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Crises and changes in productivity distributions: a regional perspective in Japan [1]

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Abstract

Is there a difference in resilience to crises between urban and rural areas? By using microdata of establishments in the manufacturing industry in Japan from 2007 to 2014, this study estimated how the productivity distribution of establishments in a region changed during two crises caused by different factors: the Global Financial Crisis of 2008 and the Great East Japan Earthquake in 2011. The results indicate the followings. (i) Although establishments in urban areas experienced a larger leftward shift in the productivity distribution than those in rural areas in both crises, their capacity to recover from crises was shown to be greater. (ii) There are several rural areas in which the productivity distribution did not change significantly as a result of crises, where productivity improvement had already stagnated. (iii) In a few rural areas, the distribution of productivity moved to the left during the crises and did not recover afterward, shifting to a different growth path compared to before the crises.

Keywords: crisis, productivity distribution, quantile approach
JEL classification: L60, O47, R11

[1]This study is conducted as a part of the Project "Regional Economy and Roles of Regional Finance in the Post COVID-19 World" undertaken at the Research Institute of Economy, Trade and Industry (RIETI). This study utilizes the micro data of the questionnaire information based on the "Census of Manufacture" and "Economic Census for Business Activity" which are conducted by the Ministry of Economy, Trade and Industry (METI), and the Census of Manufacture converter, which is provided by RIETI. The author is grateful for helpful comments and suggestions by Nobuyoshi Yamori (Kobe Univ.), Nobuaki Hamaguchi (Kobe Univ.), Masayuki Morikawa (RIETI), Keisuke Kondo (RIETI), Yoko Konishi (RIETI), and Discussion Paper seminar participants at RIETI.

1 Introduction

Japan is facing difficulties that are often faced by mature countries. Labor inputs decline as the working population shrinks and the growth of capital inputs has been sluggish based on the withdrawal of savings by an aging population and decline in investment as a result of shrinking markets. This leads to stagnant outputs, which are particularly pronounced in rural areas with relatively low populations and numbers of business establishments. One policy goal for maintaining the current economic level, particularly in rural areas, is to increase productivity through innovation. However, regional productivity growth has been hampered by large-scale negative external shocks that frequently affect the local economy. In the case of Japan, 20 years since the beginning of the 21st century, the regional economy has been repeatedly hit by negative events such as the recession caused by the bursting of the dotcom bubble in the US in 2001 and 2002, global financial crisis in 2008 and 2009, Great East Japan Earthquake in 2011, and COVID-19 pandemic in 2020 and beyond. This study statistically and quantitatively examined the extent to which these external shocks affected productivity growth. In particular, we aimed to determine whether there are differences between regions in terms of their ability to resist and recover from productivity declines caused by external shocks and if so, which regions are more vulnerable to the effects of these crises.

This study is not the first to analyze regional productivity by dividing Japan into several regions. Honma and Hu (2009) conducted a data envelopment analysis assuming that production in a region occurs using labor, private capital, public capital, and 11 different energy inputs, and studied changes in regional total-factor energy productivity between 1993 and 2003. Their results indicated that Japan's energy input productivity has improved by an average of 0.6% per year and that improvements in the productivity frontier have been led by regions other than those dependent on energy-intensive manufacturing industries. Kataoka (2011) used shift-share decomposition analysis to elucidate the factors that cause labor productivity in Japan to differ across regions. By using prefectural data from 1955 to 2005, he demonstrated that region-specific sectoral productivity differentials caused by accumulated past investments lead to regional differences in labor productivity. Okubo and Tomiura (2012) estimated the effects of policies that promote peripheral development with a focus on regional productivity. They compared the productivity of establishments in regions before and after the implementation of different policies and demonstrated that certain policies lead to less productive establishments in peripheral regions. Otsuka and Goto (2016) used data aggregated at the prefectural level to estimate total factor productivity (TFP) in regional production with capital and labor as inputs. Their results indicate that TFP in Japan increased during the period from 1980 to 2010 while the gap in TFP between regions narrowed simultaneously. For the same analysis period, Otsuka (2017) and Otsuka (2018) identified the determinants of regional TFP growth.[1] The former demonstrated that TFP growth rates are higher in regions with more social overhead capital, larger populations, a higher proportion of manufacturing industries, and greater exposure to international competition, and the latter demonstrated that interactions among people across regions are effective at increasing the rate of TFP growth.

Although the studies mentioned above have elucidated regional changes in productivity and their factors using various methods, our research aims to make contributions that differ from previous studies in terms of technical factors and research objectives. The first is the use of new analytical methods to overcome the challenges inherent in previous analyses. Many of the studies mentioned above have explained changes over time and differences between regions by comparing average productivities across regions or between different points in time. However, this method is descriptive and does not test whether changes over time or differences between regions are statistically significant. In addition to providing descriptive comparisons, an analysis involving statistical verification would increase the reliability of results. Another issue that remains to be addressed is the use of the (weighted) average of the productivities of individual firms as the productivity of a region because averaging may misinterpret the actual state of productivity. For example, assume that there are two firms with productivities of two and six in a specific region. Suppose an external shock causes the firm with a productivity of two to withdraw from the market and the productivity of the surviving firm with a productivity of six declines to five. The average productivities before and after the shock are 4 and 5, respectively, indicating that the shock increased average productivity. However, it would not be reasonable to conclude that the productivity of a region increased as a result of a shock by simply looking at this change in average productivity. This scenario arises because the effects of the withdrawal of firms from the market are not considered in a simple comparison of averages. It is often observed that firms are driven out of the market when a

[1] See also Otsuka (2021, pp. 49 to 79)

large negative shock occurs. In particular, the presence or absence of the exit of firms located in the left tail of the productivity distribution would have a non-negligible effect on the average value. Something similar to the scenario described above can occur even if there is no withdrawal of firms. Suppose there are three firms with a productivity of two and one firm with a productivity of six. If, as a result of the crisis, the productivity of the firms with productivity of two falls by 50% to one, whereas the productivity of the firm with a productivity of six increases to nine. The average productivity will not change after the shock. This indicates that the crisis did not affect average productivity, but productivity was halved for 75% of all firms. Comparing averages that do not consider the different effects of shocks on original productivity levels, as described in the example above, leads to erroneous results. Therefore, ways to avoid the fallacy of averages should be explored. To avoid these problems inherent in comparing averages, we adopted the quantile approach (QA) developed by Combes et al. (2012). This method attempts to capture changes in productivity not in terms of averages, but in terms of changes in the location and shape of the productivity distribution. Its usefulness has recently led to its use in several studies.[2] Based on the study by Adachi et al. (2021), who examined productivity dynamics for Japan using QA, we conducted an analysis of productivity from a more detailed regional perspective by dividing Japan into nine regions.[3]

The second contribution that distinguishes our study from previous studies is our research objective. We identify how crises can make a difference in a region's productivity decline and subsequent recovery. In particular, this paper will elucidate the extent to which each region had the capacity to resist and recover from declines in productivity during the two most recent major events (before COVID-19), namely the global financial crisis in 2008 and Great East Japan Earthquake in 2011. The former was a financial crisis with its epicenter in the US that hit the whole of Japan through capital markets, whereas the latter was a natural disaster that hit a portion of Japan and then affected the entire country through disruptions in the supply chain. By comparing different types of crises, we can examine the resilience of regional productivity from multiple perspectives.

The goal of our study is akin to a series of studies on resilience in regional science research. Resilience has been widely used as a generic term to describe the ability to confront and recover from external shocks. Research quantifying the resilience of economies has been active, particularly in regional economics, and is often featured in academic journals.[4] Resilience, which is related to equilibrium stability in economics and sustainability in dynamic macroeconomic theory, is an intriguing concept, but it is a buzzword and its definition is not uniquely determined (Rose, 2017). Attempts to define the concept of resilience, which was originally proposed in an engineering context by Holling (1973), are ongoing, but the challenge of making it quantitatively usable for policy analysis has yet to be resolved. Although there is no single method for capturing resilience at this time, the indicators used as outcomes are common to both employment and outputs in most studies. In contrast to defining such outcomes, we considered changes in the distribution of productivity as an output indicator of resilience. While changes in employment and production in response to a crisis are short-term responses, changes in productivity can be viewed as institutional changes that alter the production structure. Analyzing such changes in productivity has the potential to help us understand the long-term effects of crises. In particular, if the impact of a crisis on productivity varies from region to region, then the implication is that it will be a factor in creating regional differences in future employment and outputs.

Our results can be summarized as follows. First, at the time of the global financial crisis, the distribution of productivity shifted to the left in the six regions with a relatively large number of manufacturing establishments over two years after 2008. In the remaining three regions, no significant changes in the productivity distribution were observed. Among the six affected regions, most observed a rightward shift in their productivity distributions in 2010, with productivity improving to approximately half of its pre-crisis position. In one region, namely Hokuriku, the productivity distribution, which shifted 17.8% to the left during the 2008 crisis, did not show a significant recovery in the following year, indicating that it remained on a different growth path compared to before the crisis. Second, while the Great East Japan Earthquake in 2011 caused a shift in the distribution of productivity to the left of 7% to 13% in five

[2] See Arimoto et al. (2014), Kondo (2016), Accetturo et al. (2018), Jales et al. (2018), and Adachi et al. (2021).

[3] Adachi et al. (2021) used QA to clarify the dynamics of the productivity distribution in the Japanese manufacturing industry. However, they did not examine differences in changes in the productivity distribution by region and it is not clear which regions lead to changes in the productivity distribution in Japan.

