https://doi.org/10.20965/jdr.2019.p1030

Paper:

Effects of Post-Disaster Aid Measures to Firms: Evidence from Tohoku University Earthquake Recovery Firm Survey 2012–2015

Yuzuru Isoda*,†, Satoru Masuda, and Shin-Ichi Nishiyama*****

*Earth Science Division, Graduate School of Science, Tohoku University
6-3 Aramaki-aza-Aoba, Aoba, Sendai, Miyagi 980-8578, Japan
†Corresponding author, E-mail: isoda@tohoku.ac.jp
**Graduate School of Economics and Management, Tohoku University, Miyagi, Japan
***Graduate School of Economics, Kobe University, Hyogo, Japan
[Received July 5, 2019; accepted September 16, 2019]

Panel data of individual firms are a valuable source of information on the disaster resilience of the regional economy. Such data also helps to assess the effectiveness of government aids to recovery. Every year after the Great East Japan Earthquake 2011, from 2012 to 2015, Tohoku University's Graduate School of Economics and Management conducted the Tohoku University Earthquake Recovery Firm Survey (TERFS) to obtain such information. The survey collected 25,826 responses over the 4-year period from a total of 11,090 firms in the east Tohoku region, the most severely affected region. Based on this survey, this paper assesses the effects of the conventional and new government recovery aid measures introduced to help firms affected by the disaster on the levels of business activity. The paper finds that group subsidy and debt reduction had important roles in the recovery of business activities, and demonstrates the importance of a panel survey in understanding and guiding policies for the resilience of the regional economy.

Keywords: resilience, regional economy, aid measures, group subsidy, debt reduction

1. Introduction

1.1. Effects of Disaster on the Regional Economy and its Recovery

Some new firm support systems have been established to strengthen the disaster resilience of the regional economy after the Great East Japan Earthquake. This study shows how a disaster influences a regional economy and how the regional economy recovers after the disaster, using panel data on firms in the disaster-stricken area – Tohoku University Earthquake Recovery Firm Survey (TERFS) – collated by the Graduate School of Economics and Management of Tohoku University from 2012 to 2015. The effectiveness of the aid measures is also examined.

1.2. Macro Approaches

The influence of a large-scale disaster on a regional economy has been analyzed by regarding a disaster as a negative exogenous shock and evaluating a short-term effect, such as reduction of production in the stricken area immediately after the disaster and its ramifications in other areas. Although not many cases exist where medium- and long-term effects of a disaster are examined comprehensively, the conclusions of such cases are divided into the following arguments [1–3].

First, some quantitative studies conduct a correlation analysis between the disaster experience and the growth rate, based on a time series analysis (mainly in a unit of a national economy), and indicate that a disaster has a "growth acceleration effect" in the long term [4, 5]. In such studies, details on the growth mechanism and the cause-effect relationship are not always clarified sufficiently. Therefore, assumptions that introducing new technologies and innovations providing opportunities for new growth, strengthening of structural correlation, significance of R&D and knowledge transfer, and changes in productivity at the firm level have been examined [6–9].

However, some studies provide a contradictory argument [10, 11], pointing out that a temporal boom in sectors associated with reconstruction after a disaster could trigger stagnation in other sectors leading to a long-term "growth constraint effect" [12]. A re-examination of the Great Hanshin Awaji Earthquake disaster [13] and the Hurricane Katrina in New Orleans [14], by a cross-section analysis, reveals that population and wealth would likely flow out from disaster-stricken areas in a regional economy with high openness, and negative effects would easily increase. Another study argues that the "growth acceleration effect" is ostensibly observed because the data in use include many cases of disaster in high-income countries, and the disaster intensity indicators, based on the monetary amount of damage, over-evaluates the severity of disasters in high-income countries [15]. Input-output analyses and CGE models have been also applied as an analytical method [14, 16].

Furthermore, in response to increasing interest in "evidence-based policymaking," a few studies have em-

ployed quasi-experimental methods to evaluate the impact of disasters and the implementation of a reconstruction policy, and the number of such studies is rising. In these studies, a disaster is compared with a virtual (counterfactual) result that supposes no disaster in order to quantify the negative effects of a disaster [17].

1.3. Micro Approaches

Focusing on the decision-making and behavior-choice of microeconomic agents as an analysis unit, studies have also increasingly examined the process of industrial revitalization and economic reconstruction in disaster-stricken areas. Previous studies have mainly used spatially or industrially aggregated data at mesoscale, for example, at local government level or at middle division of industrial classification, partly because of data availability. On the other hand, business administration researchers have been interested in topics such as recruitment, financing, investment, and earnings projections, and several studies have been conducted using relatively few anecdotal cases. Under these circumstances, resilience research dealing with response and recovery capabilities against disasters have advanced and significantly linked to the knowledge about industrial organization and regional economics through micro-mesoscale association [18–20].

The study on firms conducted 16 months after the Northridge earthquake is considered the pioneering empirical study based on firm inspection. That study shows that the reopening of businesses was influenced not only by individual aid measures but also by the interruption of utilities and communication services [21]. Another study based on firm inspection, conducted after several disasters in the United States, examines preparedness for disaster, damage caused by a disaster, and recovery after a disaster [22]. The firm inspections conducted in 2010 and 2011 after the earthquake in New Zealand revealed that damage to customers and the problems on the staffing influenced recovery rather than damage to the facilities [23], and recovery depended on how a firm could respond swiftly under high uncertainty [24]. Most firm inspections after a disaster only include firms that continued their business after the disaster. However, one study included firms that closed their business after the disaster demonstrated that there are two patterns of such closures. Some closed their businesses immediately after the disaster due to direct damage caused by the disaster, while others closed their business after a while considering recovery conditions of firm groups and the financial situation after disaster [25]. In a pioneering study, using panel data of firms, a follow-up survey was conducted for 4 years on small firms at the relocation site in new town after the 2008 Wenchuan Earthquake. This survey showed that the firms that relocated and reopened their businesses closed them in succession [26]. These aforementioned studies descriptively or statistically examine which firm is more likely to recover, but they do not examine how policies and external aid measures contribute to recovery.

1.4. The Great East Japan Earthquake

The Great East Japan Earthquake on March 11, 2011, provides an appropriate case study to demonstrate the resilience of firms after a disaster. In this disaster, in addition to the seismic disaster – the world's largest magnitude of 9.0 – a large tsunami hit the Pacific coast of Japan, and extensive radioactive contamination was caused by an accident at the Fukushima Daiichi Nuclear Power Plant. The direct economic loss is estimated at 16.9 trillion yen, and this disaster has caused the most amount of damage in history [27]. Following the Great East Japan Earthquake, in addition to publications for the general public [28–32], an increasing number of discussion papers by RIETI and others, and academic papers [33–38] have been released, based on the economic reconstruction since then. However, a comprehensive picture of the Great East Japan Earthquake cannot yet be grasped.

1.5. Purpose of the Study

The Japanese government provided some new aid measures for the reconstruction of the regional economy and the firms immediately after the Great East Japan Earthquake. The recovery of firms can be understood through a large-scale questionnaire, "TERFS," conducted by the Earthquake Disaster Recovery Research Center of the Graduate School of Economics and Management, Tohoku University from 2012 to 2015. The extent of damage and subsequent business conditions, among other aspects, are surveyed (details are described below). Moreover, the survey also asks whether the firms received government aids. As for the Great East Japan Earthquake, some studies argue that the effects of the government's aid measures are limited [39, 40]. However, such an argument is based on analysis at the aggregate level [39], and on data at a certain point of time in the early stages after the earthquake [40]. Therefore, it is necessary to review the recovery process of individual firms based on time series data long enough for an economy to recover from such severe damage as the Great East Japan Earthquake.

Thus, this study measures the effects of various aid measures aimed at the recovery of production activities and examines which aid measure has contributed more. Hence, aid measures provided for firms by the government are summarized in Section 2, details of TERFS and the methodology are described in Section 3, the results of the analysis are presented in Section 4, and Section 5 presents the discussion.

