What happened to Kobe?

A reassessment of the impact of the 1995 earthquake in Japan

William duPont IV*
Department of Economics
University of Hawaii at Manoa

Ilan Noy**
Department of Economics
University of Hawaii at Manoa
&
School of Economics and Finance
Victoria Business School
Victoria University of Wellington

(January, 2013)

Abstract: The received wisdom is 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. We re-evaluate the evidence using a new methodology, synthetic control, and find a persistent and still continuing adverse impact of the quake on the economy of Kobe more than 15 years after the event. Using the methodology developed by Abadie et al. (2010), we construct counter-factual dynamics for the Kobe economy. We identify a decline in per capita GDP that is attributable to the quake and is persistent, long-term, and clearly observable even 13 years after the quake. GDP per capita for 2008 was 400,000 yen per person lower (12% decrease) than it would have been had the earthquake not occurred. Importantly, this adverse long-term impact is identified in a wealthy region of a developed country, and with the backing of a deep-pocketed fiscal authority.

JEL: O11, Q54, Q56, R11
Key words: Natural disaster, earthquake, Kobe, Great Hanshin, long-run

* Corresponding author: 2424 Maile Way, Honolulu, HI 96822; Tel: 1-808-956-8496; Fax 1-808-956-4347; wdupont@hawaii.edu.
** We thank seminar audiences at Monash University, Motu/GNS, Reserve Bank of New Zealand, University of Auckland, University of Canterbury, and University of Hawaii, and in particular to Yasuyuki Sawada as a conversation with him planted the seed idea for this project. Noy's work was 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, SOEST, under Institutional Grant No. NA09OAR4170060 from NOAA Office of Sea Grant, Department of Commerce. The views expressed herein are those of the authors and do not necessarily reflect the views of NOAA or any of its sub-agencies.

What happened to Kobe? A reassessment of the impact of the 1995 earthquake in Japan

"Although the Kobe earthquake was an urban natural disaster of unprecedented economic magnitude, recovery proceeded with generally unexpected speed….these responses appear to have led the recovery and countered any macroimpact of the quake."

(Horwich, *Economic Development and Cultural Change*, 2000, p. 535)

1. Why Kobe?

The March 2011 catastrophic earthquake and tsunami in the Tohoku region of Japan has horrified all of us. In the weeks following this tragedy, there was much discussion in the media and among policymakers about the disaster's likely long-term economic impact. In any attempt to predict the impact on the region, the obvious comparison was the devastating earthquake that hit Kobe on January 17, 1995.[1] At the time, this was the most destructive natural disaster to hit a high-income economy for many years. The received wisdom about the Kobe earthquake and its aftermath can be summarized thus:

> "The quintessential example comes from Japan itself: in 1995, an earthquake levelled the port city of Kobe, which at the time was a manufacturing hub and the world's sixth-largest trading port. The quake killed sixty-four hundred people, left more than three hundred thousand homeless, and did more than a hundred billion dollars in damage (almost all of it uninsured). There were predictions that it would take years, if not decades, for Japan to recover. Yet twelve months after the disaster trade at the port had already returned almost to normal, and within fifteen months manufacturing was at ninety-eight per cent of where it would have been had the quake never happened."[2]
>
> James Surowiecki, The New Yorker, 3/28/2011

[1] The destruction wrought by the earthquake destroyed much in other nearby cities as well. Throughout this paper, we (inaccurately) refer to the event as the Kobe earthquake and to our estimates as measuring the impact on Kobe, while in fact we measure the impact on Hyogo prefecture (Kobe is the largest city in the prefecture).

[2] Similarly: ""A 1995 earthquake in Kobe, Japan, caused an estimated $100 billion in damage. Within 15 months, manufacturing activity was back at 98 percent of its pre-quake levels, according to a 2000 paper by George Horwich, a professor at Purdue University. 'Destroy any amount of physical capital, but leave behind a critical number of knowledgeable human beings whose brains still house the culture and technology of a dynamic economy, and the physical capital will tend to re-emerge almost spontaneously,' Mr. Horwich wrote in the paper…" (Appelbaum, NY Times, 3/15/2011). Similar statements can be seen in other media, including the Wall Street Journal, The Economist, and the all-pervasive Wikipedia (accessed 1/17/2012).

Immediately after a previous catastrophic event, the 2004 tsunami in South-East Asia, Nobel Prize winner Gary Becker similarly wrote: ""The Kobe earthquake of 1995 killed over 6,000 persons, and destroyed more than 100,000 homes, still the economic recovery not only of Japan but also of the Kobe economy was rapid."

Much of this view can be traced to a paper by George Horwich published in *Economic Development and Cultural Change* that analyzed the Kobe event a few years afterwards. Horwich concluded that the devastation did not have much long-term impact on the Japanese economy, but like Becker later, further claimed that it did not have much impact on Kobe itself beyond the first couple of years.

Here, we re-evaluate the evidence to examine whether the 1995 earthquake had no long term economic impact on the Kobe region. Without spoiling too much, we already note that we believe the evidence shows a persistent and still continuing adverse impact of the quake on the economy of Kobe more than 12 years after the event. This conclusion, and the subject of our investigation more generally, is not only interesting for Japanese policymakers and the peoples of Kobe or Tohoku; the evidence we present is also relevant for any assessment of the long term impact of any large exogenous adverse shock. It also informs us about the alternative ways people may respond to these shocks, and how these choices help shape future economic trajectories.

We use a methodological innovation recently formalized in Abadie, Diamond and Hainmueller (2010, henceforth ADH); a paper that investigated tobacco taxes in California.[3]

[3] The first use of the synthetic control methodology is Abadie and Gardeazebal (2003), a paper that investigated the impact of ETA terrorism in the Basque. Abadie et al. (2012) examine the impact of German re-unification using

The methodology is based on simulating conditions after an exogenous event (in their case, a change in the tax rate) based on the relationship to a control group (other U.S. states). The ADH methodology presents an estimation technique that allows us to construct a no-disaster counterfactual and thus measure in detail the impact of the disaster itself.

Kobe is worth investigating with the ADH methodology for several reasons: (1) it was one of the largest disasters of the past 50 years, in terms of the monetary value of the direct destruction wreaked, and there is now a wealth of detailed post-disaster economic data that enables our long-horizon investigation; (2) the earthquake was both unexpected and unusually large, and thus clearly an exogenous event; (3) since destruction was limited to a very specific geographical region that is clearly associated with an administrative region, the other Japanese prefectures, which were not impacted at all, provide an ideal control group;[4] and (4) another careful look at Kobe will also provide us some clues about the likely long-term impact of the Tohoku/Sendai tsunami and about the future consequences of natural shocks that are likely to occur in Japan and elsewhere in the developed world.[5]

In the next section, we discuss relevant empirical work regarding the impacts of large disaster events. The interested reader can also consult a more comprehensive recent survey (Cavallo and Noy, 2011). In section 3 we describe the economy of the city of Kobe as well as the earthquake's initial impact. Section 4 details the ADH synthetic control methodology while

---

the same methodology, while Pinotti (2012) uses the same to estimate the cost of the Mafia on economic activity in Southern Italy.

[4] The nearby city of Osaka was affected by the quake, even if relatively mildly; we do not use Osaka as part of our control group.

[5] There is a significant body of research that finds that disasters affect poorer developing countries much more adversely in the short-run. Thus, we view our findings about Kobe as a lower-bound in terms of the likely long term impact of a catastrophic event on a specific region in a developing/poorer country.

section 5 describes the data. Results are reported in section 6 and the last section includes reports on robustness, caveats, and conclusions.

2. Economic Consequences of Large Disasters

Research on disasters and their long-term economic impact is sparse with few papers interested in any long-term trajectory or systematically examining the continuing dynamics of the economy following disaster events.[6] The difficulty, of course, is to separate developments, even if these involved dramatic shifts, from those that would have occurred even if the disaster had not.

Skidmore and Toya (2002), in a widely mentioned paper, find a positive association between disaster frequency and long-run GDP growth, which they interpret as caused by a creative destruction mechanism that leads to a speeding-up of adoption of new technologies and improvement in infrastructure. On the other hand, Noy and Nualsri (2007) and McDermott et al. (2011) use panel data techniques and find, on average for developing countries, an adverse long-run effect on GDP growth.

One other paper, Cavallo et al. (2012) uses the same ADH methodology to examine the average impact on the national economy of catastrophic natural disasters using a cross-country group of disaster events. They conclude that the evidence on a long-term adverse effect is likely driven by political regime changes which followed some large natural disasters. The proto-typical example they identify is the large earthquake in Iran of 1978, which was then quickly

[6] A large number of papers examine the short-term impact of specific disaster case-studies; and there is some comparative research on the short-term impact of disasters more generally (e.g., Noy, 2009 and Strobl, 2012). All of these say little about any long-term impact.

followed by the Islamic Revolution of 1979 and the Iran-Iraq war that started in 1980. Beside these events, they fail to find any evidence, even from catastrophic disasters, of long-term impact on national per capita incomes.[7]

A series of papers, initially inspired by Davis and Weinstein (2002), investigated the long-term impact of large-scale war-related destruction using geographically-detailed bombing data from World War II Japan (Davis and Weinstein, 2008), the American-Vietnam War (Miguel and Roland, 2011), and World War II Germany (Bosker et al., 2007). The first two papers failed to find any long term impact of the bombing campaigns on the distribution of economic activity; while the latter identifies evidence of long-term adverse impact of city destruction in Germany on city-size distribution.

To summarize, the literature on the long-term impact of economic shocks is inconclusive, but the weight of the evidence suggests no lasting impact of even catastrophic shocks at the national level. Papers that have examined longer run labor market effects have also failed to find any negative or positive impact beyond the first year. Several papers, however, do point to some potentially long-term impacts at the local/regional level.