[4] In only the past few years, the following journals have featured research on resilience: Cambridge Journal of Regions, Economy and Society, vol. 8, no. 2, 2015; Regional Studies, vol. 60, no. 4, 2018; Papers in Regional Science, vol. 96, no. 1, 2017; Annals of Regional Science, vol. 60, no. 2, 2018.

regions with a large weighting in the manufacturing sector, the following year (2012) saw a recovery in the distribution of productivity back to pre-crisis levels in most regions. What is particularly noteworthy is that the leftward shift in the distribution of productivity in the Tokai, Kinki, and Chugoku regions was much greater than that in the Tohoku region, which was the epicenter of the earthquake. Third, in both crises, no shift to the right of the truncation level of the productivity distribution was observed in any region, suggesting that the significant withdrawal of low-productivity establishments from the market was avoided during the crises. This implies that the government's measures to support small- and medium-sized enterprises, which were implemented during both crises, have been effective. Fourth, in many regions, when the productivity distribution shifts to the left, an upward dilation of the right end of the distribution can be observed. This indicates that although the crises caused an overall decline in the productivity of the manufacturing industry in the region, the group of establishments with high productivity increased their productivity. This change in the shape of the productivity distribution explains the unexpectedly small change in average productivity during the global financial crisis of 2008, which has been called a historic once-in-a-century crisis.

The remainder of this paper is organized as follows. In the following section, we review the concept of resilience in regions facing crises and introduce the QA employed in this study. Section 3 presents a preliminary discussion. It introduces regional classification, provides an overview of the impact of the crises, describes data, and presents the TFP measurement model. Section 4 presents the main estimation results, followed by a discussion of the possible reasons for the differing resilience levels of different regions in Section 5. The final section summarizes our conclusions.

2 Measuring the impact of a crisis

2.1 Resilience

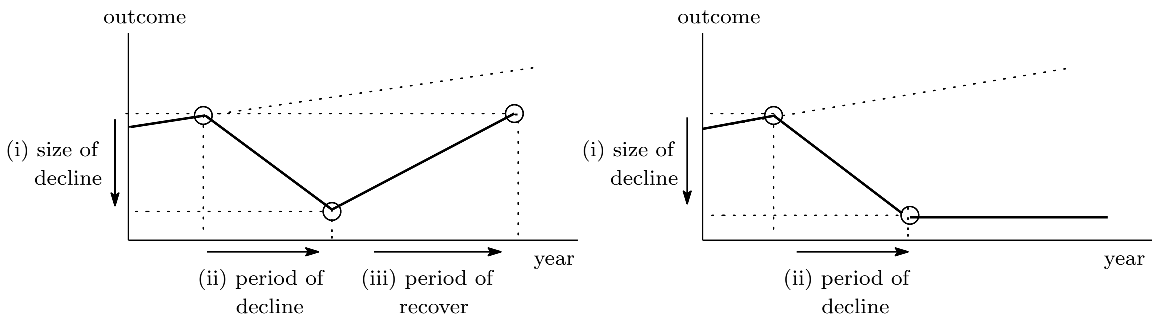
The impact of the crisis was estimated based on the concept of resilience. The regional resilience in our study was captured by three items, as shown in Figure 1. Given a crisis at a particular point in time, we capture (i) the extent to which the crisis reduced outcomes. We then measured (ii) how long the crisis resulted in a loss of outcomes based on the length of time over which a significant negative effect was detected. Finally, we determined (iii) the time required to return to the original outcome level to determine the regional ability to recover from a crisis. Figure 1(a) presents the case of a return to the original outcome level during recovery from a crisis. In contrast, Figure 1(b) illustrates a case in which the outcomes degraded by the crisis will never return to their original levels. The region described by the former figure may return to the pre-crisis growth path after a certain period of time, whereas the region in the latter figure will shift to a different growth path after the crisis.[5]

Most studies have focused on trends in economic outcomes such as employment and outputs as indicators for measuring regional resilience.[6] The interest in these measures may be related to the availability of data and political interests. In particular, the growth rates of employment and production are easy for voters to understand and are important indicators of political interests. Our goal is to move away from such short-term indicators and move closer to the source of growth in a region (i.e., TFP). In other words, we attempt to measure the resilience of production factors such as regional innovation and productivity, which can have an impact on long-term employment and production.

A few studies have employed indicators similar to ours, but the only two that share our interests are those by Balland et al. (2015), and Canello and Vidoli (2020). The former analyzed patent applications as a measure of the resilience of a region's innovation capacity. By using patent applications in 366 areas in the US from 1975 to 2002, the authors demonstrated that the resilience of innovation activities tends to be higher in areas that have a diverse and flexible knowledge base and are proximal to technologies in which their area has less comparative advantage. The latter used data from the Italian wine industry from 2009 to 2014 (i.e., the period affected by the global financial crisis) to estimate the efficiency of inputs by region and demonstrated that production efficiency is higher in regions that depend on exports

[5]There are far more diverse ways to view resilience than those discussed here. For a more detailed discussed, see Martin and Sunley (2020, p. 24).

[6]Since the pioneering studies by Davies (2011) and Fingleton et al. (2012), most studies have used employment or regional output (GDP) as an outcome measure. A few studies have used indicators other than employment and regional GDP, including those by Mazzola et al. (2018) for exports, Rizzi et al. (2018) for life expectancy, and CO_2 for emissions. See Martin and Sunley (2020) for a comprehensive review.



(a) A region with resilience to recovery

(b) a region without resilience to recovery

Figure 1: Capacity to resist and recover from a crisis

and have low financial risk. Studies that use changes in employment and outputs as outcomes examine the short-term impact of whether these indicators will return to their original equilibrium levels after a crisis. In contrast, studies such as those by Balland et al. (2015), Canello and Vidoli (2020), and ours, which use innovation capacity, efficiency, and productivity as indicators, are more concerned with the possibility that the equilibrium path may change as the result of a crisis. Our research contributes to elucidating the possibility that structural changes have occurred that have shifted the regional economy to a new growth path.

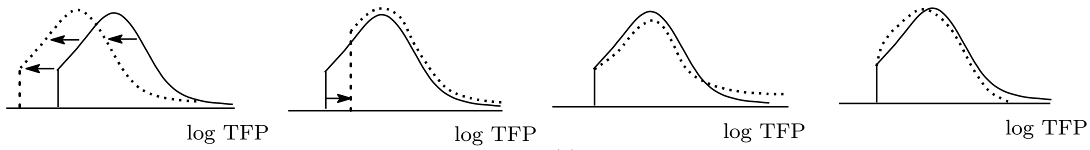
2.2 Quantile approach

We present the rate of shift in the productivity distribution as an outcome of resilience in Figure 1. Using a simple (or weighted) average of productivity as an indicator of regional productivity leads to a variety of problems, as discussed in the first section. The QA we employ allows us to estimate shifts in the productivity distribution after removing the problems that arise when comparing the averages of productivity.

By using the mathematical formulation presented by Combes et al. (2012, pp. 2556 to 2562) and discussed in the Appendix A of this paper, which is based on the study by Adachi et al. (2021, Section 3.1.1), we illustrate the concept of estimating the change in the productivity distribution in the QA based on Figure 2. The solid line in Figure 2(a) represents the productivity distribution of establishments in the manufacturing industry in the year prior to a crisis. The location and shape of the distribution changes as a result of the crisis, but if the crisis had caused an equal decline in productivity in all establishments, the post-crisis productivity distribution would have shifted, as indicated by the dotted line in Figure 2(a). In QA, changes in the location and shape of the distribution are decomposed into three components, one of which is the parallel shift effect of the distribution caused by a crisis, as shown in Figure 2(a). If the crisis shifts the productivity distribution parallel to the left, the coefficient of the shift effect S is negative and significant for estimation. Conversely, if the productivity distribution shifts in parallel to the right during the recovery period after a crisis, the coefficient representing the shift effect S is positive and significant.

Figure 2(b) presents a scenario in which the leftmost truncation of the productivity distribution moves to the right because some establishments with low productivity withdraw from the market as the result of a crisis. The productivity distribution is drawn based on the productivity of establishments that are active in the market and data on establishments whose productivity is so low that they cannot operate in the market are not available. For this reason, the distribution of productivity is truncated at the left end. Now, consider a case in which some of the least productive establishments, which were active in the market before a crisis, were forced to exit the market, while the productivity of all other establishments that survived and continued to operate in the market was unaffected by the crisis. In this case, the location and shape of the productivity distribution should change from a solid line to a dotted line in Figure 2(b).[7] In estimation under the QA, a change in the truncation point of the distribution to the

[7] There is another possibility that the cutoff point, which is truncated on the left side of the distribution, could move to the right. This is when, in a crisis, the productivity of the less productive firms located near the cutoff increases such that



(a) $S < 0$, $D = 1$, $T = 0$ (b) $S = 0$, $D = 1$, $T > 0$ (c) $S = 0$, $D > 1$, $T = 0$ (d) $S = 0$, $D < 1$, $T = 0$

Figure 2: Density distribution of productivity in the QA

Note. The solid line represents the productivity distribution before the crisis and the dotted line represents the productivity distribution after the crisis. S, D, and T are the estimates of the effects of shifts, dilation, and leftward truncations of the productivity distribution following a crisis, respectively.

right is confirmed by whether the coefficient T, which represents the truncation effect associated with the crisis, is positive and significant.