2. Government Aids to Firms Affected by the Great East Japan Earthquake

2.1. Government Aids to Firms

Referring to reconstruction policies aimed at recovery of industry after the Great East Japan Earthquake, there are two kinds of aid measures, those adopted at the time of the Great Hanshin Awaji Earthquake and followed when the Great East Japan Earthquake struck, and those adopted

at the time of the Great East Japan Earthquake for the first time [41, 42]. This study examines the following 6 aid measures.

2.1.1. Aid Measures for Financing Through Interest Assistance

Since the 2011 fiscal year, immediately after the earthquake, "Great East Japan Earthquake Recovery Special Loans" (referred to as "Recovery Special Loans" hereafter) have been implemented through the Japan Finance Corporation (Nihon Seisaku Kin-yu Koko) and Shoko Chukin Bank (Shoko Kumiai Chuo Kinko) to recover the business facilities of the disaster-stricken small and medium-sized enterprises or to support their businesses. Under such Recovery Special Loans, the interest rate is reduced by 0.5–1.4% from the actual interest rate for small and medium-sized enterprises and micro-businesses damaged directly or indirectly by the earthquake. The upper lending limits amount to 300 million yen for small and medium-sized enterprises and 60 million yen for the micro-businesses. The maximum loan period is 20 years for equipment funds and 15 years for operating funds.

In addition to Recovery Special Loans, the local governments have implemented an interest subsidy independently. The system for the interest subsidy differs with each local government. For example, Miyagi Prefecture subsidizes an amount equivalent to 1.0–1.5% of interest on loans with upper lending limits of 30 million yen. However, the period of interest subsidy provided by local governments is relatively short. For example, in Miyagi Prefecture, the period of interest subsidy is 3 years beginning from the date of borrowing. Strictly speaking, the interest cut by Recovery Special Loans and the interest subsidy by local governments are separate systems, but in a broad sense, both are considered as interest assistance. Accordingly, in the empirical analysis of this study, interest cut and interest subsidy are together termed as "interest assistance."

2.1.2. Aid Measures Against the Double Debt Problem

The double debt problem indicates a situation where although production facilities of a firm are damaged by an earthquake and/or tsunami, an existing debt must be paid back and funds for capital investment necessary for recovery must be financed anew by a financial institution. The situation of double debt exists if the following conditions are met: (1) tangible fixed assets are damaged by an earthquake, (2) a firm is not exempted from existing debt, (3) a firm takes a new loan after an earthquake. According to TERFS, in the 2012 fiscal year, 1,191 firms met these conditions out of 3,654 firms that provided a valid answer. In other words, about one-third of firms located in the disaster-stricken areas can be seen as being in double debt. However, attention should be paid to the fact that the seriousness of the double debt problem varies with each disaster-stricken firm, and not all the firms located in the disaster-stricken areas have a serious problem.

To undertake active capital investment for the reconstruction of firms, financial institutions should ideally exempt firms from their existing debt. However, this is difficult to implement. In the case of the Great Hanshin Awaji Earthquake, existing debt was hardly exempted. Aid measures against the double debt problem have been introduced for the first time in the case of the Great East Japan Earthquake. The Industry Reconstruction Corporations (Sangyo Fukkou Kikou) and the Incorporated Organization for Supporting the Turnaround of Businesses Damaged by the Great East Japan Earthquake (Jigyousha Saisei Shien Kikou, referred to as "Shien-Kiko" hereafter) have bought up credits owned by the financial institutions in order to substantially reduce the existing debts of disaster-stricken firms or have eased the conditions of repayment of the firms. The support provided by the Industry Reconstruction Corporations and the Shien-Kiko has steadily increased since 2012. The Industry Reconstruction Corporations has supported 1,153 cases, and the Shien-Kiko has supported 736 cases. In the empirical analysis of this study, the purchase of credits by the Industry Reconstruction Corporations or the Shien-Kiko is termed as "debt purchase" from the viewpoint of firms, while the reduction of the existing debts by financial institution, the Industry Reconstruction Corporations, or the Shien-Kiko is termed as "debt reduction."

2.1.3. Rent Assistance and Assistance for Disaster Restoration Works

The Ministry of Economy, Trade, and Industry and the Japan Chamber of Commerce and Industry implemented aid measures from December 2012 to March 2014 to subsidize new rent and lease for small and medium-sized enterprises that bore lease obligations because of damage to leasing equipment, including buildings, caused by the earthquake. In this aid measure, 10% of new rent and lease were subsidized. The budget for this aid measure, about 10 billion yen, is relatively small compared to those of other aid measures. In the empirical analysis of this study, assistance for rent and lease is termed "rent assistance."

Each local government, other than the central government, has implemented aid measures for post-disaster restoration. Such aid measures operate differently under each local government. For example, Iwate Prefecture has implemented an aid measure that subsidizes expenses to reopen the business for those small and medium-sized enterprises whose business assets were damaged by the earthquake. The upper limit of assistance is 20 million yen, and the maximum subsidy rate is 50% of all expenses. The question in TERFS about "whether there is receipt of lump sum or subsidy from local government" is considered as a question on aid measures by local governments. In the empirical analysis of this study, such aid measures are termed "lumpsum subsidy."

2.1.4. Taxation Assistance

Aid measures related to taxation have been implemented based on the special exemption national law en-

acted on April 27, 2011. Exceptional measures have been offered for corporate loss from damaged business assets, refunding corporate tax and other national tax. In the local tax, there also exist exceptional measures for corporate loss from damaged business assets and the tax exemption to the small and medium-sized enterprises in the areas stricken by tsunami. The question in TERFS about "whether there is exemption of tax" is considered as a question on taxation assistance. In the empirical analysis of this study, such aid measures are termed as "tax exemption."

2.1.5. Preparation of Temporary Factories and Shops

Many firms in the coastal areas lost their factories, businesses, and shops due to the tsunami. To assist the disaster-stricken small and medium-sized enterprises in reopening their businesses, the Organization for Small & Medium Enterprises and Regional Innovation has implemented new aid measures to construct temporary factories and shops and to transfer them to the disaster-stricken municipalities. These facilities have been lent free of charge to the affected firms through the municipalities. In the empirical analysis of this study, such aid measures are termed as "temporary premises."

2.1.6. Restoration and Preparation Assistance Project for Group Subsidies to Small and Medium-Sized Enterprises

This project, commonly known as "Group Subsidy," is the aid measure introduced since the Great East Japan Earthquake. In this system, if a group of small and medium-sized enterprises is formed to build the core of a regional economy and, hence, promote recovery, and if a prefecture approves the group's plan, restoration and preparation of facilities and equipment are subsidized. This system is crucial because it enables "public expenditures to restore private properties," which had been difficult to be implemented previously. The central government and prefecture subsidize less than half and less than quarter of the expenses, respectively. The amount of public expenditure toward private production facilities of firms by Group Subsidy is largest among the aforementioned aid measures. Group Subsidy is considered as the aid measure that promotes the resilience of the regional economy. Therefore, this system is described in more detail in the next section.

2.2. Group Subsidies to Small and Medium-Sized Enterprises

The system of Group Subsidy is designed based on Article 14 of the Act concerning Special Financial Support to Deal with the Designated Disaster of Extreme Severity (the act of No. 150 in 1962) [43]. This Act, concerning Special Financial Support, stipulates provisions on subsidies by the government for disaster restoration works of cooperative associations within the area designated as the disaster of extreme severity. These provisions have been applied further to other groups meeting certain conditions, and such disaster restoration works have been approved. In Group Subsidy, a group must meet any of the following conditions to be entitled to apply for the plan of disaster restoration works.

(1) Supply chain type: recovery and restoration of a group of small and medium-sized enterprises play an important role in the supply chain.
(2) Significant effects on the economy and employment type: business and employment are large and a group contributes significantly to the economy and employment in a prefecture.
(3) Basic industry type: a group constitutes an economic and social base in a certain region and is indispensable for reconstruction and maintenance of employment in the region.
(4) Shopping street type: a group improves the convenience of life and shopping for local residents and has a social function to promote exchange among them.
(5) Community regeneration type: when residents are to return to their hometown, a group is indispensable for preparation of living conditions necessary for the residents and provision of employment opportunities related closely to the region concerned (for example, response to the returnees in reviewing the warning zones established in the nuclear power plant accident or in canceling the evacuation instructions).