On Kobe, as we already pointed out, the received wisdom, at least outside of Japan, is that the city recovered very quickly, and that there were no long term impacts of the earthquake on the local economy (except some re-distribution of population and economic activity across city districts; e.g., Aldrich, 2011). Chang (2010), and Beniya (2007) examine the time-series data for Kobe following the disaster, and measure the impact of the event by

[7] Lack of data on small island states does raise the caveat that for these states; disasters are comparatively much larger and therefore may impose long-term costs.

comparing the Kobe dynamics to what happened to the aggregate national economy (i.e., implicitly assuming the Kobe would have followed nation-wide trends without the disaster). Both papers note a long-term adverse effect on gross regional product of the Kobe region (this effect disappears by 2005 in the latter work); but given their methodological approach, the statistical robustness of either papers' findings is not well established.

Several works by Ohtake and co-authors examine labor and income data at the individual/household level. They conclude that the Hanshin Earthquake had long-lasting adverse effects on individuals and households in this region (Ohtake et al., 2012a and 2012b; Kohara et al., 2006).

3. Kobe and the 1995 Earthquake – an Economic Overview

Kobe is located to the northwest of Osaka, the second largest city in Japan. Though it is, to some extent, part of the greater Osaka area, Kobe is a major city in its own right. Prior to the earthquake Kobe had a population of around 1.5 million, just over a quarter of Hyogo Prefecture's 5.47 million inhabitants. The economy of the city was mainly centered on Kobe's port, which accounted for about 39% of its Gross Industrial Product and was ranked first in Japan and sixth worldwide in terms of cargo throughput (Chang, 2000). Additional prominent industries in 1995 included steel, sake, non-leather shoe manufacturing, tourism and fashion (Olshensky et al., 2005).

On January 17th, 1995, in the early morning, a short but powerful earthquake hit the city (the epicenter was 20 km away in the northern part of Awaji Island). Over 6,400 people lost their lives, 4,571 in Kobe itself; the value of infrastructure and physical capital destroyed was estimated at US $95-147 Billion; roughly 2.5% of Japanese GDP at the time (Freeman et al., 2003). The port suffered severe damage from the earthquake, losing nearly all of its container berths.[8] None of Kobe's major industries were spared. Many of the large manufacturers suffered damage to their factories, about 80% of non-leather shoes factories were damaged, and half of the sake breweries were severely damaged. Additionally one third of Kobe's shopping districts and one half its markets were heavily damaged. (City of Kobe, 2011)

Today, many of Kobe's important industries prior to the earthquake are still a large part of the city's economy, though many have not fully recovered. Though the port was completely rebuilt by March 1997—back to 98% capacity—as of 2009 the number of cargo ships handled had still not returned to pre-earthquake levels, reaching a peak of 87.7% in 2008. Mining and manufacturing was only 81.3% compared to pre-earthquake levels, non-leather shoe production volume was only 60.4% of what it was as of November 2010. In October 2010, Sake breweries shipped less than 50% of what they did prior to the earthquake. Department stores have also not recovered; their sales as of November 2010 were only three quarters of what they were prior to the earthquake. Only tourism has seen any increase, in 2009 incoming tourists to the city were at 123.6% the level they were in 1994 (City of Kobe, 2011). These before-after changes, of course, cannot be confidently attributed to the quake, and could have been caused by other forces.

Using microeconomic household data, Sawada and Shimizutani (2008 and 2011) examine household survey data and show that credit-constrained households persistently

---

[8] It was not until March 1997, over two years after the earthquake, that its capacity would be fully restored (Chang 2000).

reduced post-quake consumption. Even if these observed changes were caused by the quake, they do not necessarily imply that the earthquake had any aggregate adverse effect on the local economy. It may well be the case that the quake speeded up the Schumpeterian creative destruction process, and that the declining industries should have been contracting for aggregate efficiency reasons. The received wisdom appears to be that this was indeed the case.

4. Methodology – Synthetic Control for Comparative Case Studies

Kobe's earthquake occurred a few years after Japan had already entered a prolonged and painful recession—the 'lost decade' that followed the collapse of the real-estate and stock-market bubbles of the late 1980s. To separate the impact of the earthquake from the effect of the Japanese recession and accurately measure the impact of the disaster on Kobe's economy, a counterfactual scenario for Kobe without the earthquake has to be established. Assuming that Kobe would have continued on its pre-1995 trajectory is difficult to justify. We employ the ADH methodology to develop predictions for a 'synthetic' Kobe economy.

One of the ADH algorithm's advantages is the ability to use the synthetic control methodology to estimate unbiased coefficients with a modest amount of information (few pre-event observations). In Abadie et al. (2010), which formalized the validity of the synthetic control methodology, the analysis is conducted with annual data from 1975 to 2009 while the event of interest occurred in 1995. The time-series length (T_0) of pre-event data available for our study of Kobe is very similar to that of Abadie et al. (2010), with 20 years of pre-disaster data.

Another key element of the synthetic control methodology is the presence of an appropriate control group. In comparative case studies that aim to identify the impact of a specific event, the research necessarily relies on a surprising/exogenous event of a relatively large magnitude and the presence of comparative units of observations that do not experience the event. The Kobe earthquake, the most destructive natural disaster in a developed country in many years (barring two later events: Hurricane Katrina in 2005 and the Tohoku tsunami of 2011), is clearly a relatively large exogenous event and, as previously discussed, Kobe has natural comparative units of observation. The other Japanese prefectures are both subject to the same external shocks and institutional and legal infrastructures, and have not directly experienced the event. Of course some prefectures are more similar to Kobe than others—the algorithm we employ is exactly aimed at identifying these similarities and differences to construct the synthetic counterfactual.

4.1 Empirical Model

Let Y_{it} be the outcome variable that shall be evaluated based on the earthquake's impact for prefecture *i*, (with *i*=1 for Hyōgo and *i*>1 for the other Japanese prefectures) and time *t* (for time periods $t = 1,...,T_0,...,T$; where T_0 is 1995); while 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.[9] The model requires the assumption that the event had no effect on the outcome variable before it occurred at time T_0 $(Y_{it}^I = Y_{it}^N \forall t < T_0)$. Although this last assumption is unjustified in

[9] This description is a modified version of Abadie *et al.* (2010). To simplify comparison, we follow their notation where *I* denotes intervention (event occurring) and *N* denotes non-intervention (event not occurring).

cases where disaster impact is frequent and therefore expected, Kobe has not experienced a similar event in a very long time, and was widely perceived in Japan as a low-earthquake-risk region. The Kobe event ended up being the largest earthquake in Japan since the Kanto earthquake of 1923.

The observed outcome is defined by $Y_{it} = Y_{it}^{N} + \alpha_{it} D_{it}$ where α_{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 $t \geq T_0$ and $i = 1$; and D_{it}=0 otherwise). The aim is to estimate α_{it} for all $t \geq T_0$ for Hyōgo prefecture (*i*=1). The problem is that for all $t \geq T_0$ it is not possible to observe Y_{1t}^{N} but only Y_{1t}^{I}.[10]

Although there is no way of accurately predicting the prefecture-specific determinants of Y_{it}, the structure of the economies is fairly similar and the external shocks affecting them (except for the earthquake) are similar as well (except for mean zero iid shocks ε_{it}). Following ADH, suppose that Y_{it}^{N} can be given by the following factor model:

$$Y_{it}^{N} = \delta_t + \theta_t Z_i + \lambda_t \mu_i + \varepsilon_{it} \qquad (1)$$

where Z_i is a vector of observed covariates (variables such as GDP per capita, population, etc.)[11] and μ_i is a vector of unknown factor loadings. Furthermore, let $W = (\omega_2, ..., \omega_{J+1})'$ be a vector of weights allocated to the different prefecture observations such that $w_j \geq 0$ for

[10] For all other observations: $D_{it} = 0$, so $Y_{it} = Y_{it}^{N}$.

[11] A full list of the additional variables we can be found further down and in the data appendix.

$j = 2,...,J+1$ and $\sum_{j=2}^{J+1} \omega_j = 1$. A synthetic control, as defined by this methodology, is a weighted combination of the controls group 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

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

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

$$\sum_{j=2}^{J+1} \hat{\omega}_j Y_{j1} = Y_{11},..., \sum_{j=2}^{J+1} \hat{\omega}_j Y_{jT_0} = Y_{1T_0} \text{ and } \sum_{j=2}^{J+1} \hat{\omega}_j Z_j = Z_1 \quad (3)$$

Abadie et al. (2010) show that under acceptable assumptions, given equation (3), then subtracting equation (2) from equation (1) yields the following

$$Y_{1t}^N = \sum_{j=2}^{J+1} \hat{\omega}_j Y_{jt} \quad (4)$$

Furthermore they prove that the equality will hold for all t given that the number of preintervention periods is large enough.[12] In our case we have 20 periods of pre-disaster data which is comparable to other work done while using this method. Therefore we can use

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

as an estimator for $\alpha_{1,t}$. Abadie et al. (2010) note that it is only possible for equation (3) to hold if it belongs to the convex hull of the related variables. That means that the observations for

[12] For the complete proof see Abadie et al. (2010) Appendix B.

the treated unit must fall within the range of the control units' respective variables. This is not an issue when looking at Hyogo as there are other prefectures which are more prosperous, such as Tokyo, as well as others that are less so, such as Kumamoto. Just because the observations fall within the convex hull does not mean that equation (3) will hold exactly, thus the goal then is to select a set of weights for which it holds approximately. Furthermore, it may be the case that equation (4) will not hold either; however, this can be verified by checking both the goodness of fit over the pre-treatment period as well as the predictor balance for all of the variables in Z_1.