Figure 2(c) reveals that neither a shift in the distribution of productivity nor a truncation effect occurred during the crisis, but that the proportion of establishments with relatively high productivity increased as a result of low productivity establishments improving their productivity to survive the crisis. Such an effect caused by a crisis is called the dilation effect and when the coefficient D indicating this effect takes on a value greater than one, positive dilation occurs in the distribution. Conversely, when D is significantly below one, negative dilation occurs as the low-productivity portion of the productivity distribution dilates upward in response to the crisis, as shown in Figure 2(d).

This study extends the work by Adachi et al. (2021), who applied the QA to the analysis of time series changes in the distribution of productivity. They used data on the manufacturing industry in Japan from 1986 to 2014 to clarify productivity dynamics empirically and determined that during normal periods and economic recovery, the productivity distribution for Japan as a whole shifted to the right with a reduction in the distribution width as a result of relatively large improvements in the productivity growth of less productive establishments. However, during economic recession, the productivity distribution shifted to the left with a widening of the distribution as the result of an increase in the number of unproductive establishments. Our study, which uses the same approach to estimate time series changes in productivity, focuses on differences in regional economies that were not targeted in the aforementioned study. To estimate changes in productivity distribution by region, we analyze the potential for a crisis to have non-homogenous impacts on different regions, as well as establishments with different productivity levels, and discuss implications for regional resilience.

3 Preliminary Analysis

3.1 Regional classification

Although there are 47 prefectures in Japan, we conducted our analysis by grouping them into nine major regions based on location (Figure 3). The main reason for this is to internalize the spillover effects of the activities of establishments. Inter-firm transactions and commuting often occur across the borders of prefectures. When productivity is estimated based on prefectures, there is a possibility of missing the effects of productivity spillover from the activities of establishments on the production of neighboring regions. Additionally, policy design and monitoring by national agencies are often conducted on a regional basis, as defined in this paper. Therefore, the analysis in this study was conducted by grouping our analysis targets into nine regions.

Among the nine regions, the largest is the Kanto region, which contained approximately 35% of the total population of Japan as of 2015, according to the 2015 Population Census conducted by the Ministry of Internal Affairs and Communications.[8] Tokyo, the capital of Japan, is located in this region. In our sample, 25,272 establishments, which had the highest number in 2007, were located in this region. This region is followed by the Kinki and Tokai regions. The former has a 16% share of the population, whereas

the productivity distribution shifted uniformly upward, except at the lowest level. However, since it is not easy to imagine such a change occurring in a crisis, we interpret the rightward shift of the cutoff point as the exit from the market of the least productive firms.

[8] `http://www.ipss.go.jp/syoushika/tohkei/Popular/P_Detail2020.asp?fname=T09-05.htm`

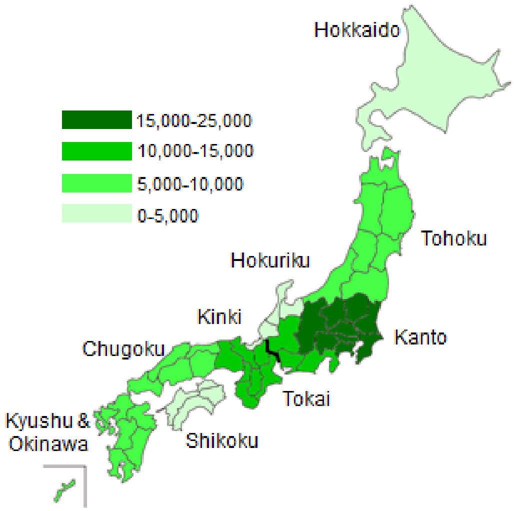


Figure 3: Regional classification

Note. The colors are categorized according to the number of establishments.

the latter has a 12% share. In 2007, there were 14,137 establishments in the Kinki region and 15,974 in the Tokai region. These three regions account for more than 60% of the population and in our 2007 sample, 62% of all establishments were located in these three regions. The remaining six regions are Hokkaido with 4% of the population (2,300 establishments), Tohoku with 7% (10,990), Hokuriku with 7% (3,542), Chugoku with 6% (6,035), Shikoku with 3% (2,744), and Kyushu-Okinawa with 14% (7,086).

3.2 Overview of the impact of the crises

Figure 4 presents the impact of the global financial crisis that began in September of 2008 and the Great East Japan Earthquake that occurred in March 2011. It shows the value added by manufacturing establishments by region between 2001 and 2014, with 2007, the year before the global financial crisis, having a value of 100. The Kanto, Tokai, and Kinki regions, which have large populations, are indicated by dots on the lines. This figure suggests that the impact of the two crises may vary by region. For example, in 2009, the Tokai and Hokuriku regions experienced the largest decline in value added during the global financial crisis, falling to 73% of the 2007 level. On the other hand, in Hokkaido and Shikoku, the level of value added in 2009 remained above 90% of the 2007 level, meaning it avoided a major impact or had the capacity to resist the decline of the value added in the crisis of 2008. The Great East Japan Earthquake had a particularly large impact on the Tohoku region, which was the epicenter of the disaster, with the 2011 index falling to 79% of the 2007 level. In the other regions, there was no significant decline in the index, unlike the Tohoku region. In the Tokai region, the value added returned to the 2007 level after 2012 and has continued to rise since then, but there are no other regions in which the value added returned to the 2007 level after the Great East Japan Earthquake.

Although the crises may have prompted short-term adjustments in regional value-added goods and services, they may also have had a varying impact on regional productivity, which defines the long-term structure of production. From this perspective, this study estimated whether the distribution of manufacturing productivity in each region changed before and after the crises and identified the capacity for resistance to and recovery from the crises in each region.

3.3 Data

We used the Census of Manufacture (CM) datasets provided by the Ministry of Economy, Trade, and Industry.[9] The scope of this survey covers not only large establishments, but also small-and medium-sized

[9]The CM data that we used run from 2007 to 2014. The CM survey was not conducted in 2011, but we replaced the 2011 data with the *Economic Census for Business Activity*, which was jointly conducted by the Ministry of Economy, Trade,

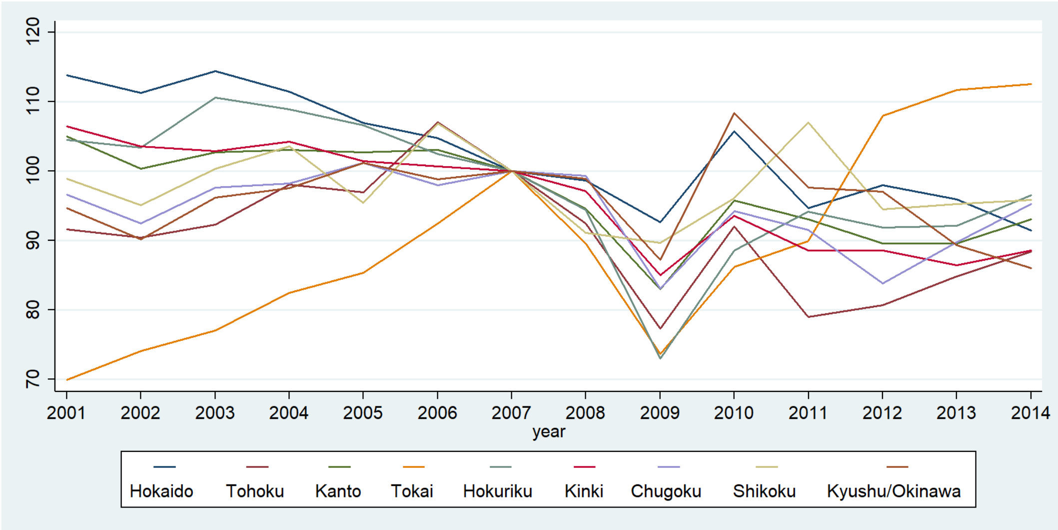


Figure 4: Changes in value added (2007 as a value of 100)

establishments. The advantage of using CM data is that code numbers are assigned to all establishments. This enabled us to trace their changes over time and construct an establishment-level panel dataset. Additionally, the CM covers a wide range of establishments by size. Both establishments listed on the stock market and unlisted firms are included in the data. The CM survey includes two forms: the first one is *Kou* for establishments with 30 or more employees and the second is *Otsu* for establishments with 29 or fewer employees. Following the literature (e.g., Adachi et al., 2021), we only used data from *Kou* to focus on all establishments with 30 or more employees. There are two reasons for this selection. First, the data in *Otsu* contain a large number of missing values, which reduces the reliability of analysis. Second, using data only from *Kou* allows us to exclude dormant establishments that may be established in Japan to avoid paying taxes. Therefore, it is desirable to use *Otsu* data to exclude from the analysis establishments that are not actually conducting business. In addition to establishments with 29 or fewer employees, we excluded samples in which the variables necessary to estimate the production function had negative values. The descriptive statistics of the full sample in all regions is reported in Appendix B.

3.4 TFP

In our analysis, two types of TFP were measured: TFP with production value as the output (added to the left side of the estimation equation) and TFP with value added as the output, which is defined as the production value minus the intermediate input cost. Intermediate inputs include materials, fuels, energy, and production outsourcing. Because both formulations have advantages and disadvantages, this paper mainly presents results based on the latter, similar to previous research. Therefore, the input variables when we consider the value added as the output variable are labor and capital stock. Because there are no data on working hours and utilization rates in the CM survey, labor is represented by the number of employees and capital stock is measured by the end-of-year book value. All nominal values were deflated using the price index. Deflators are available from the Bank of Japan and Cabinet Office of Japan.