According to the Board of Audit of Japan, in the first 18 public offerings as of the end of December 2016, it was decided to grant 497.3 billion yen, including national expenditure of 331.6 billion yen, to 690 groups in Hokkaido, Aomori, Iwate, Miyagi, Fukushima, Ibaraki, Tochigi, and Chiba Prefectures [44]. Many subsidies were approved in the 2011 and 2012 fiscal years. The target area has been limited to "the municipalities with tsunami flooded area and warning zone etc." since the 2013 fiscal year. On the other hand, the subsidies have been increased because of soaring material prices since July 2014. A flexible operating system has been adopted since the 2015 fiscal year to support not only reconstruction works but also new activities for new demand development.

As for changes in group composition, many groups fall into "significant effects on the economy and employment type" and "basic industry type" and are formed by major enterprises and groups of their subcontractors to maintain local employment. However, the trends in group composition have changed since 2013, intending to regenerate communities and rebuild life in cooperation with the local construction industry, distribution industry, and tourism. Now, the moratorium period of up to 5 years, when repayment of firm's own burden financed by the fund for business innovation without interest was deferred, is coming to an end. There is a growing interest in re-examining the repayment burden and in the movements on discontinuance and bankruptcy of businesses.

Group Subsidy has received a relatively high evaluation from the disaster-stricken firms. Accordingly, the system was applied to the Kumamoto Earthquake in April 2016

and the West Japan Heavy Rain in July 2018. On the other hand, the system was not applied to the Hokkaido Eastern Iburi Earthquake in September 2018, considering the extent of the damage. However, in addition to the problems of budget frame, source of revenue, accreditation criteria, and examination period, the business effects should be reviewed and evaluated from a point view of "what kind of group of firms has been formed for what objective, subsidies have been applied for and approved for what kind of scale and what kind of purpose, and to what extent did the group achieve the aforementioned functions of (1) to (5)." Attention should be paid, for example, to whether a new idea on agricultural diversification is born while building a new group between tourism sector and agriculture and marine product processing sector, which had a weak connection with one another previously; or to whether a new trade started between a core enterprise in the region and a local parts manufacturer after the Group Subsidy.

Contrarily, there are certain concerns. These relate to whether the system would be ineffectively managed if a firm that should have retired essentially survives with the assistance of this system, or a moral hazard may emerge if the scope of application expanded excessively. The latter would increase the number of victims who demand public aid after a disaster and fail to make efforts to help themselves. Moreover, it would be necessary to not only restore conditions to the level before the disaster but also to urge industry reorganization and business innovation.

The Tohoku Bureau of Economy, Trade, and Industry has conducted the "Questionnaire to Firms to which Group Subsidy was Granted" continuously. This is a precious information source to review the aforementioned points on Group Subsidy. Unfortunately, this questionnaire is a consciousness survey limited to the firms to which Group Subsidy was granted, and it is unsuitable for a quantitative evaluation about whether or not receipt, period, and scale of Group Subsidy are considered. Therefore, this paper reviews the effects of each aid measure, including Group Subsidy, using TERFS, which is introduced in the next section.

3. Data and Methods

3.1. Tohoku University Earthquake Recovery Firm Survey (TERFS) 2012–2015

The Graduate School of Economics and Management of Tohoku University organized the Earthquake Disaster Recovery Research Center immediately after the earthquake. This center launched a large-scale questionnaire titled "TERFS" in the 2012 fiscal year as a core study subject within the regional industry recovery research, aiming to grasp the recovery situation of the disaster-stricken firms quantitatively and record for the medium and long term. The objective of TERFS is to grasp the recovery process of firms located in the disaster-stricken areas and preserve records. The characteristics of TERFS are summarized as follows: (1) comprehensively understand the activities of firms in the disaster-stricken areas in terms of manpower, goods, and capital, (2) survey firms extensively in both inland and coastal areas of disaster-stricken Tohoku Region, (3) understand firms in the disaster-stricken areas in an industrially cross-sectoral manner, and (4) understand the dynamic recovery process of firms in the disaster-stricken areas [45, 46].

3.2. Survey Questions in TERFS

The TERFS questionnaire is 16 pages long for firms that answer the survey for the first time, and the follow-up survey is 12 pages long for those that answered TERFS previously. The questionnaire is summarized as follows [45, 46].

(1) Basic information

To understand the basic information of the firm, including the situation immediately before earthquake, the kind and amount of damage, situation of recovery, and whether the firm received public or private aid measures, and others are surveyed.

(2) Financing

To understand the problems of financing loan balance, whether there is reduction of debt burden, whether there is new borrowing (after the earthquake) and its amount, whether there is new investment (after the earthquake) and its amount, and evaluation of financing problems are surveyed.

(3) Capital investment, location, and business relationship

To understand the current situation of capital investment, relocation, and supply chain, the level of business activity compared to before the earthquake, capital investment, whether there is approved Group Subsidy, relocation of business, changes in suppliers, subcontractors, customers, and order receivers are surveyed.

(4) Human resources, employment, and labor management

To understand the employment and labor personnel system, the classification and number of employees, annual income of employees, and respondents' evaluation on securing human resources are surveyed.

The other basic information on capital, industrial classification, and address of the firms are acquired from "TRS Data Approach" created by Tokyo Shoko Research, Ltd., which is used as the sampling frame of this survey. In the follow-up surveys with firms that answered the questionnaire earlier, the items asking about the situation immediately before and after the disaster and those which do not change over time are excluded from the original questionnaire.

3.3. Sampling Methods and Responses

The firms covered by this survey are all firms that have their head offices in Iwate, Miyagi, and Fukushima

Prefectures and Hachinohe City in Aomori Prefecture. However, the financial industry, incorporated NPOs, and non-profit organizations other than the ordinary commercial company corporations are excluded from the survey. Firms that have only a branch, an office, or a factory but no head office in the disaster-stricken areas are also not covered.

In the 2012 survey, 56,101 firms were selected from the "TRS Data Approach" created by Tokyo Shoko Research, Ltd, as the population of the sampling frame. These were firms that have their head offices in the disaster-stricken areas. Stratified sampling was conducted with two strata of coast and inland. First, from the stratum of coastal municipalities, all 19,628 firms to be surveyed were extracted regardless of the scale of firm. All firms located on coast were in-principle surveyed to comprehensively understand the damage and recovery of firms located in areas expected to be seriously damaged by tsunami. Further, with regard to inland firms expected not to be damaged by tsunami, all 4,839 firms with 21 or more employees were extracted, and 5,053 firms were extracted randomly from 30,530 firms with 20 or fewer employees. The total of 30,000 firms were extracted for this survey. Because the questionnaire was sent by mail, no answer was obtained from firms that had closed their businesses at the time of the survey. The response rate was 21.9% for firms with 20 or fewer employees and 27.8% for those with 21 or more employees.

Similarly, the survey in 2013 extracted approximately 30,000 firms including firms not sampled in 2012, while the surveys in 2014 and 2015 sent questionnaires to only those firms that had already answered the questionnaire in 2012 or 2013. The survey in 2014 covered 10,956 firms and 5,713 firms answered the questionnaire with a recovery rate of 52.1%. The survey in 2015 covered 10,560 firms and 5,514 firms answered the questionnaire with a recovery rate of 52.2%. The surveys in 2014 and 2015 showed a higher recovery rate compared to those in 2012 and 2013 because the questionnaires were sent only to firms that had answered the questionnaire before. In four surveys in total, 25,826 answers were obtained from 11,090 firms and 8,097 firms answered more than once (**Fig. 1**).