The key then is to construct a set of weights such that both equations (3) and (4) hold approximately. To do this a set of weights W need to be selected that minimize the distance between the treated unit X_1 and the synthetic control X_0W during the pretreatment period. We choose W such that the following equation is minimized:

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

where V is some $(k \times k)$ symmetric and positive semidefinite matrix. In this particular case k is the number of explanatory variables. The choice of V is very important as it can greatly impact the mean square prediction error. We use a data-driven method to obtain V such that the mean squared prediction error is minimized for the period prior to the earthquake. For robustness, in the data-driven method we use three different initial values[13] to obtain V and then use the best result as our final value.[14]

[13]We use a regression based version, an equal weighted version, and one which uses the ml search function.

[14] In all of our estimations, we use the Synth STATA routine available at: http://www.mit.edu/~jhainm/software.htm#Synth.

There are likely to be some feedback loops whereby a decrease in economic activity in one region reduces trade and therefore economic activity in other regions. In this case, should we observe an adverse effect of the disaster on, for example GDP, we should interpret this as the lower-bound of the actual adverse impact (since without the event the synthetic control would have also been trending higher). In case of zero-sum variables (like population) however, any finding of a reduction in population relative to control should also be interpreted with care, though in this case the procedures identifies the upper-bound of the likely impact. These observations, however, do not detract from the relevance of our findings given the adverse impacts we document.

4.2 Statistical Significance of Results

The usual statistical significance of our reported results, based on regression-based standard errors, is not relevant in this case since the uncertainty regarding the estimate of $\hat{\alpha}_{it}$ does not come from uncertainty about the aggregate data. Uncertainty in comparative case studies with synthetic control is derived from uncertainty regarding the ability of the post-treatment synthetic control to replicate the counterfactual post-treatment in the treated observations.

One of the advantages of using this methodology is that positive weights are only assigned to a handful of control units. These controls can then be evaluated on whether or not they make an appropriate match for the treated unit in both the pre- and post-treatment periods. In this particular case we find that Fukuoka, Aichi, and Shizuoka, regularly appear as contributors to the synthetic control for Hyogo. Both Aichi and Shizuoka have major cities along the Tokaido corridor for which the city of Kobe serves as a somewhat terminal point as a satellite city of Osaka. It is not unreasonable to have them appear as potential representatives for Hyogo. Fukuoka, on the other hand, may seem out of place. Fukuoka is the northern most prefecture in Kyushu, and thus on a separate island from Hyogo. It also lies far away from Japan's busy Tokaido corridor. Upon closer inspection, however, it does share some similarities to Hyogo. Both prefectures have very similar levels of population and both have large port cities (Kobe and Fukuoka City) that take up roughly 20-30% of their population. Furthermore, we also see similar behavior between both prefectures in key variables over time.

Following Abadie et al. (2010), we further use permutation tests to examine the statistical significance of our results. We separately assume that every other Japanese prefecture in our sample is hit by a similar (and imaginary) event in the same year. We then produce counterfactual synthetic control for each "placebo disaster." These synthetic controls for the placebos are then used to calculate the impact of the placebo disasters ($\hat{\alpha}_{it}^{P}$) in every year following its (non)-occurrence.

There are cases amongst the placebo group for which the synthetic control methodology is not applicable due to the fact that it is highly unlikely that every single control unit would fall within the convex hull. The most notable in our case is Tokyo, for which no combination of weights from the remaining prefectures can replicate the actual data during the pre-treatment period.[15] Therefore, we follow ADH and remove prefectures for which the methodology is a poor match from the placebo comparison.

Determining which placebos would be considered 'poor matches', however, can be arbitrary. Abadie et al. (2010) propose that placebos should be considered or dropped relative to the fit of the treated unit during the pre-treatment period. The goodness of fit in the case of synthetic control is determined by the mean squared prediction error (MSPE), where the smaller the MSPE the better the fit. Abadie et al. (2010) choose to drop placebos where the MSPE exceeds 20 times, 5 times, and 2 times the value of the MSPE of the treated unit. We have chosen to follow this pattern, with the exception that we omit the case of 20 times exemption, as there are no prefectures which have MSPE 5 times greater than that of Hyogo, with the exception of Tokyo.[16]

We plot these placebo impacts together with the actual impact of the Kobe earthquake as calculated in relation to its synthetic counterfactual. These figures are used to examine the distribution of predictions in cases in which the treatment (the disaster) did not occur relative to the case it did (Kobe). Essentially, we investigate whether the $\hat{\alpha}_{1t}$ we estimated for Kobe is statistically different from the placebo $\hat{\alpha}_{it}^{P}$ for $i>1$.[17]

5. The Data

[15] Tokyo's size exceeds other prefectures to the degree that the weighting, that best replicates its data by minimizing the root mean square prediction error, is always 1 on the second highest prefecture and 0 on the remaining prefectures.

[16] The MSPE of Tokyo also routinely exceeds 20 times that of Hyogo.

[17] This placebo methodology is extended to multiple treated cases in Cavallo et al. (2012) to calculate the average impact size when there are multiple shocks (treated observations) and multiple controls (untreated observations).

The data used in this paper all originates from the Japanese Government's Statistics Bureau – see appendix A for details. The data concerning population is by prefecture and is available annually and based on both census data (taken every five years) and survey based estimation as of October 1st of each year. The data covering the period 1975 to 2009 was used.[18] In addition to population, we also compiled data covering prefectural GDP and income, construction, residential housing prices, rent, and migration.

The data used for GDP and income was also collected annually by prefecture. Unlike other data sets, the prefectural GDP and income data were not available in single contiguous sets. The first set covered F.Y. 1975 through 1999. The second set covered F.Y. 1990-2003 and was also based at current prices in millions of yen.[19] The remainder of the data was obtained from the Statistical Yearbook for 2011 (which covered F.Y. 2005 through 2007), the archived Statistical Yearbook for 2010 (which covered F.Y. 2004 through 2006), and the Statistical Yearbooks (2007, 2008, and 2009) accessible via the Internet Archive to fill in the remainder years. Furthermore, GDP and income data was compiled using 'current prices'. Gross expenditure data for prefectures at constant prices was also available; however, the two previous years were not included in the statistical yearbook. For cases when overlapping data was available, it was not consistent from year to year; therefore, no reliable growth rate could be obtained.[20] Growth rates were taken from the later sets then combined with the data in the earlier set to create a smoothed out data set.

---

[18] Some data collected was taken for the Fiscal Year (F.Y.). The fiscal year in Japan runs from April 1st until March 30th. In this particular case the Great Hanshin Earthquake occurred in January of F.Y. 1994.

[19] The current prices in this set are based on the data compiled for the 2007 yearbook.

[20] This can be seen by checking the Japanese Statistical Yearbook by using the Internet Archive (web.archive.org).

The data used for construction was compiled annually by prefecture. Specifically, it is the value of construction work completed by original contract. Similar to the GDP set this series was also not in a single contiguous set. The historical set covers the time period from F.Y. 1956 to 2003. Two more sets of data for F.Y. 2006 and 2007 were available via the Statistical Yearbooks for 2010 and 2011 respectively and the data concerning F.Y. 2004 and 2005 were accessible via the 2008 and 2009 Statistical yearbooks, accessible via the Internet Archive. Furthermore, the data available in the Statistical Yearbook is available in six separate pieces that had to be summed to match the historical set.[21]

The data used for residential prices is the average price of housing land by residential site by prefecture. Similar to both the GDP and Construction sets, this series was also not in a single contiguous set. The historical set covers the time period from 1980 to 2004. Two more sets of data for 2008 and 2009 were available via the Statistical Yearbooks for 2010 and 2011 respectively and the data concerning 2005 through 2007 were accessible via the 2007, 2008 and 2009 Statistical yearbooks accessible via the Internet Archive.

The data used for rent was collected every five years by prefecture. Specifically it is the rent per tatami unit (a measure of area) calculated in yen. The historical set covers the time period from 1963 to 2003. The most recent data for the year of 2008 was available via the Statistical Yearbook for 2011. The final set that we used covered the period from 1978 to 2008. The data used for Government Expenditure was collected annually by prefecture and is

[21] Accuracy was checked by using older Statistical Yearbooks accessible via the way back machine to ensure that the values matched the Historical data.

denominated in millions of yen. The historical set covers the time period from F.Y. 1947 to 2008, though we use the data starting in 1975.

The data used for migration was collected annually by prefecture. This set consists of three figures: the number of people migrating within a given prefecture, the number of people migrating to a given prefecture from elsewhere, and the number of people migrating from a given prefecture to elsewhere. Similar to other sets this series was also not in a single contiguous set. The historical set covers the time period from 1980 to 2004. The data concerning 2005 and 2007 were accessible via the 2010 Statistical Yearbook, and the data concerning 2006 was accessible via the 2009 Statistical yearbook accessible via the Internet Archive.

As previously noted, we do not use data for Osaka prefecture as part of the control group since it was directly affected by the quake. In addition, we also remove from the sample the data for the neighboring prefectures of Kyoto, Okayama, and Tokushima since all three appear to have been indirectly impacted by the earthquake. Including these prefectures may bias our results downward if these prefectures were affected adversely. If they were affected positively (since some of the economic activity transferred from Kobe to these prefectures) inserting them into the control group will lead to an exaggeration of the adverse impact of the earthquake on Hyogo. On balance, we observe no impact on the estimated impact on Kobe (see the online appendix[22]). The data for Mie Prefecture was also dropped since it deviates from its counterfactual in the 1990s pre-event data.