Formally, the Cobb-Douglas production function we specify is

$$V_{itr} = \Phi_{itr} K_{itr}^{\beta_{kr}} L_{itr}^{\beta_{lr}}, \tag{1}$$

where K_{itr} and L_{itr} indicate the capital and labor inputs used to generate the value added by establishment i located in region r in year t, V_{itr}. β_{kr} and β_{lr} are production function coefficients. Φ_{itr} denotes TFP. We use the logarithm of (1) to obtain $v_{itr} = \phi_{itr} + \beta_{kr} k_{itr} + \beta_{lr} l_{itr}$, where the lower-case letters denote the logs. From this equation, we can compute TFP by using consistent estimates of the production function coefficients as $\hat{\phi}_{itr} = v_{itr} - \hat{\beta}_{itr} k_{itr} - \hat{\beta}_{Lr} l_{itr}$. Using the data on the TFP of each

and Industry, and the Ministry of Internal Affairs and Communications.

establishment $i = 1, 2, ...$, simple and weighted average ln TFPs in the industry at year t are calculated by $TFP_t = \sum_i \ln TFP_{ti}$ and $WTFP_t = \sum_i \theta_{it} \ln TFP_{ti}$, where θ_{it} is the added-value share of establishment i in year t. There are several standard methods for estimating TFP, among which Levinsohn and Petrin's (2003) approach was adopted in this study to address endogeneity issues.[10]

4 Results

The estimation results used to test whether the location and shape of the productivity distribution changed under QA are presented in tables in Appendix D. In the following, we summarize the estimation results presented in Appendix D for the cases of the global financial crisis and the Great East Japan Earthquake by region to see how the productivity distribution changed as a result of the two crises.

4.1 Impact of the Global Financial Crisis in 2008

Table 1 summarizes the significant changes in the productivity distribution during the global financial crisis based on the estimation results in tables in Appendix D. We look at the estimation results for each region in turn, starting with the Tohoku region.

Regions	Shift			Dilation	Truncation
	Year of Decline size		Year of Recovery size		
Hokkaido					
Tohoku	2008 -6.4%**	2009 -15.1%***	2010 9.8%***		
Kanto	2008 -6.2%***	2009 -12.3%***	2010 10.9%***	2009 +*	
Tokai	2008 -8.2%***	2009 -15.3%***	2010 9.7%***	2008 +**	
Hokuriku		2009 -17.6%***			
Kinki	2008 -10.2%***	2009 -9.7%***	2010 12.0%***	2008 +**	
Chugoku		2009 -8.4%*			
Shikoku					
Kyushu Okinawa					

Table 1: Summary of results: Global financial crisis

Note. Blank spaces indicate that an effect was not significant, while + in the dilation column indicates that $D > 1$ by a significant margin and the right tail of the distribution dilated upward. $***$, $**$, and $*$ indicate that the estimates are significant at the 1%, 5%, and 10% levels, respectively.

The productivity distribution in Tohoku shifted leftward by 6.4% in 2008. In the following year of 2009, it shifted further to the left by 15.1% compared to 2008. However, in 2010, productivity was on the road to recovery, as represented by a shift in the productivity distribution to the right of 9.8% compared to 2009. Productivity resilience in the Kanto region is similar to that in the Tohoku region. In 2008, the productivity distribution shifted by 6.2% and in 2009, it shifted further to the left by 12.3%. In 2009,

[10] Along with the estimation results of Levinsohn and Petrin's (2003) approach, Appendix C shows the results based on Wooldrige (2009), another representative approach, and the results when using OLS and OLS with fixed effects. Adachi et al. (2021) also estimated productivity using the method proposed by Olley and Pakes (1996), which requires the investment data of each establishment. However, their analysis method would introduce a sample bias because investment data were missing for more than 12% of the establishments in our dataset. Therefore, we did not adopt this method.

the coefficient of the dilation effect exceeded one, indicating upward dilation at the right edge of the distribution, as shown in Figure 2(c). The productivity began to recover in 2010 and the productivity distribution is shifted to the right by 10.9% compared to 2009. The resilience of productivity in the Tokai region is also similar to that in the Tohoku and Kanto regions, but the impact of the global financial crisis on productivity in the Tokai region is the largest among all nine regions. The productivity distribution shifted 8.2% to the left in 2008 and in the following year, it shifted to 15.3% left. In 2010, the distribution of productivity shifted 9.7% to the right, but it has yet to recover the amount of the annual shift to the left. The dilation effect can also be observed in 2008. In the Hokuriku region, the productivity distribution shifted 17.6% to the left in 2009, but the shift in the productivity distribution to the right the following year was not significant. The Kinki region exhibited almost the same movement in the productivity distribution as the Tohoku, Tokai, and Kanto regions, with the productivity distribution shifting 10.2% and 9.7% to the left in 2008 and 2009, respectively, before recovering 12.0% to the right in 2010. Although the overall productivity distribution shifted to the left in 2008, the coefficient for the dilation effect was significantly above one at the 1% level, indicating that productivity increased in the rightmost tail of the distribution. The characteristics of the changes in the productivity distribution in the Chugoku region are smaller in size, but almost the same as those in Hokuriku region, with an 8.4% shift in the productivity distribution to the left in 2009 and an insignificant shift in the productivity distribution to the right in the following year. The Hokkaido, Shikoku, and Kyushu-Okinawa regions were the regions in which no significant shift, dilation, or truncation effects were detected, and no changes in the productivity distribution were observed before or after the global financial crisis. In all nine regions, it is unlikely that establishments with low productivity exited the market during the crisis because there are no significant truncation effects.

From these results, we can draw the following implications. First, although the distribution of productivity in the four regions of Tohoku, Kanto, Tokai, and Kinki shifted sharply to the left in the wake of the crisis, these regions exhibited resilience with the distribution of productivity recovering to approximately half of its pre-crisis level two years after the crisis. Second, the Hokkaido, Shikoku, and Kyushu-Okinawa regions were not significantly affected by the crisis, but also did not see a shift in the distribution of productivity to the right, indicating that productivity stagnated in these regions. Third, the Hokuriku and Chugoku regions, which have relatively small populations and numbers of establishments, may have shifted to a different growth path from before the crisis. The productivity distribution shifted to the left during the crisis without a productivity recovery after the crisis.

4.2 Impact of the Great East Japan Earthquake in 2011

The impact of the Great East Japan Earthquake on the regional productivity distribution presented in Table 2 is slightly different from that of the global financial crisis. During the global financial crisis, the productivity distribution shifted to the left over two years. However, at the time of the Great East Japan Earthquake, the productivity distribution shifted to the left only in the year of the earthquake and moved immediately to the right in the following year. Additionally, the recovery of the productivity distribution after the global financial crisis only reached approximately half of the pre-crisis level. However, in the case of the Great East Japan Earthquake, a shift to the right in the distribution of productivity has occurred to such an extent that it has returned to its pre-earthquake level, although the recovery capacity of the Kinki region is relatively small.

A common finding during the global financial crisis and Great East Japan Earthquake is that no significant truncation effect was detected, except in the Kinki region in 2012. This indicates that there was no rightward shift in the minimum level of productivity that would allow establishments to operate in the market during the crisis, implying the implementation of policies to curb the withdrawal of low-productivity establishments from the market was effective. Interestingly, Table 5 reveals that the shift in the distribution of productivity to the left were equal to or greater in the four regions of Kanto, Tokai, Kinki, and Chugoku than in the Tohoku region, which was the epicenter of the earthquake.

5 Possible factors affecting regional resilience

The QA is a method for examining how the location and shape of productivity distributions have changed. It does not specify why they have changed and it is difficult to pinpoint the specific causes for why different

Regions	Shift		Dilation	Truncation
	Year of Decline size	Year of Recovery size		
Hokkaido				
Tohoku	2011 -6.9%*	2012 9.5%***		
Kanto	2011 -6.9%***			
Tokai	2011 -9.8%***	2012 10.0%**	2011 $+^{*}$	
Hokuriku				
Kinki	2011 -8.8%***	2012 5.8%**		2012 $-^{*}$
Chugoku	2011 -13.2%**	2012 12.2%**	2011 $+^{*}$	
Shikoku				
Kyushu Okinawa				

Table 2: Summary of results: Great East Japan Earthquake

Note. Blank spaces indicate that the effect was not significant. $+$ in the column of dilation indicates that $D > 1$ and the right (left) tail of the distribution has dilated upward, and $-$ in the column of truncation indicates that $T < 0$ and the truncation point of the distribution moves to the left. $***$, $**$, and $*$ indicate that the estimates are significant at the 1%, 5%, and 10% levels, respectively.

regions exhibit different characteristics of changes in their productivity distributions. However, from what has been shown in previous studies, we may be able to infer some factors that influence the resilience of the productivity distribution to crises.

First, the resilience of regional productivity to crises may be related to the degree of spatial concentration of manufacturing establishments. The major shifts in the distribution of productivity to the left during the crises occurred in regions where relatively large numbers of establishments were located. Additionally, establishments in these regions were operating in spatially dense conditions. Table 3 presents the number of establishments per 10 km^2 by region, which reveals that compared to other regions, the Kanto, Tokai, and Kinki regions not only have a large number of establishments, but also appear to be geographically dense. This geographical concentration may have two effects. The first is the economy of agglomeration. Establishments located in these areas benefit from economies of agglomeration because their competitors and business partners are located in close proximity. In this case, when a negative external shock occurs, its effects can easily propagate among establishments and effects on productivity can be transmitted widely and rapidly. However, recovery from the crisis in the urban areas is also likely to be faster and greater than that in other regions, taking advantage of the agglomeration. Kawakubo and Suzuki (2022) show that there is a positive relationship between firm productivity and supply chain recombination probability during a crisis. If it is easier for firms in urban areas to change old trading partners and find new ones, they may recover their productivity through the route of supply chain reconfiguration when recovering from a crisis. The second factor is the effect of competition. When establishments are geographically concentrated, competition in the market will be more intense than in other regions. Therefore, a crisis is likely to encourage the least productive establishments to exit under competition. However, the capacity for recovery of the productivity distribution after a crisis may be enhanced because establishment entry is more likely to occur in such a region's market during economic recovery. Of these two effects, the former seems to have a stronger impact in Japan because no truncation effect can be observed in our estimation results.[11]

Many previous studies have indicated that urban areas with a dense concentration of economic ac-

[11] This is consistent with the findings of Kondo (2016), who concluded that agglomeration economies, rather than the severe selection of unproductive establishments in larger regions, explain the regional productivity differences in Japan.