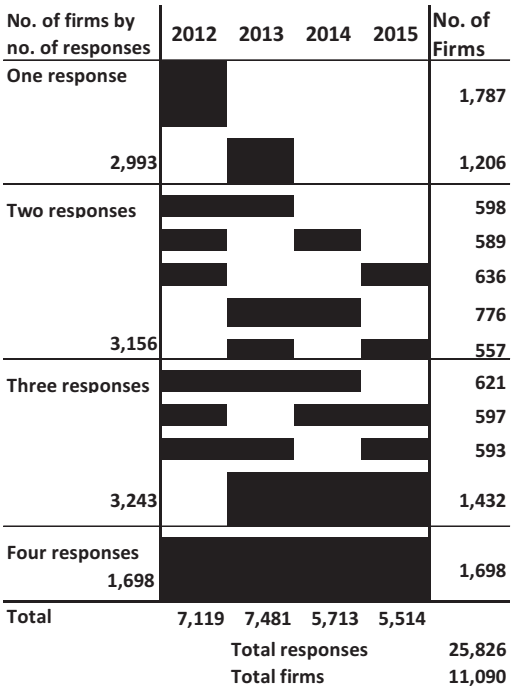

Fig. 1. Number and patterns of responses (source: TERFS). The height of the bars is proportional to the number of firms.

3.4. Method

The TERFS results can be used to obtain recovery curves of firms after a disaster. The recovery curve shows a chronological change in an index of a firm after a disaster and is expected to return to the level before a disaster over time. This study focuses on the business activity rate found in TERFS. The business activity rate is defined as "the level of business in terms of production and sales in each period, supposing that business activity in the last accounting period before an earthquake is 100%." The business activity rate is expected to be the lowest immediately after a disaster and to recover to 100% gradually. By comparing the recovery curves among the firms, depending on whether there are aid measures, the effects of the aid measures concerned can be revealed. Such a comparison would be possible using only panel data of firms.

Because TERFS repeats observations of the same firm, a linear mixed model is used [47]. A random intercept is provided to each firm to take the characteristics of the individual firm into consideration. Similarly, variations due to the industrial classification of 12 sectors, the size of firm of 4 levels and the region of 7 areas are also controlled by random intercepts. The dependent variable is the natural logarithm of business activity rate. Because the business activity rate values have large skewness, the natural logarithm is taken, which takes a negative value if the business activities of a firm fall below the level before an earthquake, and it takes 0 if the business activities are at the same level as before an earthquake. The business activity rate varies largely not only due to the differences in the degree of damage but also due to reconstruction booms or business interruptions caused by relocation after the earthquake (**Fig. 2**). Because the business activity rate fluctuated during the period of the surveys, a robust regression method is also used for estimation of parameter. This method estimates parameters by means of a weighting function and reduces the influence of outliers [48].

Then, using the parameter of a linear mixed model, the business activity rate with only a certain aid measure and the rate without any aid measure are estimated. By comparing these two activity rates, the effects of the aid measure can be understood. Furthermore, by subtracting changes in the business activity rate without an aid measure from those with that aid measure, the extent of effects of the aid measure on recovery can be measured.

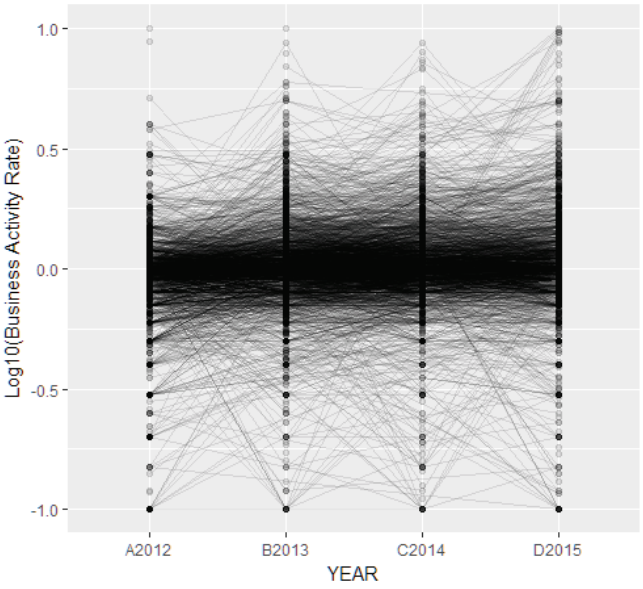

Fig. 2. Business activity rates over 4-year periods (source: TERFS).

3.5. Model

The explanatory variables include the fiscal year dummy to obtain a non-parametric recovery curve, and the 2015 fiscal year, the last year of the surveys, is taken as a reference year when the business activity rate is expected to recover nearly to the level before the disaster. To consider the magnitude of damage to firms, "damage rate" is calculated as a value between 0 and 1 by dividing the amount of damage to tangible fixed assets, excluding land, by the tangible fixed assets before the disaster. All other variables are binary. The cause of damage is distinguished by the variables "earthquake damage," "tsunami damage," and "nuclear accident." Indirect damages of "forced relocation" due to the nuclear accident and tsunami, "nuclear ill-reputation loss" due to the nuclear accident, "supplier damages," and "client damages" are also considered. These direct and indirect damages are based on answers provided by firms in the first TERFS survey.

The following aid measures were considered: "interest assistance" to support financing of firms, "debt reduction" introduced to solve the double debt problem, "debt purchase" that bought existing loans of firms from financial institutions, "temporary premises" that provided the places for business activities of small and medium-sized enterprises, "Group Subsidy" to subsidize the recovery expenses of the facilities of a group, "rent assistance" to subsidize the lease of firms, "tax exemption" including refund and exemption of tax, and "lumpsum subsidy" provided by the prefectures and local governments. Whether the assets of firms are covered by "earthquake insurance" as self-defensive measures for firms was also considered. These variables influence the level of the business activities during the surveys and the interaction between these variables and the fiscal year dummy influences the shape of the recovery curve.

For analysis, the statistical software R ver 3.4.1 was used, and the package "lme4" for the linear mixed model, "lmerTest" to obtain the test values for linear mixed model, and "robustlmm" for robust estimation of linear mixed model were also used.

4. Effectiveness of Aid Measures on Recovery Curves

4.1. Four Models

We estimate 4 models for the level of business activities in each year. Model 1 estimates the recovery curve after the disaster without considering the aid measures. Model 2 considers all the aid measures and their effects in each period. Model 3 is a parsimonious model. Model 4 shows the results of the robust linear mixed model using the same variables as in model 3, and the robust estimates are obtained by down-weighting the outliers and extreme values using Huber weight.

4.2. Results

The analysis of the deviance table is shown in **Table 1**. The statistical significance of the variables and the cross terms can be evaluated using this table. Parameter estimates are shown in **Table 2**. Because the dependent variable is a natural logarithm, the exponent of the estimated coefficient indicates a factor of change per unit change in the explanatory variable. However, in case the coefficient is close to 0, the approximation $\exp(b) \approx 1 + b$ is valid. Accordingly, the coefficients are approximated as a relative change in the business activity rate in response to a unit change in the explanatory variable. Considering this approximation, the magnitude of the effects is described below. The recovery curves obtained from the parameter estimates are shown in **Fig. 3**.

4.3. Effects of the Disaster

Model 1 is a basic model and estimates the log business activity rate of firms in each year. The intercept shows the log business activity rate of the firms without damage in 2015, the reference year, and the coefficients of the fiscal year dummy show the recovery rate of the firms without damage (**Table 2**). Neither the intercept nor each fiscal year dummy has statistical significance, indicating that firms without damage operated already in 2012 at the same level as before the disaster.

The coefficients of the cross terms between damage rate and the fiscal year dummy measure the difference between the business activity rates of the fully damaged firms (whose tangible fixed assets were damaged 100%) and that of the firms without damage in each fiscal year. The business activity rate of the fully damaged firms is lower by 13% than that of the firms without damage in 2015, and lower by an additional 30% in 2012. Of the three causes of direct damage, "earthquake damage" is statistically significant and positive, indicating that firms

Table 1. Analysis of deviance table.