[22] This appendix is available at: https://sites.google.com/site/noyeconomics/research/natural-disasters

6. Findings: What Really Happened?

We start by examining what happened to population, since in some instances (e.g., Hurricane Katrina in New Orleans) the most immediate and important effect of the disaster on those who were not directly harmed or killed was to cause people to relocate. This relocation can then become permanent. In graying Japan, of course, the population trend is not linear, and an accounting of the counterfactual is clearly important. Figure 1 presents the actual population numbers and their synthetic counterfactuals and figures 9-10, discussed later, present the related inter-prefecture migration patterns of Hyōgo prefecture (henceforth referred to, inaccurately, as Kobe). We clearly observe a large movement of people away immediately following the earthquake, but population recovers fairly quickly, and returns to (almost) trend within 5 years (by 2000).[23]

Table 1 presents the weights we obtained for the different prefectures in calculating the counterfactual as defined in equation 3 (ω_j and *j*=2…*J*). Table 2 compares the balance of the predictors between the treated (Hyogo), the controls, and the weights average of the controls calculated as the synthetic control based on the weights presented in table 1. Table 3 summarizes the differences between Hyogo and its synthetic counterpart given in figure 1; while table 4 presented a comparison of the RMSPE of Hyogo and its synthetic control for the post-event period.[24]

Accompanying figure 1 is figure 2, which tests the statistical significance of our results by comparing the population gap (the difference between the actual and the counterfactual

[23] This result is interesting in as much as it contradicts what happened in New Orleans or elsewhere in the United States following destructive natural events (e.g., Coffman and Noy, 2012, Lynham et al., 2012, and Vigdor, 2008).
[24] The use of these statistics is discussed in Abadie et al. (2010 and 2012).

from figure 1) with the population gap for the placebo disasters in other prefectures. While the initial drop in population is clearly exceptional, the data beyond the first couple of years does not suggest that population today is necessarily much different than it would have been had the earthquake not occurred.

If people returned, did income recover as well? Generally, in high-mobility environments we expect people to respond to price/wage signals, so that the return to Kobe should have been preceded by an increase in incomes (or at least the return to the pre-disaster equilibrium when compared with other alternative locations/provinces). We do not find that. In figure 3 we describe the impact of the earthquake on GDP (and its related placebos in figure 4), while we focus on per capita GDP in figure 5. We observe that GDP per capita rose immediately after the disaster above its counterfactual, partially maybe as a result of the population movements, and partly as a result of the fiscal stimulus for reconstruction. Eventually, however, per capita GDP declined below the trend/counterfactual. We find that per capita GDP is still much lower 13 years after the earthquake than it would have been had the earthquake not occurred. By 2003, GDP per capita was 9% below the counterfactual and it continued to decline through 2008, when per capita GDP was 12% (400,000 yen) lower than it would have been had 'Old Kobe' still existed.

Table 5 includes the estimated weights for the other prefectures for the per capita GDP estimates, while table 6 includes the actual numbers for the estimated gap between Hyogo and its counterfactual as presented in figure 5. Figure 6 presents the per capita GDP gap comparison with the placebo disaster events. Clearly, the decline that we observe in per capita GDP is persistent, long-term, and observable statistically even 13 years after the quake.[25] When we sum this 'lost' per capita income over the period for which we have data (1996-2008), we find that over this 13 year period the cumulative loss is almost 70% of one-year's per capita income. In the aggregate for the years 1996-2008, Hyogo prefecture lost about 172 Billion US$ as a result of the aftermath of the earthquake.[26] This amount is significantly larger than the highest estimates for the direct loss due to the earthquake's destruction in 1995.

Intriguingly, this result is apparent in spite of a massive infusion of fiscal resources into the region. Figure 7 describes local government expenditures in the prefecture, and compares it to the counterfactual. Our model enables us to clearly track the pre-earthquake level of expenditures in the region, including the increase in expenditures in the early 1990s. After 1995, the region receives a massive fiscal stimulus, at least a 15% increase each year following the disaster. As can be seen in figure 8, this fiscal stimulus was unique to Hyogo. As already described, however, this large fiscal stimulus was still unable to provide the boost necessary to bring the region back to its pre-quake potential.[27]

Figure 9 shows the short-lived spike in out-migration from Hyogo; curiously, residents only chose to leave as a result of the direct destruction, but the later economic decline that we identified did not lead to additional out-migration (above the predicted counterfactual level).

---

[25] Corresponding to these impacts on population and per capita incomes, we find that housing rental prices went up after the quake, but eventually declined and are now below the hypothetical (synthetic) no-quake Kobe. These results are not presented but are available upon request.

[26] We calculate the sum Yen amount that we estimated as the difference between the synthetic and the actual prefecture income. We convert it to US$ using the average YEN/USD exchange rate for that period.

[27] The additional spike in government expenditures in 2005 is a result of the fact that some of the transfers from the central government to Hyōgo prefecture immediately after the quake were classified as 10 year loans. In 2005, the central government assumed these liabilities and that was recorded again (information obtained from personal correspondence with the Ministry of Internal Affairs and Communications).

The data for migration into the prefecture, in figure 10, shows the expected decline in 1995, and the consequent increase above the counterfactual in the reconstruction years 1996-2000. After 2000, however, it seems that the documented economic decline led to a decrease in the amount of people moving into the prefecture.

7. Robustness, Caveats and Conclusions

In a wealthy and developed region and with the backing of a deep-pocket fiscal authority, the 1995 Kobe earthquake still resulted in significant adverse long-term impact with a reduction of 12% in per capita GDP, from which Hyogo prefecture has never fully recovered. These central results are robust to various iterations and alternative specifications that we did not present. All of these additional results are available on a companion web-appendix posted online.[28] In particular, we repeat the whole set of estimations (figures 1-10) using all available prefectures as controls (web appendix B), conducting a leave-one-out procedure when determining the list of included controls (web appendix C), and time-split estimations (web appendix D).

The presence of a large fiscal stimulus is important, given recent work that predicts that disasters are more likely to heavily impact poorer countries in the future. Poor developing countries are less likely to be able to adopt counter-cyclical fiscal policies; and this will inevitably make a large disaster's adverse consequences more severe. Haiti, following the January 2010 earthquake, is unlikely to receive its reconstruction needs, in spite of a massive international mobilization and well-publicized donor conferences (see Becerra et al., 2012).

[28] Available at: https://sites.google.com/site/noyeconomics/research/natural-disasters.

It is also important to note that we estimated the impact of the earthquake on Hyogo prefecture, and while Kobe is Hyogo's biggest city, the prefecture also includes many regions that were not affected by the earthquake (and several more cities that were – such as Nishinmiya and Ashiya). Thus, we can interpret our estimates as a lower bound on the true impact of the 1995 earthquake on the city of Kobe; since the impact we measured is the aggregate of those regions in Hyogo that were and were not directly impacted by the earthquake.

A new paper, von Peter et al. (2012), presents evidence using proprietary insurance data that suggest that insurance coverage matters substantially for the path of recovery. Insurance coverage ratio for the Kobe earthquake was very low, and that might explain some of the adverse impact we find. While insurance coverage was higher in the March 2011 Tohoku earthquake/tsunami, it was still quite low relative to, for example, the New Zealand's series of earthquakes in Christchurch in 2010-2011. For developing countries, a lack of access to explicit insurance or to a sufficient implicit ex-post one through big international bi-lateral and multi-lateral donors implies that the adverse impact of disasters is bound to be larger than the one we documented here.

While this analysis provides no specific recommendations on disaster mitigation, it sheds light on the 'true' costs of a disaster event. The true cost of the Kobe earthquake appears more than twice as large, for the region, as the estimates that are now the accepted figures for this event (95-147 US$B). The long-term impacts of disaster events are, in a sense, 'hidden' when focusing on aggregate national data or when examining only the direct and short-term costs. As this study documents, the long-term dislocations that disasters engender can be substantial and thus should not be ignored when cost-benefit analyses of disaster mitigation and resiliency programs are used to determine policy choices now, and into a future in which disaster patterns are likely to change.

8. References

Abadie, Alberto, Alexis Diamond, and Jens Hainmueller, 2010. "Synthetic control methods for comparative case studies: Estimating the effect of California's tobacco control program." *Journal of the American Statistical Association* 105(490):493-505.

Abadie, Alberto, Alexis Diamond, and Jens Hainmueller, 2012. "Comparative politics and the synthetic control method." Unpublished manuscript.

Abadie, Alberto, and Javier Gardeazabal, 2003. "The Economic Costs of Conflict: A Case Study of the Basque County." *American Economic Review* 93(1):112-132

Becerra, Oscar, Eduardo Cavallo and Ilan Noy, 2012. In the Aftermath of Large Natural Disasters, What Happens to Foreign Aid? *Review of Development Economics,* forthcoming.

Becker, Gary S., 2005. "...And the Economics of Disaster Management." *Wall Street Journal* (Eastern edition). New York, N.Y.: Jan 4, 2005. pg. A.12.

Beniya, Shohei, 2007. The evaluation of the status of disaster areas by using recovery indicators (in the case of the Great Hanshin-Awaji Earthquake). Paper presented at the 2nd International Cofnerence on Urban Disaster Reduction, November 27-29.

Bosker, Maarten, Steven Brakman, Harry Garretsen*,* and Marc Schramm, 2007. "Looking for multiple equilibria when geography matters: German city growth and the WWII shock." *Journal of Urban Economics* 61:152–169.

Cavallo, Eduardo, Sebastian Galiani, Ilan Noy, and Juan Pantano, 2012. "Catastrophic natural disasters and economic growth." *Review of Economics and Statistics,* forthcoming.

Cavallo, Eduardo, and Ilan Noy, 2011. "The economics of natural disasters - a survey." *International Review of Environmental and Resource Economics* 5(1):1-40.

Chang, Stephanie E., 2000. "Disasters and transport systems: loss, recovery and competition at the Port of Kobe after the 1995 Earthquake." *Journal of Transport Geography* 8(1): 53-65.

Chang, Stephanie E., 2009. "Urban disaster recovery: a measurement framework and its application to the 1995 Kobe earthquake." *Disasters* 34(2):303-327.

City of Kobe, 2011. *The Great Hanshin-Awaji Earthquake Statistics and Restoration Progress*. January 1, 2011.

Coffman, Makena and Ilan Noy, 2012. "Hurricane Iniki: Measuring the Long-Term Economic Impact of a Natural Disaster Using Synthetic Control." *Environment and Development Economics* 17(2): 187-205.

Davis, Donald, and David Weinstein, 2002. "Bones, Bombs, and Break Points: The Geography of Economic Activity." *American Economic Review* 92(5): 1269-1289.

