Disentangling the Effects of Multiple Treatments — Measuring the Net Economic Impact of the 1995 Great Hanshin-Awaji Earthquake

Hiroshi Fujiki and Cheng Hsiao

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Disentangling the Effects of Multiple Treatments — Measuring the Net Economic Impact of the 1995 Great Hanshin-Awaji Earthquake*

by

Hiroshi Fujiki\(^a\)

and

Cheng Hsiao\(^b\)

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Abstract

We propose a panel data approach to disentangle the impact of “one treatment” from the “other treatment” when the observed outcomes are subject to both treatments. We use the Great Hanshin-Awaji earthquake that took place on January 17, 1995 to illustrate our methodology. We find that there were no persistent earthquake effects. The observed persistent effects are due to structural change in Hyogo prefecture.

JEL Code: C18; C23; C52.

Key Words: Multiple Treatment Effects; Panel Data; Great Hanshin-Awaji Earthquake, Natural Disaster, Measurement without Theory.

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\(^a\)Faculty of Commerce, Chuo University, Tokyo, Japan, fujiki@tamacc.chuo-u.ac.jp.

\(^b\)University of Southern California, USA, WISE, Xiamen University, China, National Tsinghua University, Hsinchu, Corresponding author at Department of Economics, University of Southern California, USA, chsiao@usc.edu
1. Introduction

To evaluate the impact of certain “treatment” on some economic entity, one has to compare the outcomes of this entity in a “treated” and “untreated” states. Unfortunately, econometricians often only have data in “one” or the “other” state, not simultaneously in both states. Therefore, in evaluating the impact of a “treatment”, econometricians have to construct “counterfactuals”. Econometricians have come up with many ingenious approaches to construct counterfactuals (e.g. Abadie and Gardeazabal (2003), Abadie, Diamond and Hainmueller (2010), Heckman and Robb (1985), Heckman et.al. (1998), Hsiao, Ching and Wan (2012), Rosenbau and Rubin (1983)). A fundamental assumption of all these approaches is that the observed data for an entity under the “treatment” is only the outcomes of this specific “treatment” after controlling the impact of certain causal factors. However, in many cases, the observed outcomes could be due to several “treatments” working simultaneously. In this paper we propose a panel data approach to disentangle the impact of “one treatment” from the “other” when the observed data are the outcomes of “both” working in the same time using the Great Hanshi-Awaji earthquake impact as an illustrative example.

The Great Hanshin-Awaji earthquake took place on January 17, 1995. “The quake killed sixty-four hundred people, left more than three hundred thousand homeless, and did more than a hundred billion of dollars in damage” (Surowiecki (2011)). However, there are disagreements about the long-term impact of the earthquake on the Kobe region (Hyogo prefecture). On the one side, Horwich (2000) and Becker (2005), etc. claimed that the quake did not have much impact on Kobe region itself beyond the first couple of years. On the other side, DuPont and Noy (2012) claim that the “evidence shows a persistent and still continuing adverse impact of the quake on the economy of Kobe more than 15 years after the event”. There is also ample evidence that there was a fundamental structural change going on starting around mid 1990’s around disaster area, the Hyogo prefecture. The port of Kobe was the sixth busiest port in the world in 1994. It was still ranked
27th in 1995 during the quake year but has fallen to the 39th in the year 2005. Can one attribute this dramatic decline to the Great Hanshin-Awaji Earthquake or due to the competition of other lower cost ports in Asia such as Pusan, Hong Kong or Singapore, etc.? Moreover, the disaster area was heavily concentrated by traditional industries that lost competitiveness due to globalization. For instance, one of the most important local industries, the chemical shoe industry has been on the decline even before the quake and continues to decline thereafter due to the competition of the cheaper shoes from China and the expensive shoes from Italy and France (e.g. see Chart 1 and 2 of Fujiki and Hsiao (2013)).

In section 2, we review the related studies. Section 3 discusses the data issues. Section 4 presents the estimates of combined quake and structural change effects using Hsiao, Ching and Wan (2012) methodology. Section 5 proposes a method to disentangle “one treatment effects” from the other and presents the estimated net “quake” effects from the “structural change” effects. Concluding remarks are in section 6.

2. Literature Review

(2.1) Definition of the losses from a natural disaster

According to Hallegatte and Przyluski (2010), researchers usually distinguish the loss of a natural disaster between direct and indirect losses depending on their purposes of estimation. Direct losses are immediate consequence of disaster, especially physical phenomenon, such as the loss of buildings or houses. Among direct losses, direct market losses are estimated by the repair or replacement cost. These estimates are essential for the payments of insurance or government subsidy to the damaged area. There are also non-market direct losses, such as loss of lives, loss of natural assets. Indirect losses include all losses that are not provoked by the disaster itself, but by its consequences.

Direct loss is a “stock” concept. They are losses of wealth and human capital. The methods to estimate the direct losses are straightforward, in contrast, there is lack of consensus on how to measure indirect losses. Indirect losses are much harder to measure. There
are stimulating effects due to government recovery act. There is also the Schumpeter’s creative destruction mechanism at work that a natural disaster leads to speeding up the adoption of new technologies and improvement in infrastructure (Skidmore and Toya (2002)). On the other hand, servicing the debt arising from financing the government recovery act could crowd out local consumption and investment. It could also impede government’s expenditure on education and welfare in future. The loss of wealth and human capital could also affect the consumption and investment in the damaged area (e.g. Hayashi (2011)). Since the “indirect loss” is essentially a “flow” concept, most economists use the real GDP (RGDP) or real GDP per capita (RGDPPC) over time as a basis for measurement.