(a) Analysis of Deviance Table (Type II Wald chi-square tests)

	model 1		model 2		model 3		model 4 †	
	Chisq	d.f.	Chisq	d.f.	Chisq	d.f.	Chisq	d.f.
Year	1.135	3	1.527	3	1.529	3	na	
Damage rate	106.246	1 ***	77.949	1 ***	88.666	1 ***	na	
Year * Damage rate	30.529	3 ***	18.570	3 ***	24.922	3 ***	na	
Earthquake damage	3.584	1 .	2.946	1 .	2.542	1	na	
Year * Earthquake damage	9.353	3 *	9.572	3 *	9.425	3 *	na	
Tsunami damage	1.993	1	6.004	1 *	4.247	1 *	na	
Nuclear damage	3.735	1 .	3.507	1 .	4.985	1 *	na	
Nuclear ill-reputations loss	22.297	1 ***	21.870	1 ***	22.247	1 ***	na	
Year * Nuclear ill-reputations loss	5.908	3	–		–		–	
Forced relocation	2.762	1 .	1.227	1	–		–	
Year * Forced relocation	6.978	3 .	–		–		–	
Supplier damage	0.997	1	0.667	1	–		–	
Client damage	6.978	1 *	4.520	1 *	4.327	1 *	na	
Year * Client damage	0.997	3	–		–		–	
Group subsidy	–		2.005	1	1.915	1	na	
Year * Group subsidy	–		4.943	3	6.910	3 .	na	
Group subsidy * Damage rate	–		2.568	1	2.511	1	na	
Year * Group subsidy * Damage rate	–		16.076	3 **	16.924	3 ***	na	
Debt reduction	–		9.080	1 **	9.632	1 **	na	
Year * Debt reduction	–		2.401	3	2.452	3	na	
Debt reduction * Damage rate	–		0.437	1	0.321	1	na	
Year * Debt reduction * Damage rate	–		15.209	3 **	15.381	3 **	na	
Debt purchase	–		13.921	1 ***	14.222	1 ***	na	
Year * Debt purchase	–		19.267	3 ***	18.396	3 ***	na	
Debt purchage * Damage rate	–		0.004	1	–		–	
Year * Debt purchase * Damage rate	–		2.388	3	–		–	
Temporary premise	–		7.403	1 **	8.511	1 **	na	
Year * Temporary premises	–		6.746	3 .	–		–	
Lumpsum subsidy	–		8.043	1 **	9.607	1 **	na	
Year * Lumpsum subsidy	–		1.248	3	–		–	
Interest assistance	–		15.406	1 ***	14.489	1 ***	na	
Year * Interest assistance	–		1.104	3	–		–	
Rent assistance	–		0.008	1	–		–	
Year * Rent assistance	–		3.728	3	–		–	
Tax exemption	–		2.047	1	–		–	
Year * Tax exemption	–		0.722	3	–		–	
Earthquake insurance	–		2.229	1	–		–	
Year * Earthquake insurance	–		1.346	3	–		–	

(b) Analysis of Random effects Table:

	model 1		model 2		model 3		model 4 †	
	Chi.sq	d.f.	Chi.sq	d.f.	Chi.sq	d.f.	Chi.sq	d.f.
Firm id	360.44	1 ***	347.45	1 ***	348.21	1 ***	na	
Year * Industry	52.93	1 ***	39.15	1 ***	38.69	1 ***	na	
Year * Firm size category	21.33	1 ***	13.28	1 ***	14.90	1 ***	na	
Year * Region	2.11	1	3.64	1 .	3.51	1 .	na	
Number of obs.	9490		9311		9311		9311	
AIC	16112.4		15456.2		15427.4		na	
Deviance	16048.4		15314.2		15339.4		na	
Residual degree of freedom	9458		9240		9267		9267	

Notes: *,**, and *** represent statistical significance at the 5%, 1%, and 0.1% levels, respectively, based on Satterthwaite's degrees of freedom method for model 1–3.
†Analysis of deviance table and analysis of random effects table not available for model 4, which uses a robust linear mixed model.

damaged by the earthquake recovered more swiftly than those damaged by other causes. Firms damaged by the earthquake also benefited from the special procurement demands after the earthquake. However, the coefficients of cross terms with the fiscal year dummy show that the business activity rate fluctuated. The coefficient of "tsunami damage" does not have statistical significance but is positive because the reduction in the business activity rate caused by the tsunami is already covered by the damage rate. On the other hand, "nuclear damage" shows a negative value because the business activity rate lowered due to evacuation even if the tangible fixed assets were not damaged.

As shown in **Table 1**, "nuclear ill-reputation loss" has

Table 2. Parameter estimates for log business activity rates.