Davis, Donald, and David Weinstein, 2008. "A Search for Multiple Equilibria in Urban Industrial Structure." *Journal of Regional Science* 48(1): 29–65.

Freeman, Paul K., Michael Keen, and Muthukumara Mani. 2003. "Dealing with Increased Risk of Natural Disasters: Challenges and Options." IMF Working Paper WP/03/197

Horwich, George, 2000. "Economic lessons of the Kobe earthquake." *Economic Development and Cultural Change* 48: 521-542.

Kohara, Miki, Fumio Ohtake, and Makoto Saito, 2006. "On Effects of the Hyogo Earthquake on Household Consumption : A Note." *Hitotsubashi Journal of Economics* 47(2): 219-228.

Lynham, John, Ilan Noy, and Jonathan Page, 2012. "The 1960 Tsunami in Hawaii: Long Term Consequences of a Coastal Disaster." Manuscript.

McDermott, Thomas K.J., Frank Barry, and Richard S.J. Tol, 2011. Disasters and Development: Natural Disasters, Credit Constraints and Economic Growth. ESRI Working Paper #411.

Miguel, Edward and Gérard Roland, 2011. "The long-run impact of bombing Vietnam." *Journal of Development Economics*, 96: 1-15.

Noy, Ilan, 2009. "The macroeconomic consequences of disasters." *Journal of Development Economics* 88(2): 221-231.

Noy, Ilan, and Aekkanush Nualsri, 2007. "What do exogenous shocks tell us about growth theories?" University of Hawaii Working paper 07-28.

Ohtake, Fumio, Naoko Okuyama, Masaru Sasaki, and Kengo Yasui, 2012a. "Impacts of the Great Hanshin-Awaji Earthquake on the Labor Market in the Disaster Areas." *Japan Labor Review* 9(4): 42-63.

Ohtake, Fumio, Naoko Okuyama, Masaru Sasaki, and Kengo Yasui, 2012b. "Measuring the long-lasting effect of natural disasters: The case of the 1995 Hanshin–Awaji Earthquake." Paper presented at the East West Center, December.

Olshansky, Robert B., Laurie A. Johnson, and Kenneth C. Topping with Yoshiteru Murosaki, Kazuyoshi Ohnishi, Hisako Koura, and Ikou Kobayashi, 2005. *Opportunity in Chaos: Rebuilding after the 1994 Northridge and 1995 Kobe Earthquakes*.

Pinotti, Paolo, 2012. "The Economic Costs of Organized Crime: Evidence from Southern Italy." Unpublished manuscript, Bocconi.

Sawada, Yasuyuki, and Satoshi Shimizutani, 2008. “How Do People Cope with Natural Disasters? Evidence from the Great Hanshin-Awaji (Kobe) Earthquake in 1995.” *Journal of Money, Credit and Banking* 40(2):463-488.

Sawada, Yasuyuki, and Satoshi Shimizutani, 2011. "Changes in durable stocks, portfolio allocation, and consumption expenditure in the aftermath of the Kobe earthquake." *Review of Economics of the Household* 9(4):429-443.

Skidmore, Mark, and Hideko Toya, 2002. “Do natural disasters promote long-run growth?” *Economic Inquiry* 40(4): 664-687.

Strobl, Eric, 2012. “The economic growth impact of natural disasters in developing countries: Evidence from hurricane strikes in the Central American and Caribbean regions.” *Journal of Development Economics* 97(1):131-140.

Vigdor, Jacob, 2008. “The economic aftermath of Hurricane Katrina.” *Journal of Economic Perspectives* 22(4): 135-154.

von Peter Goetz, Sebastian von Dahlen, and Sweta Saxena, 2012. “Unmitigated disasters? New evidence on the macroeconomic cost of natural catastrophes.” BIS working paper #394.

Figure 1: Population (# of people)

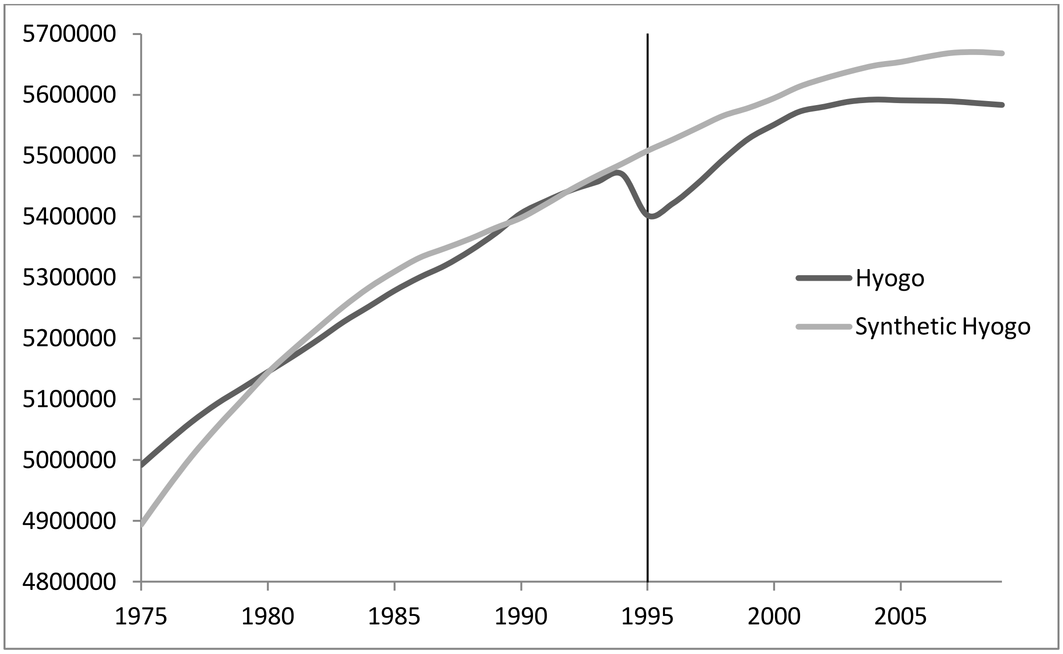

Figure 2: Placebo Population: RMSPE 2x Exclusion

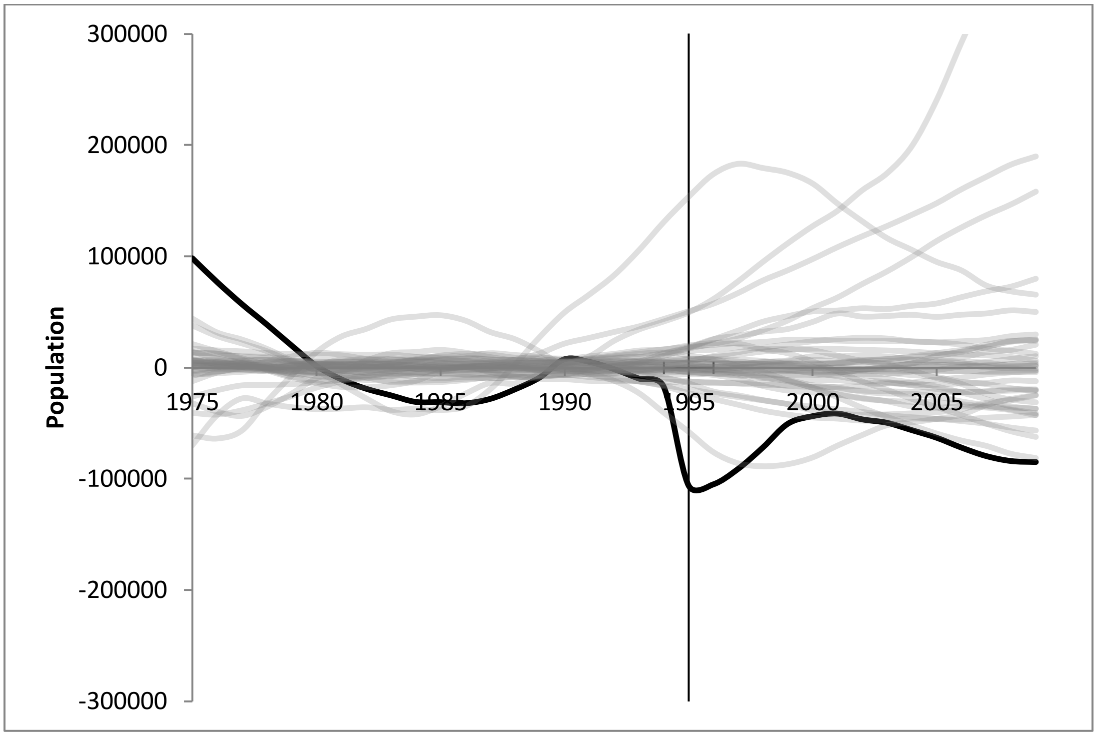

Figure 3: GDP (Millions of Yen)