	Total	Per 10 km^2
Hokkaido	2,331	0.28
Tohoku	10,990	1.48
Kanto	25,272	5.10
Tokai	15,974	5.73
Hokuriku	3,542	3.40
Kinki	14,137	5.22
Chugoku	6,035	1.90
Shikoku	2,744	1.46
Kyushu-Okinawa	7,725	1.84

Table 3: Number of establishments (2007)

	Type 1 Lifestyle related	Type 2 Processing and assembly	Type 3 Basic materials
% of establishments that export	5.0	10.5	17.5
Hokkaido	60.1	22.2	17.7
Tohoku	25.3	28.2	46.5
Kanto	22.9	29.7	47.4
Tokai	23.2	27.3	49.5
Hokuriku	26.1	29.0	44.9
Kinki	24.5	32.3	43.3
Chugoku	26.7	31.9	41.3
Shikoku	40.2	28.7	31.1
Kyushu-Okinawa	35.8	28.8	35.4

Table 4: Breakdown of manufacturing industries by region (%, 2007)

Note. Lifestyle-related industries (Type 1) include food, beverages, tobacco, feed, textiles, furniture, equipment, and printing. The processing and assembly industry industries (Type 2) include wood products, pulp, chemicals, petroleum and coal, plastics, rubber products, ceramics, steel, nonferrous metals, and metal products. The basic materials industries (Type 3) include production, business, electronic components, devices and circuits, information and communication, and transportation machinery. The table shows figures for the year of 2007.

tivities tend to be more resilient to crises than less-dense areas. Establishments located in urban areas tend to have younger workers who are more flexible (Kitsos and Bishsop, 2018) or have higher human capital on average (Eraydin, 2015; Rizzi et al., 2018). Urban establishments also tend to be more diverse (Di Caro, 2015; Balland et al., 2015) and urban areas have greater transportation capacities that encourage labor to become more mobile (Otsuka, 2018; Chacon-Hurtadoa et al., 2020). All these factors may contribute to a more flexible response by establishments during a crisis, particularly during the recovery phase.

Second, if we analyze the data more closely, the manufacturing industry can be categorized into establishments that produce different types of products and the impact of a crisis may differ depending on whether that type of product is weighted more toward domestic or overseas markets. Some studies have pointed out that the degree of openness of local firms is related to the diversity of the region, which may have something to do with the resilience of the local economy (Canello and Thomson, 2015; Canello and Vidoli, 2020).

Table 4 presents the share of establishments in each region's industrial classification categories in 2007. Here, the manufacturing industry is divided into three main categories: lifestyle-related industry (Type 1) is related to food, beverages, tobacco, feed, textiles, furniture and equipment, and printing. Processing and assembly industry (Type 2) is related to wood products, pulp, chemical industry, petroleum and coal, plastics, rubber products, ceramics, steel, nonferrous metals, and metal products. Basic materials industry (Type 3) is related to production machinery, business machinery, electronic components, devices and circuits, information and communication machinery, and transportation machinery. With this

	Shift			Dilation		Truncation
	Year of Decline size		Year of Recovery size			
Type 1	2008			2010		
Lifestyle-related	-6.0%**			+**		
Type 2	2008		2010	2009		
Processing and assembly	-8.3%***		6.6%**	+*		
Type 3	2008	2009	2010	2008	2009	
Basic materials	-4.3%**	-25.1%***	16.4%***	+***	+***	

Table 5: Summary of results: Global financial crisis

Note. Blank spaces indicate that the effect was not significant, while + in the dilation column indicates that $D > 1$ and the right tail of the distribution dilated upward. $***$, $**$, and $*$ indicate that the estimates are significant at the 1%, 5%, and 10% levels, respectively. These types follow the classifications in Table 4.

classification, the first column of the table shows what percentage of establishments in each category are exporting. For example, only 5.0% of the establishments belonging to Type 1-industries export their products abroad. On the other hand, for establishments belonging to Type 2- and Type 3-industries, the figures are 10.5% and 17.5% respectively, which means that Type 2 and 3 industries are more involved in foreign markets.[12] The second and subsequent columns of the table show the share of each type of manufacturing industry in each region. Based on this classification, in 2007, Hokkaido, Shikoku, and Kyushu had the highest weights of lifestyle-related industries (Type 1), whereas the basic materials industry (Type 3) had the highest share in other regions. Since establishments in lifestyle-related industries tend to supply products to the domestic market, rather than to overseas markets, they will be the least affected by overseas trends among the three categories. In this case, the impact of the global financial crisis tends to be smaller in the Hokkaido, Shikoku, and Kyushu-Okinawa regions. In contrast, the processing and assembly industry and the basic materials industry have relatively high dependence on exports, and are easily affected by overseas supply and demand trends. In this case, the impact of the financial crisis on the productivity distribution of establishments in other six regions may be significant.[13]

To confirm that establishments producing different types of products were affected differently by the crises, we divided the manufacturing establishments into types 1 to 3 and then estimated how their productivity distributions changed before and after the two crises. Table 5 summarizes the results of estimating the impact of the global financial crisis. This table indicates that the global financial crisis caused a leftward shift in the productivity distribution of all manufacturing industries. The shift in the type-3 industries was particularly severe in 2009, with type-3 manufacturing being affected by a 25.1% shift in the productivity distribution to the left. Subsequently, Type-2 and type-3 manufacturing recovered in 2010 with their productivity distributions shifting to the right by 6.6% and 16.4%, respectively, whereas type-1 manufacturing productivity did not recover. These results are consistent with the fact that the impact of the global financial crisis on the distribution of productivity was greater in regions containing more type-3 establishments, namely Tohoku, Kanto, Tokai, Hokuriku, Kinki, and Chugoku, rather than other three regions containing more type-1 establishments.

Regarding the impact of the Great East Japan Earthquake shown in Table 6, one can see that the productivity distribution of type-1 establishments was affected to a greater extent than that of other types. The crisis shifted the productivity distribution of type-1 establishments to the left by 11.3% in 2011, but only shifted the productivity distribution of type-2 establishments by a lower value of 9.8%, and there was no significant change in the productivity distribution of type-3 establishments. This is different from the characteristics of the impact of the global financial crisis on each type of productivity distribution, but

[12]Type 1 industries not only have a low percentage of establishments that export, but also a small export value per establishment that exports. In 2007, the export value per establishment exporting overseas was 1.5 billion yen for Type 1, 4.4 billion yen for Type 2, and 7.8 billion yen for Type 3, with Type 1 industries having the smallest export value per establishment.

[13]This point may also be interpreted from another perspective in relation to trade theory. Melitz (2003) presented a model in which firms with high productivity can export, but firms with low productivity cannot. Based on this model, firms with high productivity in exports tend to be located in urban areas, which are relatively more affected by a decline in overseas demand. In this case, our results indicate that a crisis that causes a decline in overseas demand will cause a significant change in the productivity distribution in urban areas, even if there is no change in the productivity distribution in rural areas.

	Shift		Dilation	Truncation
	Year of Decline size	Year of Recovery size		
Type 1	2011	2012	2012	
Lifestyle-related	-11.3%***	7.7%***	$-^{***}$	
Type 2	2011	2012	2012	
Processing and assembly	-9.8%***	10.9%***	$-^{**}$	
Type 3		2012		
Basic materials		6.0%***		

Table 6: Summary of results: Great East Japan Earthquake

Note. Blank spaces indicate that the effect was not significant, while + in the dilation column indicates that $D > 1$ and the right tail of the distribution dilated upward. $***$, $**$, and $*$ indicate that the estimates are significant at the 1%, 5%, and 10% levels, respectively. These types follow the classifications in Table 4.

consistent with the hypothesis that type-1 industries are more likely to be affected because the earthquake mainly affected domestic supply constraints. In the year following the earthquake crisis, the positions of all types of establishments in the productivity distribution returned to the pre-crisis level or even higher for type 3, which is consistent with the feature in Table 2, where the degree of recovery in the productivity distribution was large in all regions.

From these results, we can draw the following conclusions. First, type-3 manufacturing industries suffered significant damage during the global financial crisis. Therefore, the productivity distribution in the Tohoku, Kanto, Tokai, Hokuriku, Kinki, and Chugoku regions, which rely on these industries, changed significantly. In contrast, the other three regions, where the weight of type-3 establishments was relatively low, were less affected by the global financial crisis. Second, at the time of the Great East Japan Earthquake, the impact on the productivity distribution of type-3 establishments was so small that it was insignificant. Therefore, the urban areas that were severely affected during the global financial crisis were able to resist the impact of the second crisis and had a strong capacity to recover from the crisis.