	model 1			model 2			model 3			model 4		
Fixed effects:	est.	s.e.		est.	s.e.		est.	s.e.		est.	s.e.	
(Intercept)	−0.030	0.047		−0.005	0.043		0.001	0.042		0.083	0.024	***
Year[2014]	0.087	0.063		0.069	0.057		0.054	0.057		−0.022	0.034	
Year[2013]	0.037	0.062		0.038	0.056		0.028	0.055		−0.039	0.033	
Year[2012]	0.034	0.062		−0.001	0.056		−0.007	0.055		−0.079	0.033	*
Damage rate	−0.128	0.058	*	−0.166	0.094	.	−0.147	0.091		−0.118	0.040	**
Year[2014] * Damage rate	−0.048	0.073		0.033	0.123		0.000	0.119		0.015	0.055	
Year[2013] * Damage rate	−0.270	0.070	***	−0.039	0.112		−0.082	0.109		0.003	0.050	
Year[2012] * Damage rate	−0.298	0.068	***	−0.166	0.107		−0.206	0.102	*	−0.120	0.046	**
Earthquake damage	0.061	0.028	*	0.063	0.028	*	0.058	0.028	*	0.007	0.012	
Year[2014] * Earthquake damage	−0.097	0.036	**	−0.103	0.036	**	−0.101	0.036	**	−0.003	0.017	
Year[2013] * Earthquake damage	−0.013	0.033		−0.028	0.033		−0.023	0.033		0.006	0.015	
Year[2012] * Earthquake damage	−0.034	0.034		−0.029	0.034		−0.027	0.034		0.008	0.015	
Tsunami damage	0.024	0.017		0.043	0.017	*	0.035	0.017	*	0.009	0.006	
Nuclear damage	−0.048	0.025	.	−0.046	0.024	.	−0.053	0.024	*	−0.007	0.009	
Nuclear ill-reputation loss	−0.021	0.033		−0.081	0.017	***	−0.081	0.017	***	−0.061	0.006	***
Year[2014] * Nulcear ill-reputations loss	−0.077	0.043	.	−								
Year[2013] * Nulcear ill-reputations loss	−0.093	0.040	*	−								
Year[2012] * Nulcear ill-reputations loss	−0.056	0.041		−								
Forced relocation	−0.110	0.086		−0.047	0.042							
Year[2014] * Forced relocation	0.102	0.107		−								
Year[2013] * Forced relocation	0.160	0.104		−								
Year[2012] * Forced relocation	−0.047	0.097		−								
Supplier damage	0.015	0.015		0.012	0.015							
Client damage	−0.024	0.028		−0.030	0.014	*	−0.029	0.014	*	−0.023	0.005	
Year[2014] * Client damage	−0.020	0.035		−								
Year[2013] * Client damage	0.013	0.033		−								
Year[2012] * Client damage	−0.038	0.033		−								
Group subsidy	−			0.024	0.049		0.045	0.046		0.008	0.020	
Year[2014] * Group subsidy	−			0.109	0.063	.	0.082	0.058		0.025	0.027	
Year[2013] * Group subsidy	−			0.051	0.061		0.016	0.056		0.030	0.026	
Year[2012] * Group subsidy	−			−0.047	0.067		−0.072	0.062		−0.047	0.028	
Group subsidy * Damage rate	−			0.024	0.124		0.029	0.123		0.081	0.055	
Year[2014] * Group subsidy * Damage rate	−			−0.192	0.161		−0.187	0.159		−0.092	0.075	
Year[2013] * Group subsidy * Damage rate	−			−0.430	0.154	**	−0.438	0.153	**	−0.268	0.071	***
Year[2012] * Group subsidy * Damage rate	−			0.116	0.156		0.115	0.155		0.046	0.071	
Debt Reduction	−			−0.020	0.034		−0.020	0.033		−0.021	0.015	
Year[2014] * Debt reduction	−			−0.028	0.045		−0.035	0.044		−0.015	0.021	
Year[2013] * Debt reduction	−			−0.061	0.043		−0.056	0.043		−0.027	0.020	
Year[2012] * Debt reduction	−			0.003	0.045		−0.002	0.044		−0.012	0.020	
Debt Reduction * Damage rate	−			0.018	0.126		0.016	0.115		−0.023	0.051	
Year[2014] * Debt reduction * Damage rate	−			0.114	0.160		0.138	0.150		−0.006	0.070	
Year[2013] * Debt reduction * Damage rate	−			0.131	0.156		0.115	0.146		0.088	0.068	
Year[2012] * Debt reduction * Damage rate	−			−0.321	0.151	*	−0.314	0.142	*	−0.129	0.065	*
Debt purchase	−			−0.174	0.074	*	−0.177	0.060	**	−0.082	0.027	**
Year[2014] * Debt purchase	−			−0.183	0.105	.	−0.144	0.083	.	−0.058	0.039	
Year[2013] * Debt purchase	−			0.191	0.109	.	0.129	0.088		0.045	0.041	
Year[2012] * Debt purchase	−			0.178	0.107	.	0.209	0.086	*	0.098	0.040	*
Debt purchase * Damage rate	−			−0.017	0.185							
Year[2014] * Debt purchase * Damage rate	−			0.123	0.242							
Year[2013] * Debt purchase * Damage rate	−			−0.206	0.252							
Year[2012] * Debt purchase * Damage rate	−			0.145	0.258							
Temporary premise	−			0.058	0.098		−0.143	0.049	**	−0.132	0.019	***
Year[2014] * Temporary premises	−			−0.182	0.124							
Year[2013] * Temporary premises	−			−0.168	0.129							
Year[2012] * Temporary premises	−			−0.292	0.113	**						
Lump sum subsidy	−			−0.042	0.037		−0.058	0.019	**	−0.036	0.007	***
Year[2014] * Lump sum subsidy	−			−0.021	0.047							
Year[2013] * Lump sum subsidy	−			−0.034	0.044							
Year[2012] * Lump sum subsidy	−			0.007	0.044							
Interest assistance	−			0.063	0.033	.	0.064	0.017	***	0.041	0.006	***
Year[2014] * Interest assistance	−			−0.004	0.042							
Year[2013] * Interest assistance	−			0.023	0.039							
Year[2012] * Interest assistance	−			−0.013	0.040							
Rent assistance	−			0.117	0.085							
Year[2014] * Rent assistance	−			−0.106	0.113							
Year[2013] * Rent assistance	−			−0.203	0.108	.						
Year[2012] * Rent assistance	−			−0.142	0.106							
Tax exemption	−			−0.002	0.036							
Year[2014] * Tax exemption	−			−0.018	0.046							
Year[2013] * Tax exemption	−			−0.031	0.043							
Year[2012] * Tax exemption	−			−0.032	0.042							
Earthquake insurance	−			−0.029	0.029							
Year[2014] * Earthquake insurance	−			−0.018	0.038							
Year[2013] * Earthquake insurance	−			0.012	0.035							
Year[2012] * Earthquake insurance	−			0.020	0.036							
Random effects:	var.	s.d.		var.	s.d.		var.	s.d.		var.	s.d.	
Firm id	0.082	0.286	***	0.075	0.274	***	0.075	0.275	***	0.000	0.000	†
Year * Industry	0.004	0.060	***	0.003	0.052	***	0.003	0.052	***	0.000	0.021	†
Year * Firm size category	0.002	0.047	***	0.002	0.040	***	0.002	0.041	***	0.001	0.033	†
Year * Region	0.000	0.021		0.001	0.024		0.001	0.024		0.000	0.000	†
Residual	0.247	0.497		0.238	0.488		0.238	0.488		0.055	0.235	

Note: *,**, and *** represent statistical significance at the 5%, 1%, and 0.1% levels, respectively, based on Satterthwaite's degrees of freedom method for model 1–3, and asymptotic degrees of freedom for model 4.
†Statistical significance not available.

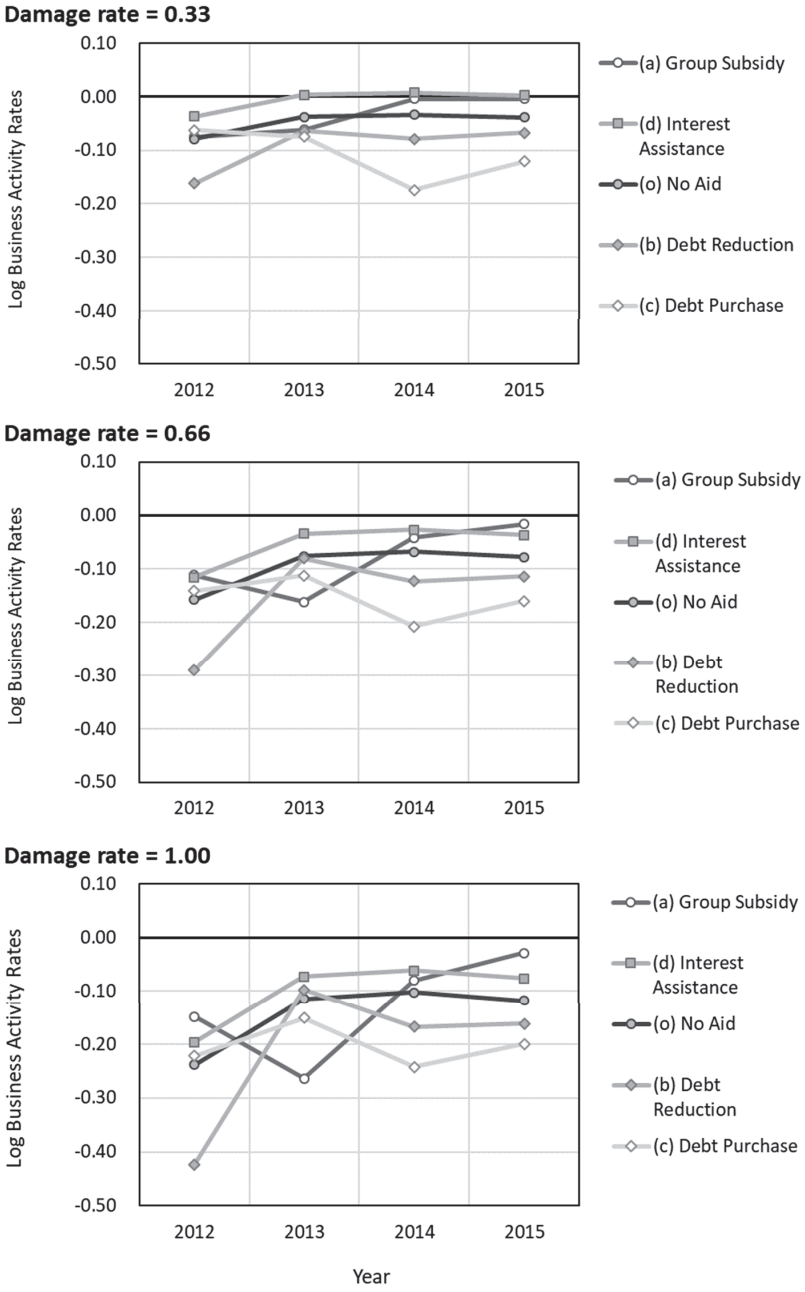

Fig. 3. Estimated recovery curves of firms with various aids, for selected damage rates. The figure is based on estimated marginal means from model 4. The values for this figure are found in **Table 3**.

significance, but the cross terms with fiscal year does not have statistical significance. This means that the ill-reputation loss caused by the nuclear accident had influenced the business activity rate continuously and reduced it by about 6–8% according to model 2–4. Damages to business partners also have significant effects but show asymmetric results. "Client damage" reduced the business activity rate by about 3%, and the cross term with the fiscal year does not have significance, indicating such reduction in the business activity rate had continued for the survey period. In contrast, "supplier damage" does not show a significant impact. "Forced relocation" caused by the tsunami and nuclear accident and its cross term with the fiscal year dummy does not have statistical significance.