(2.2) Estimates of economic losses due to the Great Hanshin-Awaji Earthquake

A. Direct market losses

The most cited official estimate of direct losses was done by Hyogo prefecture government on April 5, 1995. Their estimates of direct market losses were 9.9 trillion Japanese yen. Included in the losses are: losses for constructions for about 5.8 trillion Japanese yen, losses for ports for about 1 trillion Japanese yen, losses for expressways for about 0.56 trillion Japanese yen. The number of damaged houses was 639,686. Regarding the non-market losses, the number of casualties was 6,434, and the number of injuries was 43,792.

B. Direct market losses and indirect losses obtained from the firm level estimates

Toyoda and Kawauchi (1997) use a survey from the firms in the disaster area to estimate the average direct loss, and impute their estimates to the rest of firms in disaster area with some adjustment depending on how serious the firms are damaged to obtain total losses in the disaster area. According to their method, direct losses are 6 trillion yen and the indirect loss are 7.2 trillion yen. Their revised estimated losses in the manufacture and commerce sectors of the Hyogo Prefecture are 13.2 trillion yen.
C. Indirect losses obtained from the econometric estimates based on national or regional data

Okuyama (undated) regresses Kobe City gross regional product per capita data on its own lagged value, Japanese GDP, lagged Japanese GDP based on pre-earthquake data to generate forecasts of gross regional product without the earthquake. He shows a small negative initial shock followed by positive impacts due to the government demand injection for a few years. His results are consistent with the observation by Horwich (2000) that the economic activity of Kobe area, manufacturers or retailers, recovered from the negative shock in about two or three years.

D. Indirect losses obtained from the input-output model at the national and regional level

Takahashi, Ando and Mun (1996) use regional input-output table to obtain an estimate of the loss in Hyogo prefecture at 2.2 trillion yen. According to this study, the disaster area experienced the decline of the output about US$73 billion (or 7.3 trillion Japanese yen if $1=100 yen). Ashiya and Zinushi (2001) use the input-output table to analyze the disaster area economy and conclude that the direct loss of the physical assets in the amount of 10 trillion yen were fully reconstructed from 1995 to 1997.

E. Synthetic Control Methods

DuPont and Noy (2012), following Abadie and Gardeazabal (2003), Abadie, Diamond and Hainmuller (2010), use a control group that consists of other untreated prefectures, optimally weighted, to construct the counterfactual for Hyogo prefecture GDP in the absence of quake. They find a significant and long-term adverse effect of the disaster: about 13% of average per capita prefecture GDP as of 2007.

3. Data

The focus of our study is to measure the “indirect loss”. We use the real GDP (RGDP) or real GDP per capita (RGDPPC) over time as a basis for our measurement of indirect losses.
(3.1) Data on Prefecture GDP Series

Japanese regional aggregate data is published by each prefecture, and the latest data is available from 1955 to fiscal year 2009. The Cabinet Office of the Government of Japan collects data from each prefecture, and publishes them altogether around February of each year.

The prefecture aggregates are revised every year, and the consistent constant price data for the period 1955 to 2009 do not exist because of the changes in the base years. Moreover, the estimates are compiled based on two different methods of the system of National Account; the 1968 System of National Account (SNA) or the 1993 SNA. Currently, the 1955-2009 prefecture data are compiled using different accounting methods and price indexes. For the period from 1955 to 1974, the data were compiled using the 1968 SNA method (base year 1980, hereafter the series 1); from 1975 to 1989, the 1968 SNA method (base year 1990, hereafter the series 2); from 1990 to 2003, the 1993 SNA method (base year 1995, hereafter the series 3); and from 1996 to 2009, the 1993 SNA method (base year 2000, hereafter the series 4). The Japanese Cabinet Office selects the following series as the official statistics: the series 1 from 1955 to 1974; the series 2 from 1975 to 1989; the series 3 from 1990 to 1995; and the series 4 from 1996 to 2009. Therefore, the official statistic have jumps in the year 1975, 1990 and 1996 either due to changes in the base year or choice of the SNA methods.

We use the data on the nominal gross prefecture expenditure and its deflator together with population from 1955 to 2009 to adjust the official statistics. Regarding the nominal gross prefecture expenditure, we adjust three jumps in the series as follows: First, we obtain the adjusted series 3 by multiplying the series 3 data from 1990 to 1995 by the ratio of the 1996 data in the series 3 to the 1996 data in the series 4 to adjust the discontinuity in the year 1996. Second, to adjust the discontinuity in the year 1990 and 1975, we multiply the series 2 data from 1975 to 1989 and the series 1 data from 1955 to 1974 by the ratio of the 1990 data in the series 2 to the 1990 data in the adjusted series 3. (See chart 3 of Fujiki
and Hsiao (2013) which shows adjusted series and original series for Hokkaido region).