6 Conclusion

This study examined the resilience of Japan's regional economies to two crises with different causes, namely the 2008 global financial crisis and 2011 Great East Japan Earthquake. The contributions of this study, which differ from those of previous studies, can be divided into policy and technical aspects. Regarding the former, we identified the medium- and long-term impacts of the crises on the regional economy by considering changes in the productivity distribution of manufacturing establishments as an outcome measure, rather than employment or outputs. Our first finding shows that during the two crises, no change in the cutoff point of the productivity level necessary to survive in the market moved in the right direction in any region. This implies that it is unlikely that the crises triggered the exit of less productive firms from the market and the resources they held were reallocated to productive firms. Although the period covered is different, Fukao and Kwon (2006) also point out, using the expression "low metabolism," that the lack of reallocation of factors from unproductive to productive firms during recessions is the reason for the sluggish TFP growth rate in Japan. While the various measures taken by the government to save low-productivity firms from bankruptcy during the crisis may have been effective in the short term, in the medium to long term, they may have been a factor that impeded a shift in the productivity distribution to the right. Our second finding demonstrates that although a crisis tends to have a negative impact on productivity in urban areas, the productivity distribution recovers in the direction of its original level during the recovery period following a crisis. However, our analysis also identified some stagnant regions (e.g., rural areas) that were not affected by the crisis and did not see productivity growth. Additionally, we found some rural areas that were negatively affected by the crisis and did not recover productivity after the crisis ended, shifting to a different growth path compared to before the crisis. These findings reveal that major crises have significantly different impacts on urban and rural areas, which widens the productivity gap between regions and leads to future employment and income disparities. In particular, the productivity distribution may not return to its original position after the crisis in rural areas, and taking this into account, it would be important to make precautionary investments to avoid or mitigate the shocks of the crisis in advance.

What differentiates our study from previous studies in terms of technical aspects is that we applied a new method called the QA to the productivity analysis of regional economies. Previous studies have used stochastic frontier analysis, data envelope analysis, and factor decomposition analysis to compare average productivity values over time or across regions. The QA differs from these approaches in that it does not look at the impact of a crisis in terms of changes in average productivity, but rather in terms of changes in the location and shape of the productivity distribution across regions, which facilitates more comprehensive examination of the impact of a crisis on regional productivity. In the QA, analysis considers the possibility that the impact of a crisis will be different for establishments with originally different productivities. Based on this perspective, the QA removes the effects of changes in the shape of the productivity distribution, measures the rate of shift in the distribution of productivity, and provides a different perspective compared to analyses based on averages.

Finally, we will discuss directions for future research. First, it would be beneficial to examine the resilience of regional economies to crises by defining a new outcome measure. When analyzing regional resilience, there is an advantage to using a single indicator, such as employment, output, and the change in the productivity distribution that we focused on, to simplify the analysis and make the results easier to interpret. However, a better approach would be to analyze the resilience of a region using a more aggregated set of indicators. Social welfare, although difficult to quantify, would be a good target for such indicators to consider. Second, in our analysis, firms with fewer than 30 employees were excluded from the sample based on a large amount of missing data. However, if we assume that smaller establishments are more vulnerable to crises, we should look for data that allows us to capture the productivity of very small establishments to confirm the robustness of the results derived in this study.

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Appendices

Appendix A. Here, we describe the QA model by omitting the subscripts representing different regions. The cumulative density function of the log productivity distribution for active establishments at year t is represented by F_t. To obtain changes in the distributions of productivity for an active establishment between two time periods $t = 0, 1$, we define $\tilde{F}$ as the underlying cumulative density function of log productivity that we would observe in the absence of any truncation, productivity shift, and dilation in each time period. In other words, we cannot observe $\tilde{F}$. The differences between the unobserved and observed distributions of log productivity are summarized in the three parameters representing the left truncation T_0, dilation D_0, and shift S_0.

$$F_0(\phi) = \max \left\{ 0, \frac{\tilde{F}\left(\dfrac{\phi - S_0}{D_0}\right) - T_0}{1 - T_0} \right\}, \text{ where } T_0 \in [0, 1). \tag{2}$$

Here, ϕ is the productivity of establishments operating in the market. Additionally, we can describe the cumulative density function of the distribution of log productivity for surviving establishments at $t = 1$ as F_1 as follows:

$$F_1(\phi) = \max \left\{ 0, \frac{\tilde{F}\left(\dfrac{\phi - S_1}{D_1}\right) - T_1}{1 - T_1} \right\}, \text{ where } T_1 \in [0, 1). \tag{3}$$

Here, T_t captures the relative strength of the truncation compared to the previous period. If the natural selection mechanism is enhanced during a recession, the left truncation should move to the right ($T_t > 0$). D_t measures the dilation ratio compared to the previous period. Specifically, $D_t > (<)1$ indicates that the dispersion of establishment productivity spreads (shrinks). S_t indicates that surviving establishments are equally affected by a recession. In other words, $S_t > (<)0$ means that establishments equally increase (decrease) their productivity during a recession.

We now compare the two distributions with cumulative density functions F_0 and F_1. According to (2) and (3), the unobserved distribution $\tilde{F}$ can mediate these two distributions. The following relationship between F_0 and F_1 can then be obtained:

$$F_1(\phi) = \max\left\{0, \frac{F_0\left(\dfrac{\phi - S}{D}\right) - T}{1 - T}\right\} \quad \text{if} \quad T_0 > T_1, \tag{4}$$

$$F_0(\phi) = \max\left\{0, \frac{F_1(D\phi + S) - \dfrac{-T}{1-T}}{1 - \dfrac{-T}{1-T}}\right\} \quad \text{if} \quad T_0 < T_1, \tag{5}$$

where $D \equiv D_1/D_0$, $S \equiv S_1 - DS_0$, and $T \equiv (T_1 - T_0)/(1 - T_0)$. We use (4) and (5) to obtain an econometric specification that can be estimated from the data. We identify S, T, and D, as opposed to S_t, T_t, and D_t. The parameter S measures the extent to which the distribution shifts to the left or right as a result of an economic downturn. If $S < 0$, then the recession lowers the productivity of surviving establishments equally, corresponding to part (a) in Figure 2. In contrast, if $S > 0$, then the recession evenly increases the productivity of surviving establishments. The parameter T measures the relative strength of left truncation by comparing T_0 to T_1. For example, $T > 0$ indicates that the lower limit of productivity required to survive in the market rose in the recession following a crisis, which corresponds to part (b) in Figure 2. In contrast, $T < 0$ indicates that a recession reduces the lower limit of productivity for operating in the market. The parameter D measures the dilation of the log productivity of the distribution for active establishments during a recession. $D > 1$ indicates that establishments with relatively high productivity achieve greater productivity improvements than establishments with lower productivity. This corresponds to part (c) in Figure 2. In contrast, when $D < 1$, the productivity of relatively less productive establishments is improved compared to establishments with high productivity, which corresponds to part (d) in Figure 2.

Equations (4) and (5) define the key relationship between changes in the productivity distribution and the parameters $\{S, D, T\}$. Because we cannot estimate these parameters using (4) and (5), these two equations are transformed into quantiles and combined into a single equation to estimate S, D, and T. Suppose that $\tilde{F}$ is invertible and that F_0 and F_1 are invertible. $\lambda_0(u) \equiv F_0^{-1}(u)$ and $\lambda_1(u) \equiv F_1^{-1}(u)$ denote the u^{th} quantiles of F_0 and F_1, respectively. If $S > 0$, then (4) applies and can be rewritten as

$$\lambda_1(u) = D\lambda_0(T + (1 - T)u) + S \quad \text{for } u \in [0, 1]. \tag{6}$$

If $S < 0$, then (5) applies and can be rewritten as

$$\lambda_0(u) = \frac{1}{D}\lambda_1\left(\frac{u - T}{1 - T}\right) - \frac{S}{D} \quad \text{for } u \in [0, 1]. \tag{7}$$

We change the variable $u \to T + (1 - T)u$ in (7) as follows:

$$\lambda_0(T + (1 - T)u) = \frac{1}{D}\lambda_1(u) - \frac{S}{D} \quad \text{for} \quad u \in \left[\frac{-T}{1-T}, 1\right]. \tag{8}$$

Combining (6) and (8) for all S yields

$$\lambda_1(u) = D\lambda_0(T + (1 - T)u) + S \quad \text{for} \quad u \in \left[\max\left(0, \frac{-T}{1-T}\right), 1\right]. \tag{9}$$

(9) cannot be estimated because the set of ranks $\left[\max\left(0, \frac{-T}{1-T}\right), 1\right]$ includes an unknown parameter T. Therefore, we make a final change in the variable $u \to r_T(u)$, where

$$r_T(u) = \max\left(0, \frac{-T}{1-T}\right) + \left[1 - \max\left(0, \frac{-T}{1-T}\right)\right] u,$$

This transforms (9) into

$$\lambda_1(r_T(u)) = D\lambda_0(T + (1-T)r_T(u)) + S \quad \text{for } u \in [0,1]. \tag{10}$$

Now, let $\theta = (T, D, S)$ denote the parameter vector. To estimate θ, we use the infinite set of equalities given by (10), which can be rewritten in more general terms as $m_\theta(u)$ for $u \in [0,1]$ and

$$m_\theta(u) = \lambda_1(r_T(u)) - D\lambda_0(T + (1-T)r_T(u)) - S \quad \text{for } u \in [0,1].$$

To consider the asymmetric relationship between the two distributions arising from the opposite transformation, we use an infinite set of equalities

$$\tilde{m}_\theta(u) = \lambda_1(\tilde{r}_T(u)) - \frac{1}{D}\lambda_0\left(\frac{\tilde{r}_T(u) - T}{1-T}\right) + \frac{S}{D} \quad \text{for } u \in [0,1],$$

where $\tilde{r}_T(u) = max(0, T) + [1 - max(0, T)]u$. The estimator we use is

$$\hat{\theta} = \text{argmin}_\theta M(\theta) = \int_0^1 [\hat{m}_\theta(u)]^2 du + \int_0^1 [\hat{\tilde{m}}_\theta(u)]^2 du. \tag{11}$$

Let $\hat{m}_\theta(u)$ and $\hat{\tilde{m}}_\theta(u)$ denote the empirical counterparts of $m_\theta(u)$ and $\tilde{m}_\theta(u)$, respectively, where the true quantiles λ_0 and λ_1 are replaced by some estimators $\hat{\lambda}_0$ and $\hat{\lambda}_1$. We state the result $\hat{\theta} = (\hat{T}, \hat{D}, \hat{S})$ and the measure of goodness of fit R^2 as follows:[14]

$$R^2 = 1 - \frac{M(\hat{T}, \hat{D}, \hat{S})}{M(0,1,0)}. \tag{12}$$

Additionally, the standard errors of the estimated parameters $\hat{\theta}$ are bootstrapped. For each bootstrap replication, we draw observations with the same sample size as the data with replacement and estimate θ.

