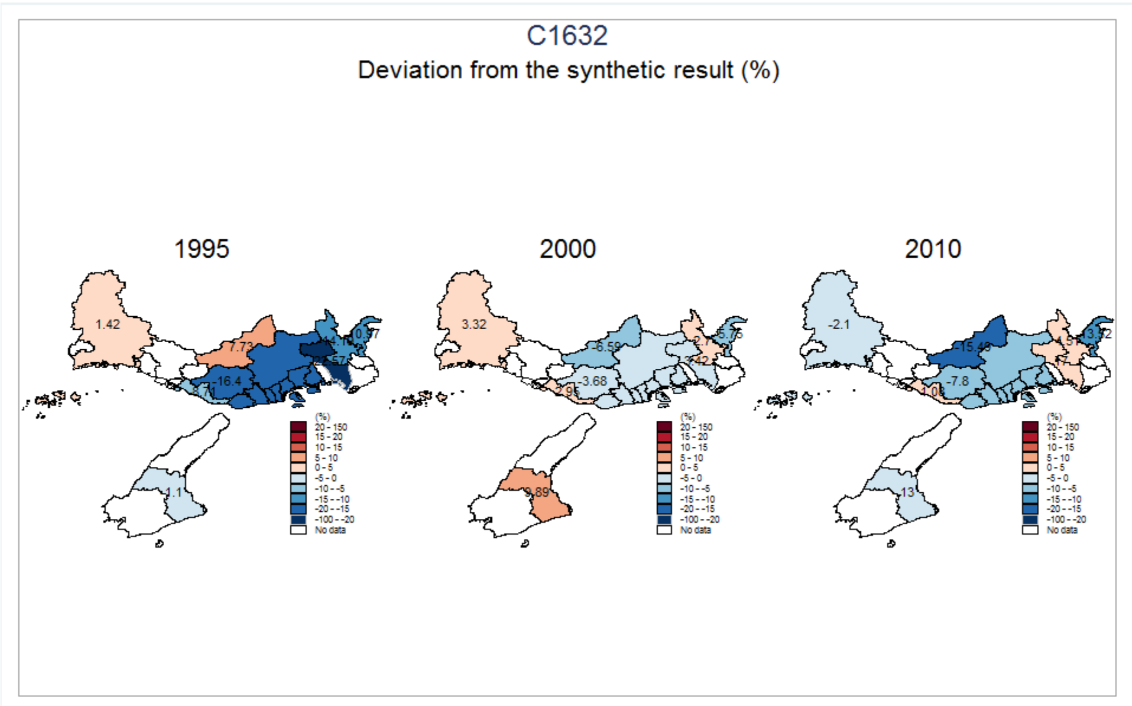



Figure 7: Taxable income



We next study aggregate unemployment (figure 8), and then employment in the secondary (manufacturing) and tertiary (services) sectors in figures 9 and 10, respectively.[11] The evidence on aggregate unemployment is quite clear. Unemployment increased, both in the short- and in the long-term, and both in Kobe City itself, and in the peripheral towns. Remarkably, the evidence seems to suggest a stronger adverse impact in the long-term (15 years after the earthquake).

The secondary (manufacturing) sector in Kobe City declined both in the short- and long-terms; this decline is observable in both the number of secondary-sector businesses operating in the city, and the level of employment in this sector. The spatial distribution is quite different for the tertiary sector (services). As before, we observe a short-term decline for Kobe City, its wards, and the surrounding towns in both number of operating businesses and employment. However, once we examine the longer-horizon, 15 years after the earthquake, we observe an increase in the number of tertiary (services) businesses operating, accompanied by a smaller increase in employment when evaluated against employment trends elsewhere in Japan. Essentially, it appears that Kobe City experienced a shift from secondary to tertiary employment. This shift may explain the declines in aggregate taxable income, and as the wages in service sector jobs are typically lower than in the industrial/manufacturing sector.

[11] Equivalent analysis of the number of businesses in the secondary and tertiary sectors is available in the appendix.