Regarding the deflator for nominal gross prefecture expenditure, we first estimate several unavailable data points and then adjust three jumps in the official statistics. We use the growth rate for prefecture CPI data to estimate the unavailable data series for four areas, Fukushima 1975-1979, Saitama 1975-1976, Okayama 1975-1984, and Okinawa 1975-1980. We adjust the jumps in the official data series in 1996 and 1990 in the same way as we did for the nominal gross prefecture expenditure series. Regarding the adjustment for the jump in the year 1975, we multiply the series 1 from 1955 to 1974 by the ratio of the 1980 data in the adjusted data series 2 to 100, because we know that the base year of the deflator of series 1 is 1980, and thus the 1980 data for the deflator in the data series 1 should be 100. (For example, see Chart 4 of Fujiki and Hsiao (2013)).

4. Estimates of the Combined Effects of Earthquake and Structural Change

(4.1) Statistical Method

We first present the estimates of combined earthquake and structural change effects based on Hsiao, Ching and Wan (HCW) method (2012). HCW assumes that the observed outcome of a variable \( y \) for the \( i \)th unit at time \( t \), \( y_{it} \), is a function of \( K \) common factors (across individual unit), \( f_t \), the fixed idiosyncratic component, \( \alpha_t \), and the random idiosyncratic component \( \epsilon_{it} \), \[ y_{it} = \alpha_t + b_i' f_t + \epsilon_{it}, \quad i = 1, \ldots, N, \quad t = 1, \ldots, T. \] (4.1)

Stacking the \( N \times 1 \) \( y_{it} \) into a vector yields, \[ y_t = B f_t + \alpha + \epsilon_t, \] (4.2)

when \( y_t = (y_{it1}, \ldots, y_{iNt})' \), \( \alpha = (\alpha_1, \ldots, \alpha_N)' \), \( \epsilon_t = (\epsilon_{it1}, \ldots, \epsilon_{iNt})' \), and \( B \) is the \( N \times K \) factor loading matrix, \( B = (b_1, \ldots, b_N)' \). The contemporaneous covariance between \( y_{it} \) and \( y_{jt} \) is then equal to \[ \text{Cov} (y_{it}, y_{jt}) = b_i' E(f_t f_t') b_j. \] (4.3)
Therefore, in principle one element of $y_t$ can be predicted by other elements of $y_t$. In other words, we can write $y_{1t}$ as a function of $\tilde{y}_t$ where $\tilde{y}_t = (y_{2t}, \ldots, y_{Nt})'$,

$$y_{1t} = E(y_{1t} | \tilde{y}_t) + u_{1t}. \tag{4.4}$$

Suppose there was no treatment for all $N$ units from $t = 1, \ldots, T_1$, i.e., $y_t = y_t^0$. From period $T_1 + 1$ onwards, the first unit received treatment, $y_{1t} = y_{1t}^0, t = T_1 + 1, \ldots, T$, while the rest of units did not, $y_{it} = y_{it}^0, t = 1, \ldots, T, i = 2, \ldots, N$. HCW suggests predicting

$$\hat{y}_{1t}^0 = E(y_{1t}^0 | \tilde{y}_t) \tag{4.5}$$

$$= a + b' \tilde{y}_t^*, \quad t = T_1 + 1, \ldots, T.$$ 

HCW suggests using the data from 1 to $T_1$ to obtain estimates of $a, b$ based on the least squares regression of $y_{1t}$ on a subset of $\tilde{y}_t^*, \tilde{y}_t^*$, selected from some model selection criterion (AIC (Akaike 1974)) or BIC (Schwarz 1978)).\footnote{See Bai and Ng (2008) for further discussions on generating accurate predictions.} Then estimate the treatment effects after period $T_1 + 1$ as\footnote{Although $y_t$ could be nonstationary, this result holds whether $y_t$ is stationary or nonstationary, see Bai, Li and Ouyang (2013).}

$$\hat{\Delta}_t = y_{1t} - \hat{y}_{1t}^0 \tag{4.6}$$

$$= y_{1t} - \hat{a} - \hat{b}' \tilde{y}_t^*, \quad t = T_1 + 1, \ldots, T.$$ 

where $\hat{a}$ and $\hat{b}$ are the least squares estimates.

If $\Delta_t$ is stationary, then the average treatment effects $\Delta$ can be estimated by

$$\hat{\Delta} = \frac{1}{T - T_1} \sum_{t=T_1+1}^{T} \hat{\Delta}_t. \tag{4.7}$$

Equation (4.7) is a consistent estimator of $E(\Delta_t) = \Delta$ if $T_1$ and $(T - T_1)$ both tend to infinity.

Under the assumption that $u_{1t}$ are independently, identically distributed with mean 0 and variance $\sigma_u^2$, the covariance matrix of $(\hat{a}, \hat{b}')$ is given by

$$\text{Cov} \left( \begin{array}{c} \hat{a} \\ \hat{b} \end{array} \right) = \sigma_u^2 (X'X)^{-1}, \tag{4.8}$$
where $X = (1, \tilde{y}_t^*')$ is a $T_1 \times (k + 1)$ matrix and $k$ is the dimension of $(\tilde{y}_t^*)$. Then the heteroscedastic prediction error variance of $\tilde{y}_t^0$ for $t = T_1 + 1, \ldots, T$ is equal to

$$
s^2_{y_t^0} = E[(\tilde{y}_t^0 - y_{1t}^0)^2] = \sigma_u^2 \left(1 + \tilde{x}_t'(X'X)^{-1}\tilde{x}_t\right), \quad t = T_1 + 1, \ldots, T, \tag{4.9}\n$$

where $\tilde{x}_t^* = (1, \tilde{y}_t^*)$. Hence the confidence band of the treatment effects can be constructed as

$$\hat{\Lambda}_i = c_\Delta \sigma_{y_t^0}, \quad t = T_1 + 1, \ldots, \tag{4.10}\n$$

where $c_\Delta$ is the critical value of a standard normal or $t$-distribution for the given confidence level, say $c_\Delta = 1.96$ for 95% confidence level.