All random intercepts provided to the industry, firm size category, and individual firm in each fiscal year have statistical significance, but the random intercept provided to region does not have significance. Another analysis, which is not reported in this study, reveals that the construction industry recovered most quickly and operated at a far higher level than before the disaster, but fisheries and related industries, which is the main industry in most tsunami-stricken areas, continued their businesses at a far lower level. Small and medium-sized enterprises recovered more quickly than large enterprises but to a lower

level than the latter. Such differences due to industry and firm size cannot be shown explicitly by the models in this study but are controlled by random intercepts.

4.4. Effects of Aid Measures

The variables of aid measures are introduced into model 2. The effects of aid measures can be divided into the following: (1) aid measures have effects, (2) the cross term between aid measures and the fiscal year has effects, and (3) the cross term among aid measures, the damage rate, and the fiscal year has effects (**Table 1**). First, the category of aid measures having effects means that there is a difference in the level of recovery curve. The provisions of "temporary premises," "lumpsum subsidy," and "interest assistance" fall into this category. Second, the category of the cross term between aid measures and the fiscal year having effects means that the effects cause a difference in the shape of the recovery curve. "Debt purchase" falls into this category. Lastly, the category of the cross term among the aid measures, the damage rate, and the fiscal year having effects means that the effects cause a difference in the shape of recovery curve according to the damage rate. "Group Subsidy" and "debt reduction" fall into this category. The effects of these aid measures differ according to the damage rate because "Group Subsidy" covers a part of the recovery cost of the damaged production facilities, and "debt reduction" reduces the existing debts of the impaired production facilities. "Rent assistance" and "tax exemption" do not have statistical significance, and "earthquake insurance," which was purchased before the earthquake as a defensive measure for firms, does not have statistical significance.

Because firms can receive multiple aid measures, the effects of the cross term of multiple aid measures are measured, but a statistically significant cross term cannot be found. Accordingly, the effects of multiple aid measures are thought to appear in additive fashion in the natural logarithm of the business activity rate.

The effects of the aid measures are based on the coefficients in model 3, a parsimonious model in which the non-significant variables are excluded (**Table 2**). First, seeing aid measures that are effective for the business activity rate, the provisions of "temporary premises" and "lumpsum subsidy" have negative coefficients, indicating that these aid measures were provided to the firms with a low business activity rate. Contrarily, "interest assistance" has a positive coefficient, indicating that this aid measure was provided to firms with a high business activity rate. As for the aid measures whose cross term with the fiscal year has effects, they cause a difference in the shape of the recovery curve such that explaining is difficult using only the coefficients. Therefore, this is explained later using figures.

Although the same variables are used in model 4 and model 3, model 4 shows robust estimates where the impact of the extreme values of the business activity rate during the observation is excluded. In this robust linear mixed model, 2,279 observed values are considered as outliers from 9,311 values, and the outliers are down-weighted according to the divergence from the mean to estimate the parameters. In robust regression, neither the analysis of the deviance table nor AIC can be obtained because the likelihood cannot be defined ordinarily.

The absolute values of the estimates in model 4 are generally smaller than those in model 3 in **Table 2**. The standard errors of the estimates in all the variables are smaller so that it becomes easier to examine whether there is a significant difference. As another remarkable difference, it can be seen that the intercept in model 4 is significantly positive and the business activity rate of the firms without damage increased by 8% in 2015, the reference year, than before the earthquake. The fiscal year dummy of 2012 is significantly negative, meaning that the business activity rate of firms without damage continued to increase from 2012 to 2015. Furthermore, no variables according to direct and indirect damage, except for "nuclear ill-reputation," have significance in model 4. "Nuclear ill-reputation" has significance and decreased the business activity rate by 6%. The variables of aid measures between models 3 and 4 have differences similar to general tendencies: the absolute values of the coefficients are smaller and their standard errors are also smaller.

4.5. Recovery Curves of Recipients of Various Aid Measures

Because the effects of "Group Subsidy," "debt reduction," and "debt purchase" are expressed as the cross term among the variables and it is difficult to explain such effects, **Fig. 3** is used for explanation, which visualizes the estimated marginal means calculated using the estimates of model 4 and the variance-covariance matrix of the estimates. **Fig. 3** shows the recovery curve of the log business activity rate of the firms for cases of damage rate of 33%, 66%, and 100%. The mean values of the log business activity rate of firms that received either one of the "Group Subsidy," "debt reduction," "debt purchase," or "interest assistance," and that of firms without aid is shown, supposing that the level of the log business activity rate of firms without damage takes zero. All other binary variables are set as zero. A damage rate of 33% is the mean damage rate of firms that received "Group Subsidy."

Figure 3 shows that the business activity rate of no-aid firms is lower than the pre-disaster level by 4% for 33% damage rate. Contrarily, the business activity rate of firms that received "Group Subsidy" or "interest assistance" recovers similar to the pre-disaster level. The business activity rate of firms that received "debt reduction" or "debt purchase" falls below that of no-aid firms in 2015. The business activity rate of firms that received "debt reduction" is lower than those of other groups. It can, therefore, be interpreted that "debt reduction" was provided to the firms with especially low business activity rate, and such firms recovered to a similar level to that of no-aid firms.

The recovery curves of firms with a larger damage rate are generally lower than those of firms with a damage

Table 3. Estimated mean of log business activity rates and the pairwise comparisons.

	Damage rate = 0.33			Damage rate = 0.66			Damage rate = 1.00		
	Year	mean	(s.e.)	Year	mean	(s.e.)	Year	mean	(s.e.)
(O) No Aid									
	2012	−0.079	0.008 ***	2012	−0.157	0.016 ***	2012	−0.238	0.024 ***
	2013	−0.038	0.010 ***	2013	−0.076	0.020 ***	2013	−0.115	0.031 ***
	2014	−0.034	0.013 *	2014	−0.068	0.026 *	2014	−0.103	0.039 *
	2015	−0.039	0.013 **	2015	−0.078	0.027 **	2015	−0.118	0.040 **
(A) Group Subsidy									
	2012	−0.075	0.016 ***	2012	−0.111	0.022 ***	2012	−0.149	0.034 ***
	2013	−0.062	0.015 ***	2013	−0.161	0.023 ***	2013	−0.264	0.034 ***
	2014	−0.004	0.016	2014	−0.042	0.024	2014	−0.081	0.037 .
	2015	−0.004	0.018	2015	−0.016	0.027	2015	−0.029	0.041
(B) Debt Reduction									
	2012	−0.162	0.014 ***	2012	−0.291	0.022 ***	2012	−0.423	0.033 ***
	2013	−0.064	0.016 ***	2013	−0.081	0.027 **	2013	−0.098	0.042 .
	2014	−0.079	0.018 ***	2014	−0.123	0.031 ***	2014	−0.168	0.047 **
	2015	−0.068	0.018 ***	2015	−0.114	0.032 **	2015	−0.162	0.048 **
(C) Debt Purchase									
	2012	−0.062	0.030	2012	−0.141	0.033 ***	2012	−0.222	0.037 ***
	2013	−0.075	0.033 .	2013	−0.112	0.037 **	2013	−0.152	0.044 **
	2014	−0.174	0.031 ***	2014	−0.208	0.037 ***	2014	−0.243	0.047 ***
	2015	−0.121	0.030 ***	2015	−0.160	0.037 ***	2015	−0.200	0.048 ***
Pairwise (A) Group Subsidy − (O) No Aid									
	2012	0.004	0.016	2012	0.046	0.023	2012	0.089	0.036 *
	2013	−0.024	0.016	2013	−0.086	0.026 **	2013	−0.149	0.039 ***
	2014	0.029	0.018	2014	0.026	0.029	2014	0.022	0.044
	2015	0.035	0.018	2015	0.062	0.030	2015	0.089	0.047
Pairwise (B) Debt Reduction − (O) No Aid									
	2012	−0.083	0.013 ***	2012	−0.133	0.022 ***	2012	−0.185	0.035 ***
	2013	−0.026	0.015	2013	−0.005	0.026	2013	0.017	0.040
	2014	−0.045	0.016 *	2014	−0.055	0.028	2014	−0.065	0.043
	2015	−0.029	0.017	2015	−0.036	0.030	2015	−0.044	0.047
Pairwise (C) Debt Purchase − (O) No Aid									
	2012	0.016	0.029	2012	0.016	0.029	2012	0.016	0.029
	2013	−0.037	0.031	2013	−0.037	0.031	2013	−0.037	0.031
	2014	−0.140	0.028 ***	2014	−0.140	0.028 ***	2014	−0.140	0.028 ***
	2015	−0.082	0.027 **	2015	−0.082	0.027 **	2015	−0.082	0.027 **