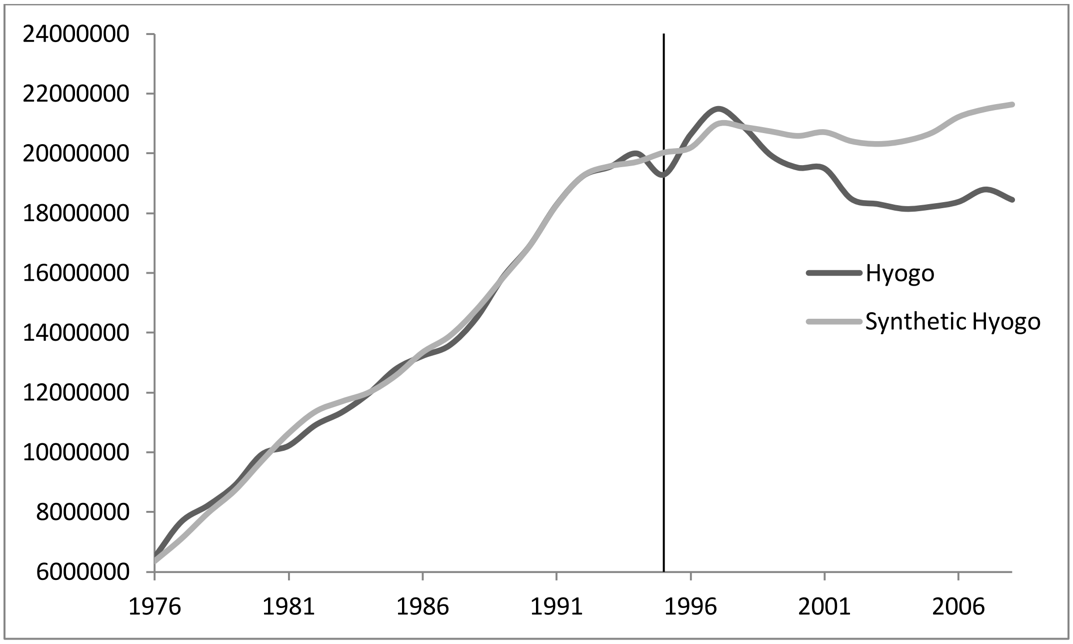

Figure 4: Placebo GDP (Millions of Yen): RMSPE 5x Exclusion / 2x Exclusion

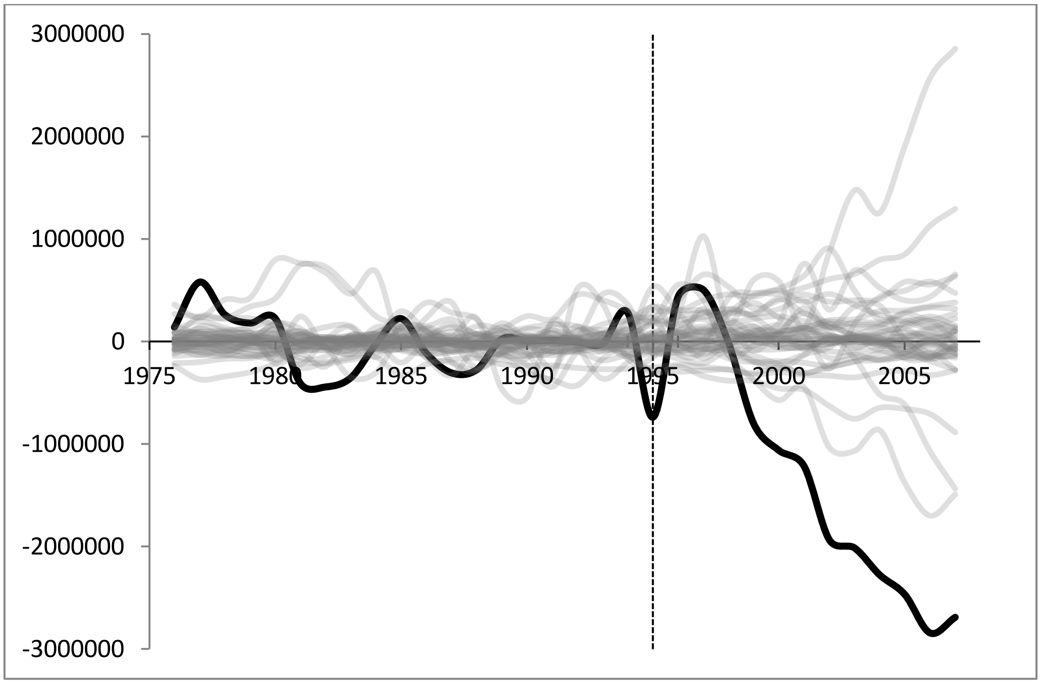

Figure 5: GDP per capita (Millions of Yen per Person): Kobe

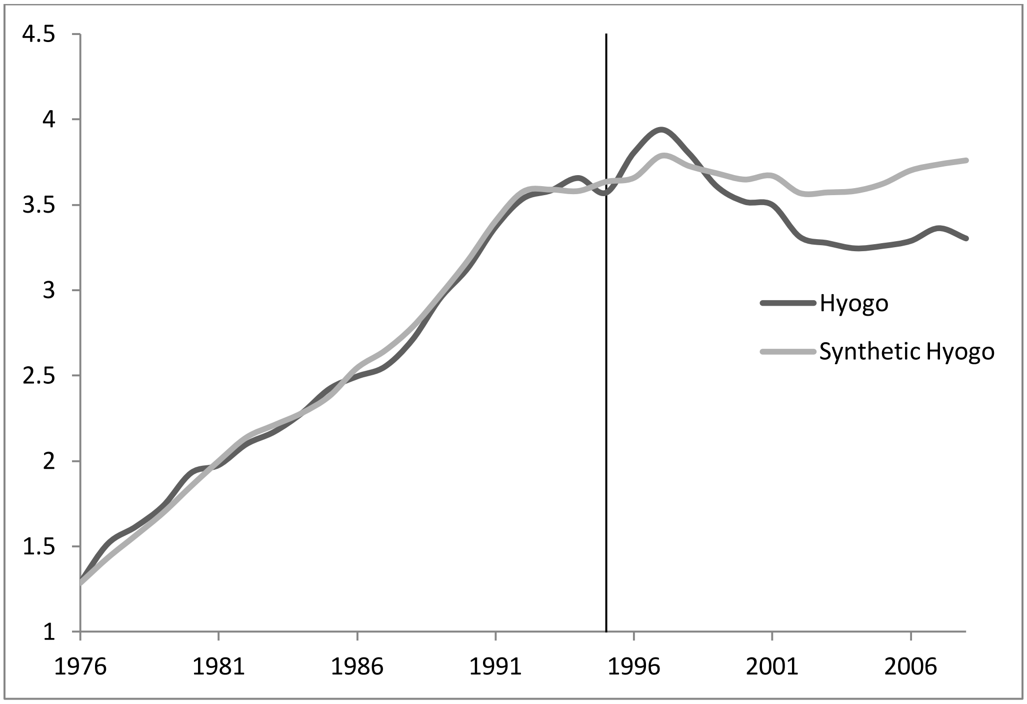

Figure 6: Placebo GDP per capita (Millions of Yen per Person): RMSPE 2x Exclusion

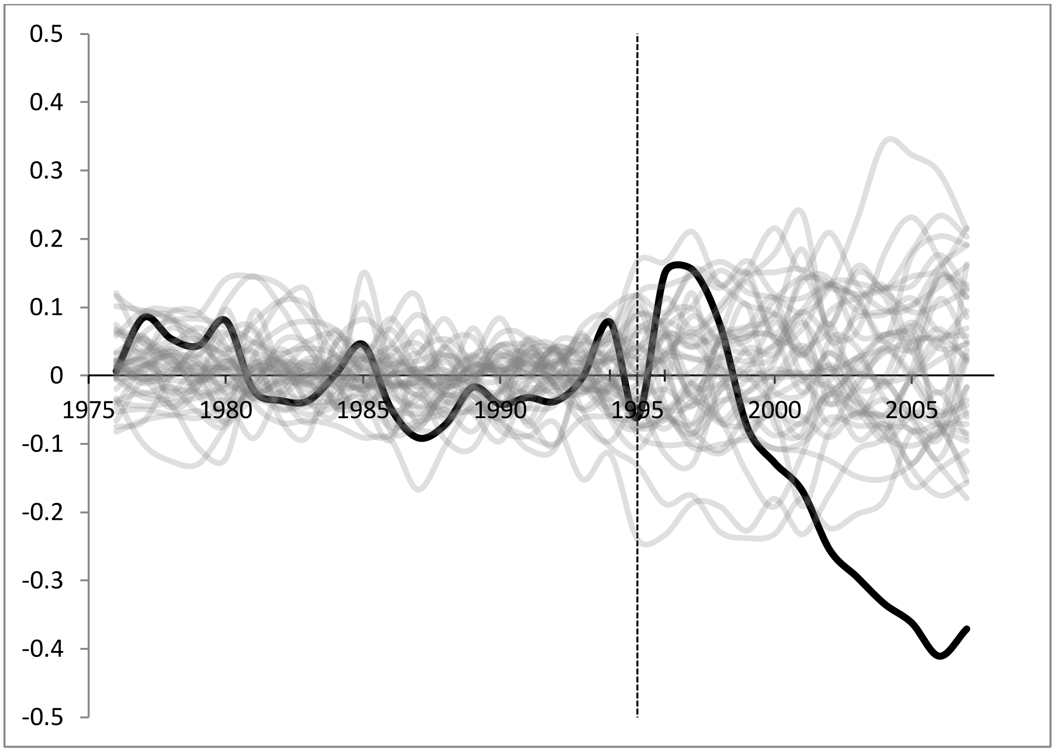

Figure 7: Local Government Expenditures: Hyogo Prefecture

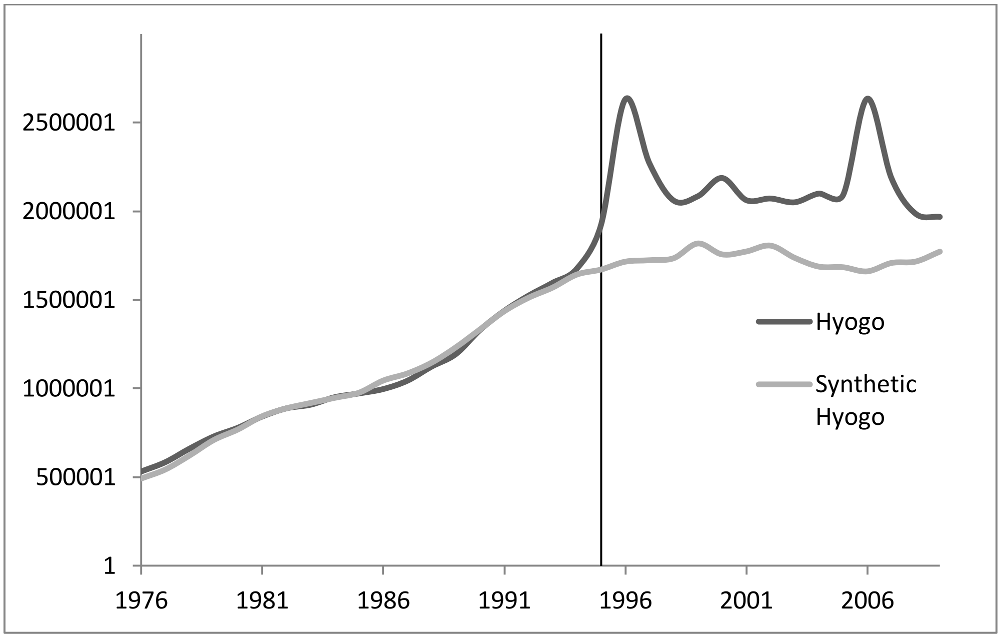

Figure 8: Placebo Local Government Expenditures (Millions of Yen): RMSPE 2x Exclusion