The asymptotic variance of the long-run treatment effects (4.7) can be approximated using the Newey-West (1987) heteroscedastic and autocovariance consistent estimator. Its confidence band can similarly be constructed.

We apply the method of Hsiao, Ching and Wan (2012) to the log of real per capita GDP and log of real GDP on Hyogo Prefecture before and after the Great Hanshin-Awaji Earthquake.\(^3\)

(4.2) **Selection of prefectures to estimate counterfactual**

Although we have 46 other prefectures, it is hard to consider all 9,366,819 combinations of data series if we follow the Hsiao, Ching and Wan (2012) approach. Moreover, we only have 39 pre-event observations. Fortunately, a unique feature of Japanese prefecture data series is that they are extremely highly correlated. Table 1 shows the simple correlation coefficients of Hyogo Prefecture and other prefectures for log real GDP per capita in descending order for the whole sample period, for the subsample period from 1955 to 1993 (before the Great Hanshin-Awaji Earthquake) and for the subsample period from 1994 to 2009 (after the Great Hanshin-Awaji Earthquake). (For other series, see Fujiki and Hsiao (2013)).

\(^3\)We also conducted analysis on components of GDP such as consumption, construction and service sectors. For detail, see Fujiki and Hsiao (2013).
Table 1 shows three things. First, in overall samples, the simple correlation coefficients are well above 0.99 for 44 out of 46 prefectures. Second, before the Great Hanshin-Awaji Earthquake, the correlations are even higher for 31 out of 46 prefectures. Finally, after the Great Hanshin-Awaji Earthquake, the correlations get lower, and in some regions even negative. Only Osaka, the neighbor prefecture, has the correlation of 0.8175. Based on those observations, given that our objective is to use other prefectures data before the Great Hanshin-Awaji Earthquake to construct the counterfactuals, we feel that using BIC to select the best predictive model based on a maximum of five or six prefectures that have highest simple correlations is probably a good starting point for constructing a good predictive model for counterfactuals.

(4.3) Regression Results

Table 2 shows the results of forecasting models for log real GDP per capita (RGDPPC) data for Hyogo prefecture before the Great Hanshin-Awaji Earthquake.\textsuperscript{4} For example, the first column of Table 2 reports the results of regressing the Hyogo log RGDPPC on log RGDPPC of Tochigi, Fukui, Gifu, Toyama, and Tottori. As we anticipate, the goodness of the fit is great. However, although using more regressors gets better within sample fit, they do not necessarily yield more accurate post-sample prediction. To balance the within sample fit with the accuracy of post-sample predictions, we use BIC to select a parsimonious model.\textsuperscript{5} Based on BIC, we end up choosing two prefectures, Tochigi and Tottori, for the forecast of Hyogo prefecture without quake as reported in the fourth column of Table 2.\textsuperscript{6}

\[
\hat{y}_{it} = 0.433 \text{ Tochigi}_t + 0.367 \text{ Tottori}_t + 0.261 \\
R^2 = .998
\]  

(4.11)

We proceed in the same way for log real GDP that yields,\textsuperscript{7}

\textsuperscript{4}Standard errors are in parentheses. $R^2$ denotes the adjusted $R^2$. For detail and results of nominal GDP or GDPPC or sectoral components, see Fujiki and Hsiao (2013).

\textsuperscript{5}For other procedures to improve the accuracy of post-sample predictions, see e.g. Bai and Ng (2008).

\textsuperscript{6}If our understanding is correct, DuPont and Noy (2012) appear to use all the rest of 46 prefecture data from 1975 to 2009 to estimate the counterfactual.

\textsuperscript{7}For detail, see Hsiao and Fujiki (2013).
\[
\hat{y}_{1t} = 0.362 \text{ Ischikawa}_t + 0.274 \text{ Toyama}_t + 0.221 \text{ Chiba}_t + 3.383 \\
(0.123) \quad (0.116) \quad (0.0861) \quad (0.483) \\
\bar{R}^2 = .999
\]  
(4.12)

(4.4) Counterfactual and Economic Impacts\(^8\)

The upper panels in Figure 1 and 2 report the actual data and counterfactuals constructed as the forecast of the regression model defined in (4.11) and (4.12). The lower panels in Figure 1 and 2 report the combined economic impacts if the effects of Great Hanshin-Awaji Earthquake, which are defined as the gap between the counterfactual and the actual data after the fiscal year 1994 (Note that January 1995 is in the fiscal year 1994).\(^9\) The findings corroborate those of DuPont and Noy (2012) that there appears to be a persistent adverse quake effects, although DuPont and Noy (2012) report 13% decrease in per capita nominal GDP as of 2007 compared with the counterfactual level, we estimate 8.9% decrease as of 2007 compared with counterfactual. The discrepancy could be due to differences in constructing counterfactuals. It could also be that they assume the effects of quake begin at 1995 data, while we correctly assume it began at the fiscal 1994 data.

(4.5) Are the Effects Due to Earthquake or Structural Change?