Appendix B. Descriptive statistics for all regions are shown in Table 7.

Total	Obs.	Mean	Std. Dev.	Min.	Max.
Value added	1,278,732	2085.73	12167.26	0.01	3489033.00
Production value	1,274,029	5372.69	29479.53	0.01	7286348.00
Capital	1,278,732	1129.29	6042.98	0.01	639445.10
Labor employment	1,278,718	1571.40	3767.14	30.00	269176.00
Intermediate goods	1,278,732	2827.12	19420.33	0.01	4984702.00

Table 7: Descriptive statistics

Note. These are descriptive statistics for all regions. Establishments whose value added takes a negative value are excluded from the sample.

Appendix C. The results of the production function estimation are given in Table 8.

Appendix D. Tables 9–11 show the estimation results. The top number for each year in each region is the estimated coefficient. The second number in the parentheses is the z-value. The two numbers in the third row indicate 95% confidence intervals. $*$, $**$, and $***$ indicate that the coefficients are significant at the 10%, 5%, and 1% levels, respectively. To illustrate how to read each table, let us examine the estimation results for the Tohoku region presented in the second block in Table 9. In 2007, there was

[14] In the QA, R^2 is defined by the degree of change in the three components shift (S), dilation (D), and truncation (T). For example, if there is no change in the three components $\hat{S} = 0, \hat{D} = 1$, and $\hat{T} = 0$, then $M(0,1,0)$. Therefore, $R^2 = 0$. According to this definition, R^2 tends to take on a large value when the impact of the shock is quantitatively large and tends to be small when the impact of the shock on the change in the distribution is small, even if the estimated coefficients are significant.

	OLS	FE	LP	W
ln k	0.291	0.064	0.104	0.105
	(508.71)	(73.19)	(65.20)	(74.56)
ln l	0.808	0.778	0.601	0.600
	(707.97)	(385.70)	(134.73)	(579.99)
Obs.	1,278,718	1,278,716	1,278,716	1,129386

Table 8: Estimation of the production function

Note. Each entry represents the production function coefficients. Z-values are in parentheses. OLS, FE, LP, and W mean that the estimation method of the production function is by the OLS, OLS with fixed effects, Levinsohn and Petrin (2003), and Wooldridge (2009) approaches, respectively. Obs. stands for the sample size.

no significant change in the distribution of productivity in the Tohoku region. However, in 2008, the coefficient indicating the shift effect was -0.066, which is significant at the 5% level. This indicates that the productivity distribution shifted 6.4% to the left in 2008 compared to 2007.[15] The coefficient for the following year of 2009 was -0.164, indicating an even larger shift to the left by 15.1% compared to the previous year. In 2010, the coefficient indicating the shift effect was 0.094, meaning that the productivity distribution shifted by 9.8% to the right compared to 2009. During the period of 2007 to 2014, dilation and truncation effects were not significant in the Tohoku region. The estimated results in Tables 9 to 11 for the remaining regions are read in the same manner.

[15]The percentage change is obtained by using $e^{-0.066} - 1 = 0.064$ for the coefficient of the estimation result. The same applies to calculating the other coefficient values in percentages.

Hokkaido					
	Shift	Dilation	Truncation	Obs.	R^2
2007	0.039	0.968	-0.003	2331	0.902
	(0.34)	(0.69)	(-0.0)		
	-0.188 - 0.266	0.877 - 1.058	-0.068 - 0.062		
2008	-0.115	1.047	0.003	2295	0.66
	(-1.54)	(-1.0)	(0.47)		
	-0.283 - 0.052	0.955 - 1.139	-0.008 - 0.014		
2009	0.098	0.976	-0.004	2212	0.874
	(0.27)	(0.24)	(0.38)		
	-0.604 - 0.799	0.784 - 1.169	-1.772 - 1.765		
2010	-0.137	1.073	0.001	2143	0.698
	(-1.64)	(-1.48)	(0.38)		
	-0.301 - 0.0267	0.977 - 1.169	-0.006 - 0.009		
2011	0.062	0.958	0.001	2090	0.703
	(0.93)	(0.96)	(0.40)		
	-0.069 - 0.193	0.872 - 1.043	-0.004 - 0.007		
2012	0.012	0.999	-0.001	2069	0.147
	(0.03)	(0.01)	(-0.0)		
	-0.654 - 0.677	0.851 - 1.148	-2.242 - 2.240		
2013	-0.003	0.994	0.001	2084	0.256
	(-0.03)	(0.11)	(0.11)		
	-0.194 - 0.188	0.884 - 1.103	-0.009 - 0.010		
2014	0.018	0.995	-0.001	2103	0.486
	(0.17)	(0.10)	(-0.05)		
	-0.197 - 0.234	0.895 - 1.094	-0.057 - 0.055		

Tohoku					
	Shift	Dilation	Truncation	Obs.	R^2
2007	-0.009	0.995	0.001	10990	0.708
	(-0.25)	(-0.25)	(0.82)		
	-0.076 - 0.059	0.956 - 1.034	-0.000 - 0.001		
2008	-0.066**	1.019	-0.001	10862	0.898
	(-2.02)	(0.91)	(-0.61)		
	-0.130 - -0.002	0.978 - 1.060	-0.002 - 0.001		
2009	-0.164***	1.039	0.000	10329	0.932
	(-3.98)	(1.62)	(0.04)		
	-0.245 - -0.083	0.992 - 1.086	-0.001 - 0.001		
2010	0.094***	1.013	0.001	9908	0.892
	(2.67)	(0.50)	(0.41)		
	0.025 - 0.163	0.962 - 1.063	-0.002 - 0.004		
2011	-0.072*	1.013	-0.002	9613	0.744
	(-1.67)	(0.50)	(-1.37)		
	-0.155 - 0.012	0.962 - 1.063	-0.005 - 0.000		
2012	0.091***	0.978	0.001	9422	0.889
	(2.83)	(-1.01)	(0.90)		
	0.027 - 0.153	0.935 - 1.020	-0.001 - 0.003		
2013	0.006	0.996	0.000	9453	0.125
	(0.15)	(-0.16)	(0.29)		
	-0.070 - 0.082	0.946 - 1.046	-0.001 - 0.002		
2014	-0.023	1.020	-0.001	9483	0.82
	(-0.71)	(0.78)	(-0.85)		
	-0.085 - 0.039	0.982 - 1.058	-0.002 - 0.001		

Kanto					
	Shift	Dilation	Truncation	Obs.	R^2
2007	0.006	0.985	0.000	25272	0.695
	(0.23)	(-1.21)	(-0.42)		
	-0.045 - 0.057	0.961 - 1.010	-0.000 - 0.000		
2008	-0.0635***	1.020	0.000	25150	0.725
	(-2.82)	(0.96)	(0.34)		
	-0.108 - -0.019	0.987 - 1.037	-0.000 - 0.000		
2009	-0.131***	1.025*	0.000	23871	0.959
	(-5.69)	(1.96)	(0.18)		
	-0.177 - -0.086	1.000 - 1.050	-0.000 - 0.000		
2010	0.103***	0.995	0.000	22991	0.881
	(3.04)	(-0.28)	(-0.15)		
	0.036 - 0.170	0.960 - 1.030	-0.002 - 0.001		
2011	-0.0715***	1.079	0.000	23010	0.73
	(-3.05)	(1.51)	(0.50)		
	-0.117 - -0.025	0.994 - 1.049	-0.000 - 0.000		
2012	0.0333	0.946	0.000	22896	0.462
	(1.43)	(0.29)	(-0.0)		
	-0.012 - 0.079	0.976 - 1.031	-0.001 - 0.001		
2013	0.005	0.990	0.000	22668	0.444
	(0.20)	(-0.78)	(-0.48)		
	-0.048 - 0.058	0.964 - 1.015	-0.000 - 0.000		
2014	0.008	1.001	0.000	22662	0.565
	(0.59)	(-0.14)	(0.51)		
	-0.036 - 0.068	0.971 - 1.025	-0.000 - 0.000		