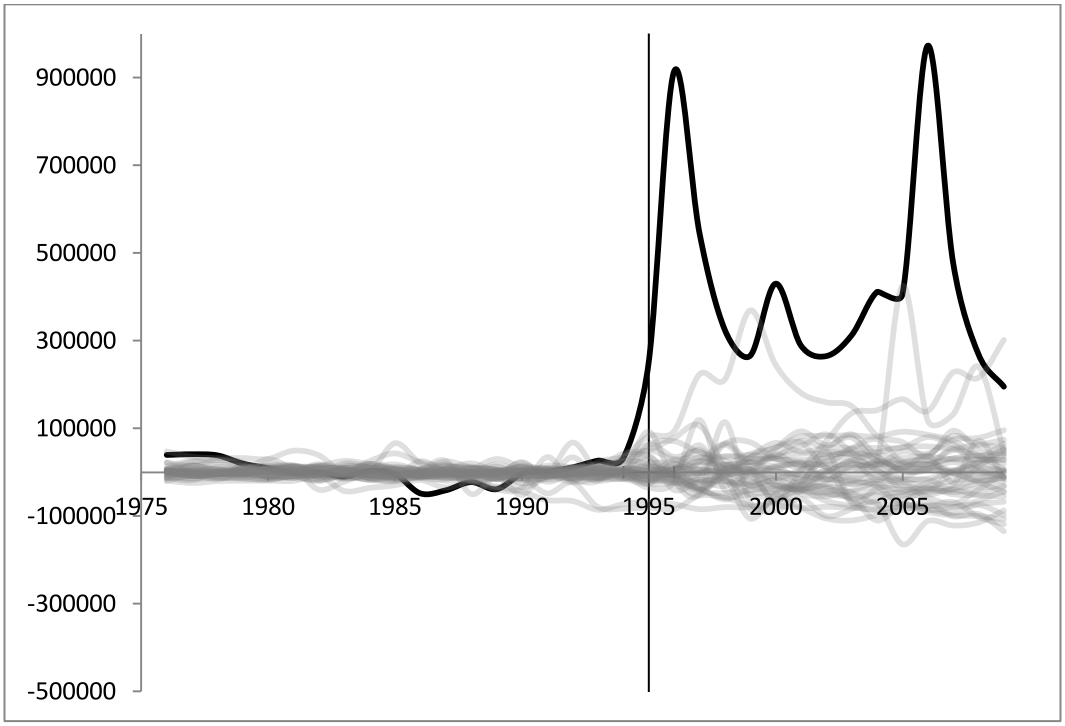

Figure 9: Migration out of the Prefecture: Hyogo Prefecture

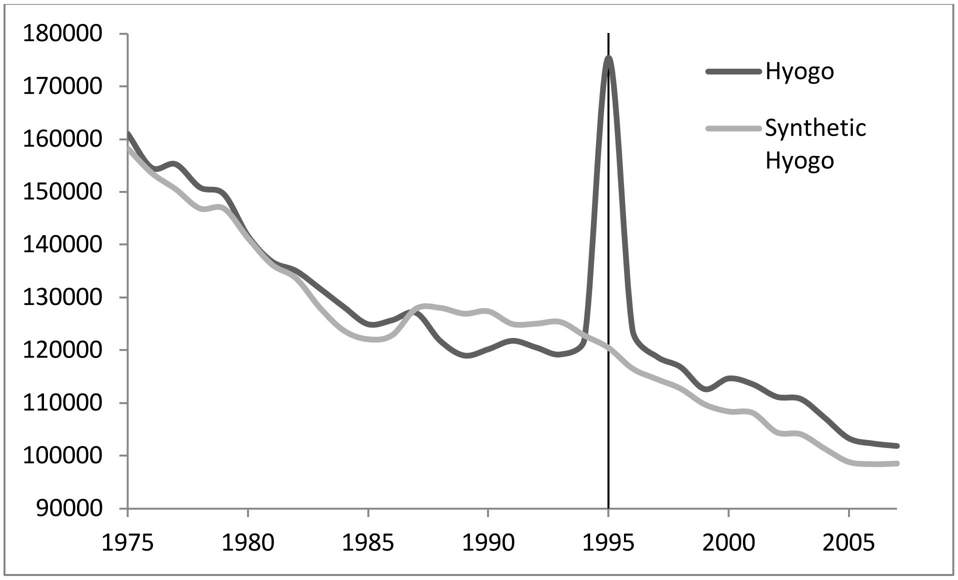

Figure 10: Migration into the Prefecture: Hyogo Prefecture

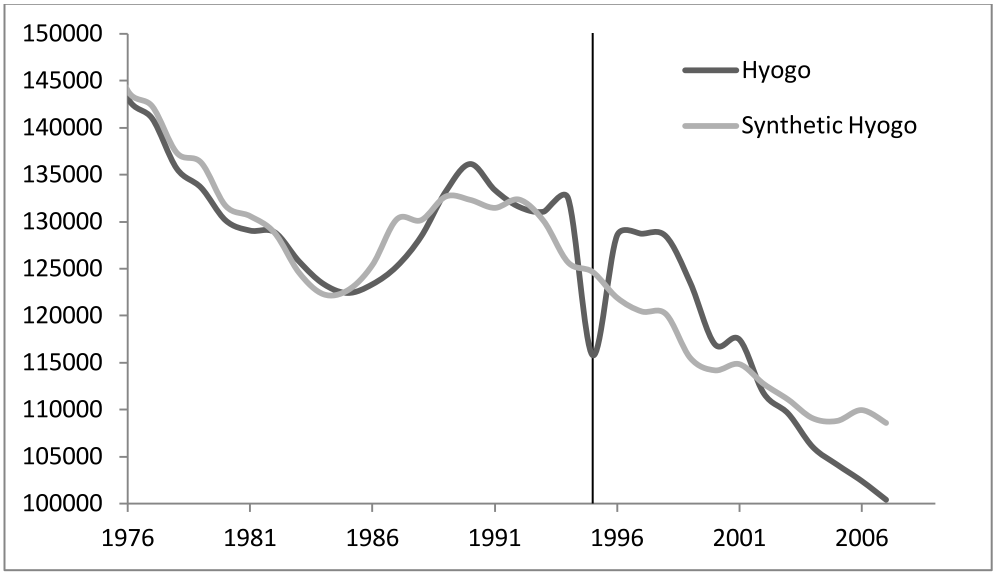

Table 1: Prefecture Weight - Population

Prefecture	Weight						
Hokkaido	0.157	Tokyo	0.034	Shiga	0	Ehime	0
Aomori	0	Kanagawa	0.002	Kyoto	-	Kochi	0
Iwate	0	Niigata	0	Osaka	-	Fukuoka	0.668
Miyagi	0	Toyama	0	Nara	0	Saga	0
Akita	0	Ishikawa	0	Wakayama	0	Nagasaki	0
Yamagata	0	Fukui	0	Tottori	0	Kumamoto	0
Fukushima	0	Yamanashi	0	Shimane	0	Oita	0
Ibaraki	0	Nagano	0	Okayama	-	Miyazaki	0
Tochigi	0	Gifu	0	Hiroshima	0	Kagoshima	0
Gunma	0	Shizuoka	0.006	Yamaguchi	0	Okinawa	0
Saitama	0	Aichi	0.128	Tokushima	-		
Chiba	0	Mie	-	Kagawa	0		

Table 2: Predictor Balance - Population

	Treated	Synthetic	Control AVG[ǂ]
GDP per Capita	2.476365	2.530505	2.610544
GDP	1.31E+07	1.42E+07	14205684
Income	1.10E+07	1.10E+07	10879626
Population	5255137	4273780	4467824
Construction	12278.16	12305.63	30821.09
Residential	161293.3	124607.9	135738.1
Rent	1828	1826.983	1780.557
Expenditure	1041785	863463	1178192
Intra-migration	156803.6	156451.9	150529.6
In-migration	131956.8	133007.3	143854.1
Out-migration	133337.9	120713.9	143607.2

ǂ Weighted by average pre-treatment population

Table 3: Difference between Actual and Synthetic - Population

Year	Deviation	% Deviation
1995	-105691	-1.9190211
1996	-104737	-1.8953224
1997	-90822.7	-1.6377093
1998	-71550.6	-1.2856667
1999	-50327	-0.9022175
2000	-43459.8	-0.7768956
2001	-41134	-0.7328265
2002	-46320.2	-0.8232385
2003	-49389.6	-0.8760013
2004	-56009	-0.9916941
2005	-62836.3	-1.1114707
2006	-71701	-1.2664215
2007	-79316	-1.3992868
2008	-83777	-1.4776066
2009	-84657	-1.493686