There are substantial evidence that the persistent decline in Hyogo economy could be due to structural change rather than the earthquake. For instance, the annual report of Kobe (The Port of Kobe (2011)) indicates that the Kobe port was the second busiest port in the world in the year 1972 (measured by the amount of containers), and it was sixth busiest port in the world in 1994 (the year before the Great Hanshin-Awaji Earthquake). The Great Hanshin-Awaji Earthquake destroyed almost all important facilities in the port

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\(^8\)The \(F\)-statistics of Chow structural break tests for (4.11) and (4.12) at the fiscal year 1994 are \(F (3,49)=2.97\) with \(P\)-value 0.041 and \(F (4.47)=2.36\) with \(P\)-value 0.066. They appear to indicate that the relations between Hyogo and other prefectures before and after quake are not the same.

\(^9\)DuPont and Noy (2012) seem to assume that the effect of the Great Hanshin-Awaji Earthquake show up in the data on 1995 (page 9, line 8, or Figure 3). We assumed they used the same dataset on fiscal year basis, and thus their estimates must be interpreted with caution.
of Kobe, and the port stopped dealing with the containers coming from abroad at that time. However, the port facility was reconstructed within two years. The number of ships arriving at the port of Kobe rebounded strongly in the year 1996 and 1997, but it never raised above the number of the arriving ships in the year 1994. Can we attribute this persistent decline to the Great Hanshin-Awaji Earthquake? We breakdown the analysis of the number of arriving ships in three parts.

First, regarding the coast ships excluding the ferry boats, the damage due to the Great Hanshin-Awaji Earthquake seems to be limited to the year 1995 and 1996.

Second, regarding the number of arriving coastal ferry boats, we see dramatic decrease in the year 1998. The decrease can be attributed to the opening of the new bridge in April, 1998, called “Akashi-Kaikyo-Ohashi” that linked Kobe city and Awaji-island. Trucks travelling from Shikoku Island to Honshu has since moved away from ferries to the express way. The new bridge had been under construction before the Great Hanshin-Awaji Earthquake, and the decline of arrival of coastal ferry boats seems to have nothing to do with the Great Hanshin-Awaji Earthquake.

Third, regarding the number of ocean-going ships, it was true that ships moved away from the port of Kobe to other Japanese ports, such as Tokyo, Osaka or Yokohama immediately after the Great Hanshin-Awaji Earthquake. However, the decrease in the arriving ocean-going ships in the port of Kobe reflect another long-run factor: the loss of competitiveness with other East Asian ports. For example, after the introduction of regular container sea route between Korea and China in 1993, many traders prefer to use Pusan instead of Kobe as a hub terminal to trade with China, partly because Pusan was closer to China and partly because the cost of the Pusan port was cheaper than Kobe. The dramatic decrease in the transshipment and the percentage of transshipment in the port of Kobe should be attributed to the effects of competition with other East Asian ports. One can find a similar decrease in the shipments in the other Japanese ports, such as Yokoyama. For example, the world ranking of shipments in the port of Yokoyama fell from 8th in the
year 1995 to the 27th in the year 2005. In this sense, one could similarly argue that the Great Hanshin-Awaji Earthquake only accelerated the decline of the activity of the port of the Kobe (for detail, see Fujiki and Hsiao (2013)).

The most significant contributing components of Hyogo GDP are the activities of Kobe port and the output of traditional industries. The decline in Hyogo is not just due to the decline in the port of Kobe, but also due to the changing industry structure of Hyogo. Chemical shoes industry was one of the most important local industries in the city of Kobe since the 1950s. About 1,600 shoe producers located in Nagata Word and Suma Word of Kobe City in the year 1995. About 80 percent of the factories were burned down due to the fires arising from the Great Hanshin-Awaji Earthquake. The immediate economic losses from the Great Hanshin-Awaji Earthquake amounted to 300 billion yen in this industry alone. However, the data regarding the decline in the output and employment of the member firms of the chemical shoes industry associations are indicative of the loss of competitiveness of labor-intensive industries. The level of production increased to about 80% of the pre-earthquake level in the year 1999; nonetheless, it kept on decreasing since then. The number of employees remains low after the Great Hanshin-Awaji Earthquake. This decline in the shoe industry should be attributed to the competition of the cheaper shoes from China and the expensive shoes from Italy and France, which would have happened irrespective of the occurrence of the quake. (For detail, see Fujiki and Hsiao (2013)).

5. Disentangle the Net Earthquake Effect from the Effect of Structural Change

Suppose the net effect of natural disaster happened at time $T_1 + 1$ is transitory and suppose from period $T_2 + 1$ onwards,

$$y_{1t} = y^2_{1t}, \text{ for } t = T_2 + 1, \ldots, T.$$  \hspace{1cm} (5.1)
Using the similar methodology as HCW, we can construct

\[ y_{1t} = E(y_{1t} \mid \tilde{y}_t) + \eta_t, \]

\[ = c + d' \tilde{y}_{t}^{**} + \eta_t, \quad t = T_2 + 1, \ldots, T; \quad (5.2) \]

where \( \tilde{y}_{t}^{**} \) is a subsector of \( \tilde{y}_t \). Then by the similar reasoning as HCW, we can backcast \( y_{1t} \) under the new structure for the period before \( T_2 \) using the estimated \( c \) and \( d \) based on data from \( T_2 + 1 \) to \( T \),

\[ \tilde{y}_{1t}^2 = \hat{c} + \hat{d}' \tilde{y}_{t}^{**}, \quad t = 1, \ldots, T_2. \quad (5.3) \]