Figure 8: Number of Unemployed

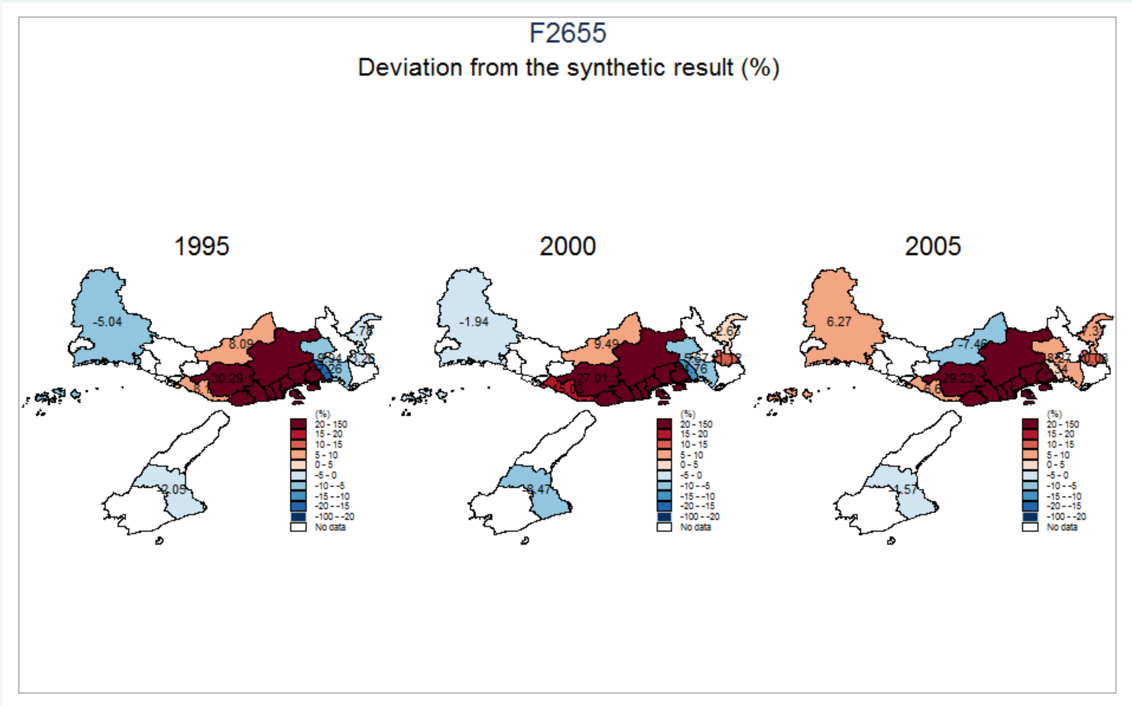



Figure 9: Number of employees in the secondary sector

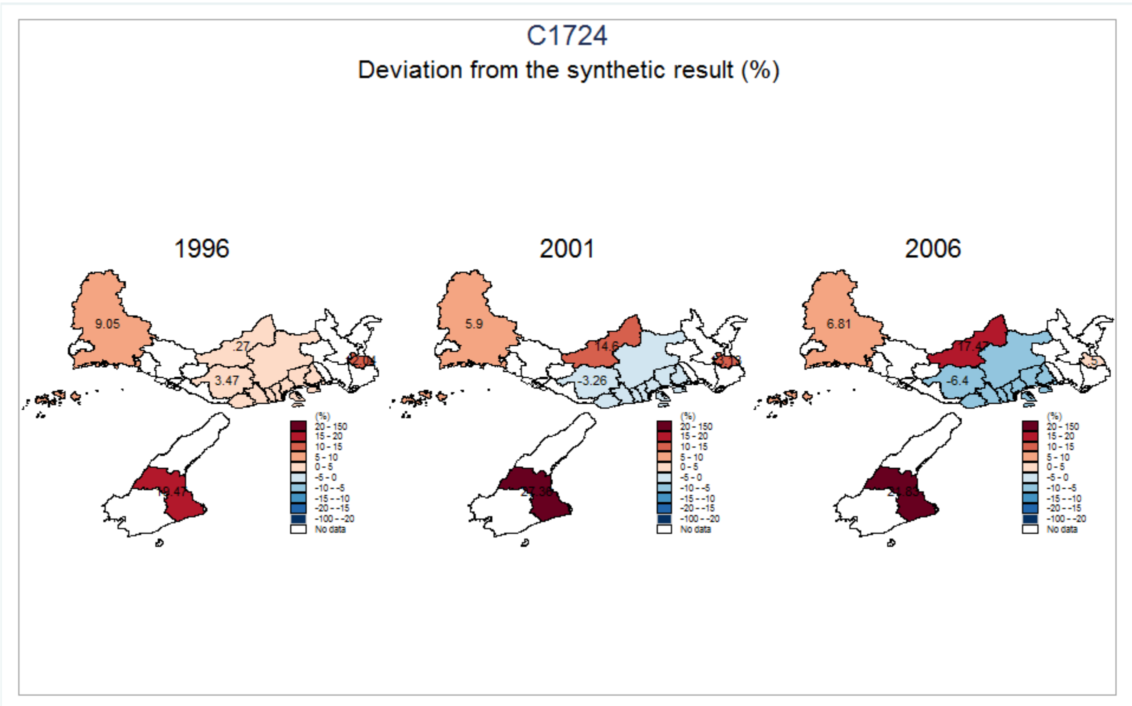
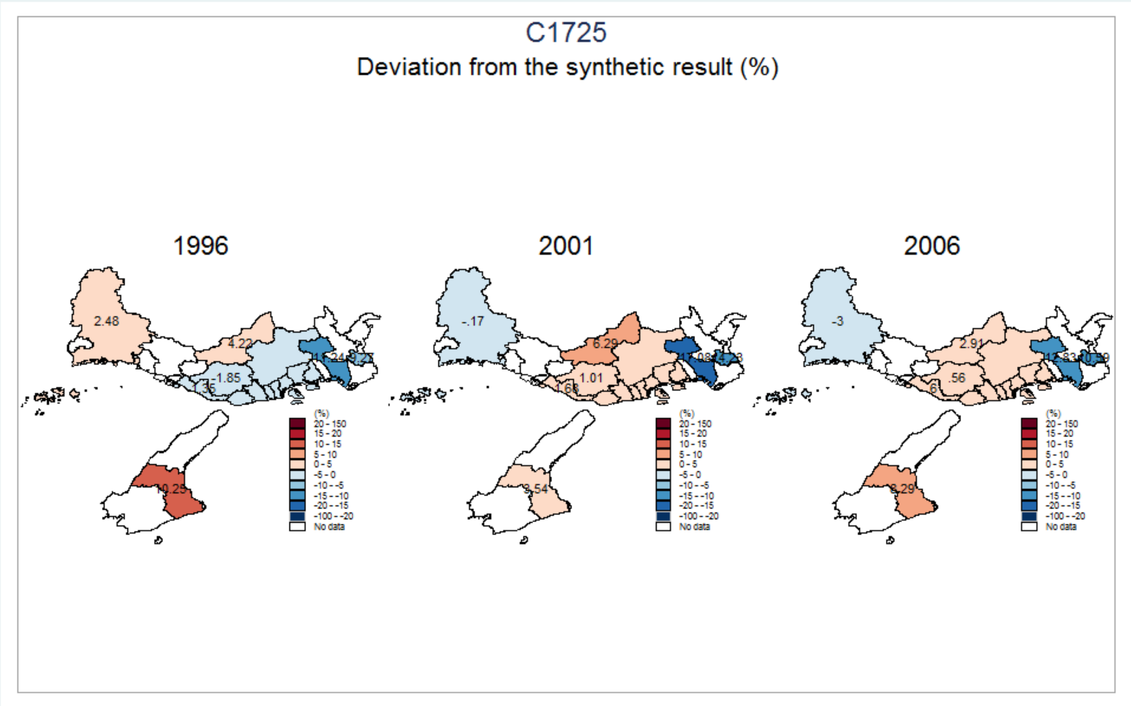