Table 4: RMSPE Treated vs. Control (1995-2009) - Population

	Hyogo	Control Mean
RMSPE (5x Exclusion)	69559.5184	51363.582
RMSPE (2x Exclusion)	69559.5184	34351.025

Table 5: Prefecture Weight – Per Capita GDP

Prefecture	Weight						
Hokkaido	0.096	Tokyo	0	Shiga	0	Ehime	0
Aomori	0	Kanagawa	0.061	Kyoto	-	Kochi	0
Iwate	0	Niigata	0	Osaka	-	Fukuoka	0.165
Miyagi	0	Toyama	0	Nara	0	Saga	0
Akita	0	Ishikawa	0	Wakayama	0	Nagasaki	0.04
Yamagata	0	Fukui	0	Tottori	0	Kumamoto	0
Fukushima	0	Yamanashi	0	Shimane	0	Oita	0
Ibaraki	0	Nagano	0	Okayama	-	Miyazaki	0
Tochigi	0	Gifu	0	Hiroshima	0	Kagoshima	0
Gunma	0	Shizuoka	0.15	Yamaguchi	0	Okinawa	0
Saitama	0	Aichi	0.209	Tokushima	-		
Chiba	0.28	Mie	-	Kagawa	0		

Table 6: Difference between Actual and Synthetic – Per capita GDP

Year	Deviation	% Deviation
1995	-0.061486	-1.69202
1996	0.149982	4.101461
1997	0.155029	4.094726
1998	0.075005	2.013402
1999	-0.0752	-2.04182
2000	-0.127778	-3.50382
2001	-0.168347	-4.58867
2002	-0.254843	-7.14388
2003	-0.294854	-8.25591
2004	-0.334156	-9.33337
2005	-0.362128	-9.99613
2006	-0.410692	-11.0992
2007	-0.370886	-9.92995
2008	-0.454794	-12.0991

Appendix A: Data Table

Type	Source	Chapter	Series	Frequency	Duration	Location	Year
Population	Historical Statistics of Japan	2	5	Annual	1884-2009	Prefecture	2011
GDP and Income	Historical Statistics of Japan	3	37a	Annual	F.Y. 1975-1999	Prefecture	2011
GDP and Income	Historical Statistics of Japan	3	37b	Annual	F.Y. 1990-2003	Prefecture	2011
GDP and Income	Japan Statistical Yearbook	3	14B	Annual	F.Y. 2003-2005	Prefecture	2009
GDP and Income	Japan Statistical Yearbook	3	14B	Annual	F.Y. 2004-2006	Prefecture	2010
GDP and Income	Japan Statistical Yearbook	3	14B	Annual	F.Y. 2005-2007	Prefecture	2011
Construction	Historical Statistics of Japan	9	17	Annual	F.Y. 1956-2003	Prefecture	2011
Construction	Japan Statistical Yearbook	9	10		F.Y. 2004	Prefecture	2008
Construction	Japan Statistical Yearbook	9	10		F.Y. 2005	Prefecture	2009
Construction	Japan Statistical Yearbook	9	10		F.Y. 2006	Prefecture	2010
Construction	Japan Statistical Yearbook	9	10		F.Y. 2007	Prefecture	2011
Residential Price	Historical Statistics of Japan	15	20	Annual	1980-2004	Prefecture	2011
Residential Price	Japan Statistical Yearbook	17	14		2005	Prefecture	2007
Residential Price	Japan Statistical Yearbook	17	14		2006	Prefecture	2008
Residential Price	Japan Statistical Yearbook	17	14		2007	Prefecture	2009
Residential Price	Japan Statistical Yearbook	17	14		2008	Prefecture	2010
Residential Price	Japan Statistical Yearbook	17	14		2009	Prefecture	2011
Rent	Historical Statistics of Japan	15	22	Every 5 Years	1963-2003	Prefecture	2011
Rent	Japan Statistical Yearbook	18	16		2008	Prefecture	2011
Gov. Expenditure	Historical Statistics of Japan	5	12d	Annual	F.Y. 1947-2008	Prefecture	2011
Migration	Historical Statistics of Japan	9	17	Annual	1956-2004	Prefecture	2011
Migration	Japan Statistical Yearbook	9	10		2006	Prefecture	2009
Migration	Japan Statistical Yearbook	9	10		2005, 2007	Prefecture	2010

Appendix B – Additional Tables and Figures in Web Appendix
Available at: https://sites.google.com/site/noyeconomics/research/natural-disasters

Appendix A: Benchmark results (same as in paper)
Figure A1.1: Population (# of people)
Table A1.1: Prefecture Weight
Table A1.2: Predictor Balance
Table A1.3: Difference between Actual and Synthetic
Table A1.4: RMSPE Treated vs. Control (1995-2009)
Figure A1.2: Placebo Population (# of people): RMSPE 5x Exclusion
Figure A1.3: Placebo Population (# of people): RMSPE 2x Exclusion

Figure A2.1: GDP (Millions of Yen)
Table A2.1: Prefecture Weight
Table A2.2: Predictor Balance
Table A2.3: Difference between Actual and Synthetic
Table A2.4: RMSPE Treated vs. Control (1995-2008)
Figure A2.2: Placebo GDP (Millions of Yen): RMSPE 5x Exclusion / 2x Exclusion

Figure A3.1: GDP per capita (Millions of Yen per Person): Kobe
Table A3.1: Prefecture Weight
Table A3.2: Predictor Balance
Table A3.3: Difference between Actual and Synthetic
Table A3.4: RMSPE Treated vs. Control (1995-2008)
Figure A3.2: Placebo GDP per capita (Millions of Yen per Person): RMSPE 5x Exclusion
Figure A3.3: Placebo GDP per capita (Millions of Yen per Person): RMSPE 2x Exclusion

Figure A4.1: Local Government Expenditures: Hyogo Prefecture
Table A4.1: Prefecture Weight
Table A4.2: Predictor Balance
Table A4.3: Difference between Actual and Synthetic
Figure A4.2: Placebo Local Government Expenditures (Millions of Yen): RMSPE 5x
Figure A4.3: Placebo Local Government Expenditures (Millions of Yen): RMSPE 2x

Figure A5.1: Intra-Prefecture Migration: Hyogo Prefecture
Table A5.1: Prefecture Weight
Table A5.2: Predictor Balance
Table A5.3: Difference between Actual and Synthetic
Figure A5.2: Placebo Intra-Prefecture Migration (Number of People): RMSPE 5x
Figure A5.3: Placebo Intra-Prefecture Migration (Number of People): RMSPE 2x

Figure A6.1: Migration into Hyogo Prefecture
Table A6.1: Prefecture Weight

Table A6.2: Predictor Balance
Table A6.3: Difference between Actual and Synthetic
Figure A6.2: Placebo Migration into the Prefecture (Number of People): RMSPE 5x
Figure A6.3: Placebo Migration into the Prefecture (Number of People): RMSPE 2x

Figure A7.1: Migration out of Hyogo Prefecture
Table A7.1: Prefecture Weight
Table A7.2: Predictor Balance
Table A7.3: Difference between Actual and Synthetic
Figure A7.2: Placebo Migration out of the Prefecture (# of People): RMSPE 5x Exclusion
Figure A7.3: Placebo Migration out of the Prefecture (# of People): RMSPE 2x Exclusion

Appendix B: All 46 Prefectures as Controls
Figure B1.1: Population (# of people)
Table B1.1: Prefecture Weight
Table B1.2: Predictor Balance
Table B1.3: Difference between Actual and Synthetic

Figure B2.1: GDP (Millions of Yen)
Table B2.1: Prefecture Weight
Table B2.2: Predictor Balance
Table B2.3: Difference between Actual and Synthetic

Figure B3.1: GDP per capita (Millions of Yen per Person)
Table B3.1: Prefecture Weight
Table B3.2: Predictor Balance
Table B3.3: Difference between Actual and Synthetic

Figure B4.1: Local Government Expenditures (Millions of Yen)
Table B4.1: Prefecture Weight
Table B4.2: Predictor Balance
Table B4.3: Difference between Actual and Synthetic

Figure B5.1: Intra-Prefecture Migration (# of people)
Table B5.1: Prefecture Weight
Table B5.2: Predictor Balance
Table B5.3: Difference between Actual and Synthetic

Figure B6.1: Migration into the Prefecture (# of people)
Table B6.1: Prefecture Weight
Table B6.2: Predictor Balance
Table B6.3: Difference between Actual and Synthetic

Figure B7.1: Migration out of the Prefecture (# of people)
Table B7.1: Prefecture Weight
Table B7.2: Predictor Balance
Table B7.3: Difference between Actual and Synthetic

Appendix C: Leave-One-Out Test
Figure C1.1: Population (# of people)
Table C1.1: Prefecture Weight
Table C1.2: Predictor Balance
Table C1.3: Difference between Actual and Synthetic

Figure C2.1: GDP (Millions of Yen)
Table C2.1: Prefecture Weight
Table C2.2: Predictor Balance
Table C2.3: Difference between Actual and Synthetic

Figure C3.1: GDP per capita (Millions of Yen per Person)
Table C3.1: Prefecture Weight
Table C3.2: Predictor Balance
Table C3.3: Difference between Actual and Synthetic

Figure C4.1: GDP per capita (Millions of Yen per Person)
Table C4.1: Prefecture Weight
Table C4.2: Predictor Balance
Table C4.3: Difference between Actual and Synthetic

Appendix D: Predictor Variable Time Split
Figure D1.1: Population (# of people)
Table D1.1: Prefecture Weight
Table D1.2: Predictor Balance
Table D1.3: Difference between Actual and Synthetic

Figure D2.1: GDP (Millions of Yen)
Table D2.1: Prefecture Weight
Table D2.2: Predictor Balance
Table D2.3: Difference between Actual and Synthetic

Figure D3.1: GDP per capita (Millions of Yen per Person)
Table D3.1: Prefecture Weight
Table D3.2: Predictor Balance
Table D3.3: Difference between Actual and Synthetic