Again, the prediction error variance of \( \tilde{y}_{1t}^2 \) for \( t = 1, \ldots, T_2 \) can be computed using the formula

\[
\text{Var} (\tilde{y}_{1t}^2) = E \left[ \left( \tilde{y}_{1t}^2 - y_{1t}^2 \right)^2 \right] \\
= \sigma_\eta^2 \left[ 1 + \tilde{x}_t^* \left( X^{**} \cdot X^{**} \right)^{-1} \tilde{x}_t^* \right] \\
= \sigma_{y_t^2}^2, \quad \text{for} \quad t = 1, \ldots, T_2, \quad (5.4)
\]

where \( \tilde{x}_t^* = (1, \tilde{y}_t^{**}) \), \( X^{**} \) is a \( (T_2 - T_1) \times k^* \) matrix with the \( j \)-th row being \( \tilde{x}_t^{*j} \) and \( k^* \) is the dimension of \( \tilde{x}_t^* \). Given \( \tilde{y}_{0t}^0 \) and \( \tilde{y}_{1t}^2 \), the combined earthquake and structural change effects for the period \( (T_1 + 1) \) to \( T \) can be estimated by

\[ \hat{\Delta}_t = (y_{1t} - \tilde{y}_{1t}^0), \quad \text{for} \quad t = T_1 + 1, \ldots, T; \quad (5.5) \]

the net earthquake effects between \( T_1 + 1 \) and \( T_2 \) by

\[ \hat{Q}_t = (y_{1t} - \tilde{y}_{1t}^2), \quad \text{for} \quad t = T_1 + 1, \ldots, T_2; \quad (5.6) \]

and the structural change effects since \( T_1 + 1 \) by

\[ \hat{S}_t = (\tilde{y}_{1t}^2 - \tilde{y}_{1t}^0), \quad t = T_1 + 1, \ldots, T; \quad (5.7) \]

where \( \tilde{y}_{1t}^2 = \tilde{y}_{1t}^2 \) for \( t = T_1 + 1, \ldots, T_2 \), and \( \tilde{y}_{1t}^0 = y_{1t}^2 = y_{1t} \) for \( t = T_2 + 1, \ldots, T \).

The confidence intervals for \( \hat{\Delta}_t, \hat{Q}_t \) and \( \hat{S}_t \) can be constructed using the formulas,

\[ \hat{\Delta}_t \pm c_\Delta \sigma_{\tilde{y}_t}; \quad (5.8) \]
\[ \hat{Q}_t = c_Q \sigma_{\hat{y}_t}; \]  

(5.9)

and

\[ \hat{S}_t = c_S \sqrt{\sigma_{\hat{y}_t}^2 + \sigma_{\hat{y}_t}^2}, \text{ for } t = T_1 + 1, \ldots, T_2, \]

(5.10)

\[ \hat{S}_t = c_S \sigma_{\hat{y}_t}, \text{ for } t = T_2 + 1, \ldots, T, \]

where \( c_\Delta, c_Q \) and \( c_S \) are the critical values of the standard normal or \( t \)-distribution with given confidence level, say 1.96 for 95\% confidence level.

We apply this methodology to separate the net earthquake from the structural change effects. Our selection of \( T_2 \) is based on two considerations: (i) The observed value of \( \hat{y}_{1t} \) from \( T_2 + 1 \) onwards no longer contains the earthquake effect; (ii) There are reasonably large number of post-\( T_2 \) observations to get a reliable approximation of \( E\left( \hat{y}_{1t}^2 | \hat{y}_t \right) \) for \( t \) from \( T_2 + 1 \) onwards.

Consideration of (i) favors pushing \( T_2 \) far ahead from the quake year 1995. Consideration of (ii) favors pushing \( T_2 \) as close to 1995 as possible. There are 15 post-quake observations. Hayashi (2011) (or Horwich (2000)) has concluded that the recovery period ended in the 1998 fiscal year, thereafter, Hyogo prefecture has experienced a structural change.\(^{10}\) We find the backcast Hyogo time series are sensitive to where \( T_2 \) is chosen if \( T_2 \) falls between 1996 - 1999, but appear to be fairly stable from 2000 onwards.\(^{11}\)

The separation of the quake effects and structural break effects depends critically on the choice of \( T_2 \). To further check if setting \( T_2 = \) year 2000 is a reasonable choice, we consider two additional approaches. The first approach treats the backcast \( \hat{y}_{1t}^2 \) as if they were the actual outcomes of Hyogo economy under the new economic structure, then use the pre-1995 hypothetically generated data to generate counterfactuals under the post 2000 structure in the absence of quake.

\(^{10}\) Including the recovery demand, Hayashi (2011) identified the effects of the Great Hashin-Awaji earthquake as the gap between the level of fiscal year 1993 and fiscal years 1994 to 1998 which amounts to 7.7 trillion yen on value added basis and 14.4 trillion yen in output level. The direct market loss of 9.9 trillion yen estimated by the Hyogo Prefecture is close to his estimates.