Figure 10: Number of employees in the tertiary sector




## 4. Conclusions, caveats, and future considerations

The three central empirical regularities that emerged from our synthetic control analysis are: First, the income and to a lesser extent the population of Kobe City have both decreased. This effect of the earthquake lasted for over fifteen years, indicating a significant permanent negative impact. Such a negative impact can be found especially in the central area (e.g., Chuo, Hyogo, and Nagata wards), which is closest to the epicenter of the earthquake. Second, the surrounding areas, in particular East of Kobe (e.g., Nishinomiya city), experienced positive permanent impacts after facing short-run negative effects in the immediate aftermath of the earthquake. This positive impact however did not result in increased employment in this region; rather, this region’s increased population is mostly employed in nearby Osaka (further to the East). Third, the peripheral areas seem to have been insulated from the large direct and indirect impacts of the earthquake.

Once the spatial and dynamic responses of each region, city and ward has been described, as we have done here, the next research task is to identify the policy determinants of these differing trajectories, and to further investigate whether possible policy shifts could have led to more favorable outcomes. Instead of relying on the ward-level dataset we used, other alternative sources of information and methodology may yield additional insights about the process of recovery (or lack thereof) in Kobe post-1995, and especially on its policy determinants.

Two types of costs associated with disasters are especially important, the direct irreversible costs、mostly mortality and morbidity, and the long-term or permanent costs, as they impose large permanent impacts on human wellbeing in the affected regions.[12] Our results here suggest that large catastrophic shocks, such as the 1995 Kobe earthquake, impose long-term/permanent costs on the affected region. These costs are typically not clearly identified and are thus not considered when assessing the benefits from disaster risk reduction and mitigation policies. This failure leads to under-investment to reduce risks from disasters, and in trying to mitigate their impacts. Maybe more importantly and less obviously, we also believe that this failure to recognize the long-term permanent impacts leads to complacency during the post-disaster recovery process itself. Policymakers and the public believe that recovery will be achieved, and are thus mostly making policy and electoral decisions based on short-term considerations rather than in an attempt to guide this long-term process to a more successful conclusion.

A different concern and motivation for our research agenda is the well-documented increasing economic costs of natural disasters (e.g., 14), even if there is uncertainty regarding the reasons

[12] The few papers that have examined long-term impacts of natural hazards include (11), (12) and (13).

for this trend. The socio-economic dynamics we investigated here are bound to become more important in the future, even if some of the more dire predictions regarding the impact of climate change on extreme climatic events do not materialize (15). Our publics, our governments, our international organizations, and the international agreements and covenants we agree on (most relevant is the Hyogo Framework for Action[13]) must take into account these long-term permanent impacts in guiding future actions.

[13] The HFA, a 10 years agreement whose aim was "to make the world safer from natural hazards," is to expiring in 2015, and a new framework agreement is currently being negotiated.

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**Additional figures available in appendix**