Table 9: Estimation results: Hokkaido, Tohoku, Kanto

Tokai

	Shift	Dilation	Truncation	Obs.	R^2
2007	-0.013	1.002	0.000	15974	0.898
	(-0.40)	(0.12)	(-0.72)		
	-0.076 - 0.051	0.969 - 1.035	-0.001 - 0.000		
2008	-0.086***	1.029**	0.000	15935	0.717
	(-2.93)	(1.99)	(0.64)		
	-0.143 - -0.028	1.001 - 1.058	-0.000 - 0.000		
2009	-0.166***	1.028	0.000	15211	0.977
	(-4.83)	(1.38)	(0.0)		
	-0.234 - -0.099	0.988 - 1.068	-0.000 - 0.000		
2010	0.093***	1.009	0.000	14738	0.956
	(3.13)	(0.52)	(0.56)		
	0.034 - 0.151	0.975 - 1.043	-0.000 - 0.001		
2011	-0.103***	1.030*	0.000	14923	0.827
	(-3.14)	(1.69)	(-0.59)		
	-0.167 - -0.038	0.995 - 1.065	-0.002 - 0.001		
2012	0.095***	0.973	0.000	14902	0.789
	(4.22)	(-1.32)	(-0.15)		
	0.084 - 0.230	0.933 - 1.013	-0.002 - 0.002		
2013	-0.039	1.014	0.000	14704	0.428
	(-1.26)	(0.91)	(-0.45)		
	-0.099 - 0.021	0.984 - 1.045	-0.001 - 0.001		
2014	0.015	0.993	0.000	14796	0.708
	(0.41)	(-0.38)	(0.78)		
	-0.055 - 0.084	0.957 - 1.028	-0.000 - 0.001		

Hokuriku

	Shift	Dilation	Truncation	Obs.	R^2
2007	-0.044	1.011	-0.001	3542	0.336
	(-0.39)	(0.23)	(-0.02)		
	-0.265 - 0.178	0.917 - 1.105	-0.074 - 0.072		
2008	-0.002	0.987	0.000	3475	0.337
	(-0.04)	(-0.48)	(0.14)		
	-0.096 - 0.093	0.933 - 1.040	-0.002 - 0.003		
2009	-0.194***	1.033	0.000	3280	0.894
	(-3.21)	(1.02)	(0.03)		
	-0.312 - -0.075	0.969 - 1.096	-0.003 - 0.003		
2010	0.126	0.996	0.002	3149	0.874
	(1.40)	(-0.08)	(0.25)		
	-0.050 - 0.303	0.900 - 1.093	-0.012 - 0.016		
2011	-0.084	1.035	-0.002	3241	0.816
	(-0.50)	(0.57)	(-0.02)		
	-0.411 - 0.243	0.915 - 1.156	-0.134 - 0.132		
2012	0.082	0.983	-0.001	3320	0.802
	(1.44)	(-0.45)	(0.05)		
	-0.029 - 0.193	0.909 - 1.057	-0.005 - 0.005		
2013	-0.022	0.996	0.001	3311	0.393
	(-0.36)	(-0.12)	(0.25)		
	-0.139 - 0.095	0.928 - 1.064	-0.007 - 0.009		
2014	-0.050	1.035	-0.001	3338	0.585
	(-0.77)	(0.88)	(-0.47)		
	-0.177 - 0.077	0.957 - 1.113	-0.006 - 0.003		

Kinki

	Shift	Dilation	Truncation	Obs.	R^2
2007	-0.012	0.992	0.000	14137	0.794
	(-0.30)	(-0.42)	(-0.49)		
	-0.086 - 0.063	0.955 - 1.030	-0.001 - 0.000		
2008	-0.108***	1.039**	0.000	14046	0.857
	(-3.31)	(2.48)	(0.50)		
	-0.171 - -0.043	1.008 - 1.069	-0.000 - 0.001		
2009	-0.102***	1.013	-0.001	13472	0.965
	(-3.37)	(0.82)	(-0.88)		
	-0.161 - -0.042	0.982 - 1.044	-0.002 - 0.000		
2010	0.113***	0.978	0.000	13054	0.933
	(3.87)	(-1.38)	(0.65)		
	0.055 - 0.170	0.947 - 1.009	-0.000 - 0.001		
2011	-0.092***	1.023	0.000	13098	0.825
	(-3.05)	(1.33)	(0.49)		
	-0.151 - -0.032	0.990 - 1.057	-0.000 - 0.001		
2012	0.057**	0.988	-0.002*	13030	0.664
	(1.99)	(-0.72)	(-1.69)		
	0.000 - 0.113	0.955 - 1.021	-0.003 - 0.000		
2013	0.032	0.983	0.001	12896	0.895
	(1.16)	(-1.16)	(1.41)		
	-0.022 - 0.086	0.955 - 1.012	-0.000 - 0.002		
2014	-0.020	1.013	0.000	12949	0.693
	(-0.58)	(0.72)	(-0.30)		
	-0.087 - 0.047	0.978 - 1.048	-0.002 - 0.001		

Table 10: Estimation results: Tokai, Hokuriku, Kinki

Chugoku					
	Shift	Dilation	Truncation	Obs.	R^2
2007	-0.054	1.019	0.000	6035	0.586
	(-1.18)	(0.78)	(-0.39)		
	-0.143 - 0.035	0.971 - 1.066	-0.001 - 0.001		
2008	-0.046	1.007	-0.001	6000	0.708
	(-1.03)	(0.28)	(-0.44)		
	-0.134 - 0.041	0.958 - 1.055	-0.004 - 0.002		
2009	-0.088*	1.017	0.001	5769	0.738
	(-1.84)	(0.63)	(0.46)		
	-0.182 - 0.005	0.964 - 1.070	-0.002 - 0.003		
2010	0.007	1.039	(-0.0)	5600	0.746
	(0.05)	(0.82)	(-0.01)		
	-0.249 - 0.263	0.945 - 1.132	-0.093 - 0.092		
2011	-0.141***	1.048*	0.001	5599	0.700
	(-2.69)	(1.71)	(0.97)		
	-0.244 - -0.038	0.993 - 1.103	-0.001 - 0.003		
2012	0.115**	0.956	0.002	5592	0.685
	(2.41)	(-1.62)	(0.68)		
	0.021 - 0.209	0.903 - 1.009	-0.002 - 0.006		
2013	-0.015	1.012	0.000	5564	0.741
	(-0.38)	(0.51)	(-0.43)		
	-0.092 - 0.062	0.965 - 1.058	-0.002 - 0.001		
2014	0.017	1.003	0.001	5575	0.587
	(0.34)	(0.10)	(0.48)		
	-0.082 - 0.117	0.943 - 1.062	-0.001 - 0.002		

Shikoku					
	Shift	Dilation	Truncation	Obs.	R^2
2007	-0.025	1.003	0.001	2744	0.629
	(-0.21)	(0.05)	(0.03)		
	-0.170 - 0.132	0.891 - 1.116	-0.002, 0.004		
2008	-0.001	0.990	-0.001	2709	0.801
	(-0.02)	(-0.28)	(-0.57)		
	-0.259 - 0.208	0.920 - 1.060	-0.006, 0.003		
2009	-0.144	1.059	0.002	2611	0.543
	(-1.42)	(1.06)	(0.68)		
	-0.342 - 0.054	0.951 - 1.168	-0.008, 0.012		
2010	0.015	1.017	0.002	2535	0.546
	(0.22)	(0.44)	(0.42)		
	-0.115 - 0.144	0.942 - 1.092	-0.013, 0.016		
2011	-0.052	1.003	0.000	2553	0.507
	(-0.68)	(0.06)	(-0.08)		
	-0.204 - 0.099	0.911 - 1.094	-0.007, 0.006		
2012	0.102	0.977	0.001	2593	0.533
	(0.95)	(-0.46)	(0.02)		
	-0.108 - 0.312	0.879 - 1.076	-0.004, 0.006		
2013	0.009	0.996	-0.002	2575	0.841
	(0.12)	(-0.09)	(-0.63)		
	-0.135 - 0.153	0.910 - 1.083	-0.006, 0.003		
2014	0.010	0.989	-0.001	2541	0.185
	(0.06)	(-0.15)	(-0.02)		
	-0.320 - 0.340	0.842 - 1.136	-0.004, 0.005		

Kyushu-Okinawa					
	Shift	Dilation	Truncation	Obs.	R^2
2007	0.008	0.985	-0.002*	7725	0.883
	(0.23)	(-0.74)	(-1.91)		
	-0.060 - 0.076	0.945 - 1.025	-0.004 - 0.000		
2008	-0.066	1.028	0.000	7711	0.339
	(-1.27)	(0.98)	(0.34)		
	-0.168 - 0.036	0.971 - 1.084	-0.001 - 0.002		
2009	-0.071	1.015	0.000	7396	0.497
	(-1.49)	(0.64)	(-0.08)		
	-0.164 - 0.022	0.969 - 1.061	-0.002 - 0.001		
2010	0.066	1.002	0.000	7193	0.748
	(1.59)	(0.08)	(0.49)		
	-0.015 - 0.148	0.955 - 1.049	-0.001 - 0.001		
2011	-0.027	1.004	0.000	7097	0.419
	(-0.47)	(0.13)	(-0.28)		
	-0.138 - 0.084	0.944 - 1.064	-0.003 - 0.002		
2012	0.040	0.989	0.001	7062	0.810
	(0.78)	(-0.35)	(0.74)		
	-0.059 - 0.139	0.927 - 1.051	-0.001 - 0.002		
2013	0.041	0.980	-0.002	7103	0.585
	(1.08)	(-0.90)	(-1.33)		
	-0.033 - 0.115	0.936 - 1.023	-0.004 - 0.000		
2014	0.002	1.001	0.000	7086	0.125
	(0.03)	(0.03)	(0.19)		
	-0.096 - 0.099	0.941 - 1.062	-0.002 - 0.003		

Table 11: Estimation results: Chugoku, Shikoku, Kyushu-Okinawa

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