\(^{11}\) For detail, see Fujiki and Hsiao (2013).
Treating the hypothetically generated $\hat{y}^2_{1t}$ for the period $t = 1, \ldots, T_1$, as if they were $y_{1t}$ under the new structure, and using the similar methodology as HCW, we can let
\[
\hat{y}^2_{1t} = b'_1 f_t + \alpha^*_t + \epsilon^*_1.
\] (5.11)
Then
\[
\begin{pmatrix} \hat{y}^2_{1t} \\ \hat{y}_t \end{pmatrix} = B^* f_t + \alpha^* + \epsilon^*_t, \quad t = 1, \ldots, T_1,
\] (5.12)
where $B^* = (b^*_1, b^*_2, \ldots, b^*_N)'$, $\alpha^* = (\alpha^*_1, \alpha^*_2, \ldots, \alpha^*_N)'$, and $\epsilon^*_t = (\epsilon^*_{1t}, \epsilon^*_{2t}, \ldots, \epsilon^*_{Nt})'$. There will have a $1 \times N$ vector $\hat{w}$ such that $\hat{w}' B^* = 0'$. Therefore, we can let
\[
\hat{y}^2_{1t} = E(\hat{y}^2_{1t} | \hat{y}^n_t) + v_{1t}, \quad t = 1, \ldots, T_1,
\] (5.13)
where $\hat{y}^n_t$ denotes the vector of $\hat{y}_t$ without the prefectures $\hat{y}^{**}_t$ that are used to generate $\hat{y}^2_{1t}$\(^{12}\).

Approximating $E(\hat{y}^2_{1t} | \hat{y}^n_t)$ using the data from 1955 to 1993 yields
\[
E(\hat{y}^2_{1t} | \hat{y}^n_t) \simeq \hat{a}^* + \hat{b}^* \hat{y}^n_t = \hat{y}^{2*}_t.
\] (5.14)
Using (5.14) to generate $\hat{y}^{2*}_{1t}$ for $t = T_1 + 1, \ldots, T$, We can obtain the estimated net earthquake effects
\[
\hat{Q}_t = y_{1t} - \hat{y}^{2*}_{1t}, \quad t = T_1 + 1, \ldots, T_2, T_2 + 1, \ldots, T.
\] (5.15)
If the earthquake effects are no longer present, we should expect $\hat{Q}_t$ close to zero after year 2000. Let $T_2$ = year 2000, our backcasting model for Hyogo log GDP PPC is
\[
y^2_{1t} = \begin{pmatrix} 1.352 & 0.617 & 0.524 & -0.547 \\ 0.254 & 0.58 & 0.117 & 0.210 \\ -1.051 & \hat{b}_{1t}, & 0.367 \end{pmatrix}
\] (5.16)
\[
\hat{R}^2 = 0.980.
\]
\(^{12}\)We need to delete those prefectures that generate the hypothetically generated $\hat{y}^2_{1t}$, otherwise, we will simply end up with a model using $\hat{y}^n_t$ with perfect fit.
The estimated models for generating predicted hypothetically generated Hyogo log RGDPPC under the new structure in the absence of quake is given by

\[
\hat{y}_{1t}^{2*} = 1.293 \text{ Saitama}_t + 0.916 \text{ Chiba}_t + 0.403 \text{ Miyazaki}_t + 0.438 + \hat{\epsilon}_{1t}, \\
\hat{\epsilon}_{1t} \sim N(0, \sigma^2_{1t}), \\
\bar{R}^2 = .986. \tag{5.17}
\]

Figure 3 plots the estimated combined quake and structural change effects, the economic adjustment effects and the net quake effects together with their respective 95% confidence intervals for the log RGDPPC when \( T_2 \) is set at the year 2000.

To check if the earthquake effects indeed approaches to zero after year 2000, we plot (5.15) for the years after year 2000. Indeed, the estimated net quake effects after year 2000 is close to zero.

The backcast model for log RGDP is given by

\[
\hat{y}_{1t}^2 = .916 \text{ Kanagawa}_t + 0.401 \text{ Fukushima}_t + 0.352 \text{ Aichi}_t + 0.705 + \hat{\epsilon}_{1t}, \\
\hat{\epsilon}_{1t} \sim N(0, \sigma^2_{1t}), \\
\bar{R}^2 = .959. \tag{5.18}
\]

The model for the hypothetically generated log RGDP for the period 1955 - 1993 is

\[
\hat{y}_{1t}^{2*} = .692 \text{ Osaka}_t + 0.423 \text{ Oita}_t - 1.761 + \hat{\epsilon}_{1t}^*, \\
\hat{\epsilon}_{1t}^* \sim N(0, \sigma^2_{1t}), \\
\bar{R}^2 = .998. \tag{5.19}
\]

Figure 4 plots the estimated net earthquake, structural change and combined effects and their respective 95% confidence intervals. Again, the estimated net quake effects for log RGDP after year 2000 is negligible.\(^{13}\)

To further check if \( T_2 = 2000 \) is a reasonable choice, we consider fitting a stock adjustment model of the form,

\[
y_{1t} - y_{1,t-1} = \gamma(y_{1t}^{*} - y_{1,t-1}), \tag{5.20}
\]

\(^{13}\)A referee suggests using structural break tests to identify the break point. Using the 1995-2009 data, the Chow (1960) structural break tests have \( F(6,3)=6.58 \) with \( P \)-value 0.07 for (5.16) and \( F(4,7)=5.06 \) with \( P \)-value 0.03 for (5.18). Given the assumption that the net earthquake effect approaches to zero as \( t \) approaches year 2000 and the limited post-quake sample observations, they do not appear to contradict the assertion that the net quake effects disappear before year 2000.
to the Hyogo RGDPPC or RGDP series for the period after the quake and $y_{1t}^*$ is the potential value of $y_{1t}$ under the new structure. In general, one would expect $0 < \gamma < 1$ unless the economy is already in equilibrium, then $\gamma = 1$. Suppose

$$y_{1t}^* = \beta^* \bar{y}_t^n + u_t, \quad (5.21)$$

then

$$y_{1t} = (1 - \gamma)y_{1,t-1} + \beta^* \bar{y}_t^n + u_t, \quad (5.22)$$

for $t$ from year 2000 onwards where $\beta^* = \beta \gamma$. Table 3 presents the estimated lag dependent variable coefficients for the stock-adjustment models for log Hyogo real GDPPC for the model selected by BIC by letting $T_2=1997, 1998, 1999, 2000, 2001$. As one can see that the estimated lagged hyogo coefficient is insignificantly different from zero, which implies an instant adjustment to the new equilibrium state $y_{1t}^*$, (i.e. $\gamma = 1$) for $T_2=2000$ or 2001. On the other hand, had $T_2=1997, 1998, 1999$, the lagged dependent variable coefficients are less than 1 and highly significant. This evidence appears to further support the selection of $T_2=2000$.

It is interesting to note that our approach indicates that the net stimulating quake effect on Hyogo real GDP due to government recovery effort is underestimated by the standard approach due to ignoring the presence of structural change ($\bar{y}_{1t}^2 - \bar{y}_{1t}^0$) for the period 1995 to 2000. The average of the earthquake effects (5.6) (ATE of the earthquake effects) for log RGDPPC for the period 1994-2000 is 0.1360 with standard error of 0.0594, but for the period 2001-2009, it is -0.0056 with standard error of 0.0164. For log RGDP, it is 0.0378 with standard error of 0.0328 for the period 1994-2000 and -0.0068 with the standard error of 0.0227 for the period 2001-2009. These results corroborate with the finding of Cavallo et.al. (2013) that natural disasters do not have significant effect on subsequent economic growth. On the other hand, there do appear to have persistent structural change effects for the economy of Hygo. Table 4 shows that the average of structural beak effects (5.7) (ATE of structural change effects) for log RGDPC is -0.0859 with the standard error
of 0.0483 and for log RGDP is -.0549 with the standard error of 0.0089. In other words, Hyogo economy has experienced a fall of 8.5% in real GDP per capita and 5.4% in real GDP due to the loss of competitiveness in Hyogo economy. However, it should be noted that these conclusions are drawn based on the assumption that the correlations patterns between Hyogo prefecture in the absence of treatment and other prefectures stay the same for the period prior to the treatment (pre-1994) and the period after the treatment (post-1994). Unfortunately, no Hyogo observations in the absence of treatment for the period after 1994 are available, we do not know how to test the hypothesis that the correlation patterns of Hyogo prefecture in the absence of treatment stay the same for the period pre-1994 and post-1994. Thus, this hypothesis is a maintained hypothesis, not a testable hypothesis. Should the maintained hypothesis do not hold, these estimates no longer make any sense.

6. Concluding Remarks

Isolating the impact of one factors from other factors can be tricky, in particular, when the outcomes are the working of a number of factors. This paper suggests a panel data approach to separate one impact from another. We applied our method to the analysis of the impact of the Great Hanshin-Awaji Earthquake on January 17, 1995. We found stronger initial stimulation effects due to the government recovering act in the period 1995 - 1998 and smaller negative quake impact in 1999 and 2000 than the convention estimates. These results corroborate the finding of Cavallo et.al. (2013) that natural disasters do not have significant effect on subsequent economic growing using panel country data and Abadre, et.al. (2010) synthetic method. We did not find persistent negative quake effects. We attributed the Hyogo per capita GDP lagging behind national average to the changes in the economic structure, not to the earthquake.

Many issues remain such as the reliability or unavailability of the data and the selection of proper regressors when the number of candidates far exceed the available time series observations, etc. This study is only a first attempt to separate the impacts of one
“treatment” from another when the observed outcomes are the working of both or more. We hope to further work on the improvement of our method in future studies.

REFERENCES


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Skidmore, Mark and Hideko Toya (2002). “Do Natural Disasters Promote Long-Run
Growth?” *Economic Inquiry* 40(4), 664-687.


Table 1: Correlation with Hyogo Prefecture based on log real GDP per capita

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<th>Data from 1955 to 1993</th>
<th>Data from 1994 to 2009</th>
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Table 2: OLS regressions based on log real GDP per capita

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Standard errors in parentheses

$^*$ $p < 0.05$, $^{**} p < 0.01$, $^{***} p < 0.001$
Table 3: $T_2$ and the Coefficient of Lagged RGDPPC for the Stock Adjustment

Model (5.6)

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<td>(3.17)</td>
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* p<0.05        ** p<0.01        *** p<0.001
Table 4: Estimated Long-Run Net Earthquake Effects and Structural Change Effects

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Figure 1: Actual, counterfactual, within sample prediction error (1955-1993), and measuring of economic impacts (1994-2009) based on log real GDP per capita.
Figure 2: Actual, counterfactual, and within sample prediction error (1955-1993), and measuring of economic impacts (1994-2009) based on log real GDP
Figure 3: Plot of the Net Earthquake Effects, Structural Change Effects and Combined Effects for Hyogo log RGPPC
Figure 4: Plot of the net Earthquake Effects, Structural Change Effects and Combined Effects for Hyogo log RGDP