Note: *, **, and *** represent Bonferroni corrected asymptotic significance at the 5%, 1%, and 0.1% levels, respectively.

rate of 33%. Nonetheless, it can be recognized that the business activity rate of firms that received "Group Subsidy" recovered nearly to the level of firms without damage, even when the damage rate was 100%. The recovery curves of the firms who received "Group Subsidy," especially among the more heavily damaged, show a peculiar characteristic: they fall once in 2013 and rise subsequently. The reason is unknown, but the possible explanation is that businesses have been interrupted during the transition period from operation at temporary facilities to permanent premises due to the land raising works, etc., which lowered the business activity rate in 2013.

4.6. Differences in the Business Activity Rates Among Various Aids

Table 3 shows the values of the recovery curves according to each kind of aid measure. It shows the mean values of the log business activity rate in each fiscal year and the results of the pairwise comparisons between with and without aid measures. First, for no-aid firms, the business activity rate recovers for all damage rates, but in 2015 is significantly negative, indicating that it does not recover to the level before the earthquake. In contrast, the business activity rate of the firms that received "Group Subsidy" does not have significance for all damage rates after 2014, indicating that it recovers to the level before the earthquake. As for firms that received "debt reduction" or "debt purchase," the business activity rate in 2015 is significantly below the level before the earthquake for all damage rates, and the business activity rate does not recover to the level before the earthquake.

The pairwise comparisons in the lower part of **Table 3** show the differences between the mean log business activity rate of the firms that received each kind of aid measures and that of the no-aid firms. The business activity rate of the firms that received "Group Subsidy" exceeds

Table 4. Changes in the means log business activity rates and pairwise comparisons.

Damage rate = 0.33			Damage rate = 0.66			Damage rate = 1.00		
Year	mean	(s.e.)	Year	mean	(s.e.)	Year	mean	(s.e.)
(O) No Aid								
2012–15	0.040	0.015 *	2012–15	0.079	0.031 *	2012–15	0.120	0.046 *
2013–15	−0.001	0.017	2013–15	−0.002	0.033	2013–15	−0.003	0.050
2014–15	−0.005	0.018	2014–15	−0.010	0.036	2014–15	−0.015	0.055
(A) Group Subsidy								
2012–15	0.071	0.023 **	2012–15	0.095	0.034 *	2012–15	0.120	0.053
2013–15	0.058	0.023 *	2013–15	0.145	0.035 ***	2013–15	0.235	0.053 ***
2014–15	0.000	0.024	2014–15	0.026	0.036	2014–15	0.052	0.055
(B) Debt Reduction								
2012–15	0.094	0.023 ***	2012–15	0.176	0.038 ***	2012–15	0.261	0.058 ***
2013–15	−0.004	0.024	2013–15	−0.034	0.042	2013–15	−0.065	0.063
2014–15	0.012	0.026	2014–15	0.009	0.044	2014–15	0.006	0.067
(C) Debt Purchase								
2012–15	−0.058	0.042	2012–15	−0.019	0.050	2012–15	0.022	0.060
2013–15	−0.046	0.044	2013–15	−0.047	0.053	2013–15	−0.048	0.065
2014–15	0.053	0.042	2014–15	0.048	0.053	2014–15	0.043	0.067
Pairwise (A) Group Subsidy − (O) No Aid								
2012–15	0.031	0.024	2012–15	0.016	0.038	2012–15	0.000	0.059
2013–15	0.059	0.024 *	2013–15	0.147	0.039 ***	2013–15	0.238	0.061 ***
2014–15	0.005	0.025	2014–15	0.036	0.042	2014–15	0.067	0.064
Pairwise (B) Debt Reduction − (O) No Aid								
2012–15	0.055	0.021 *	2012–15	0.097	0.038 *	2012–15	0.141	0.058 *
2013–15	−0.002	0.022	2013–15	−0.031	0.040	2013–15	−0.061	0.062
2014–15	0.017	0.023	2014–15	0.019	0.042	2014–15	0.021	0.064
Pairwise (C) Debt Purchase − (O) No Aid								
2012–15	−0.098	0.040 *	2012–15	−0.098	0.040 *	2012–15	−0.098	0.040 *
2013–15	−0.045	0.041	2013–15	−0.045	0.041	2013–15	−0.045	0.041
2014–15	0.058	0.039	2014–15	0.058	0.039	2014–15	0.058	0.039

Note: *, **, and *** represent Bonferroni corrected asymptotic significance at the 5%, 1%, and 0.1% levels, respectively.

that of the no-aid firms in the last year for all damage rates, although it does not have statistical significance. As for firms with damage rates of 66% and 100% that received "Group Subsidy," the business activity rate in 2013 falls below that of the no-aid firms, as mentioned above, and it has statistical significance. The differences between the business activity rate of the firms that received "debt reduction" and that of the no-aid firms in 2015 do not have significance for all of damage rates. However, the business activity rate in 2012 falls below that of the no-aid firms, suggesting that "debt reduction" was provided to the firms with low business activity. In contrast, the business activity rate of the firms that received "debt purchase" is lower than that of the no-aid firms for all damage rates after 2014, and the gap between the business activity rates has expanded.

Because the effect of "interest assistance" on the business activity rate of firms is fixed, this is not shown in **Table 3**. The mean log business activity rate of the firms that received "interest assistance" is calculated by adding 0.041 to that of the no-aid firms (model 4 in **Table 2**). This coefficient has statistical significance. Accordingly, the difference between the business activity rate of the firms that received "interest assistance" and that of the no-aid firms also has statistical significance in all the fiscal years. Similarly, the same thing is applied to the provisions of "temporary premise" and "lumpsum subsidy," whose cross terms with the fiscal year dummy do not have significance. Because these aid measures have significant negative coefficients, the business activity rates of firms that received these aid measures fall significantly below that of the no-aid firms in all the fiscal years.

4.7. Differences in the Changes in Business Activity Rates Among Various Aids

Next, changes in the business activity rates from each fiscal year up to 2015 are examined considering each kind of aid measures (**Table 4**). The values in **Table 4** are found by subtracting the mean value in each year from that in 2015, and the main focus of this table is the changes in the business activity rate from 2012 to 2015. The log business activity rate of "debt reduction" increased the most from 2012 to 2015 for all damage rates and "Group Subsidy" and "no aid" follow "debt reduction." On the other hand, changes in firms that received "debt purchase" from 2012 to 2015 do not have significance.

The results of the pairwise comparisons in the lower part of **Table 4** are found by subtracting the changes of the no-aid firms between the fiscal years from those of the firms that received each kind of aid measure. This means that the effects of each kind of aid measure on recovery

can be measured. From the pairwise comparisons, it can be seen that the business activity rate of "debt reduction" increased the most, and "Group Subsidy" follows "debt reduction," but "Group Subsidy" does not have significance. However, the business activity rate of firms that received "Group Subsidy" has the lowest mean values in 2013. Therefore, it can be recognized that the increase in such firms from 2013 to 2015 has significance. As for "debt purchase," the change from 2012 to 2015 is negative for all damage rates.

Because the effects of "interest assistance" on the business activity rate are fixed, as mentioned in the previous section, they are not listed in **Table 4**. The changes in the business activity rate of firms that received "interest assistance" are the same as those of the no-aid firms. If the changes of the mean log business activity rate of the no-aid firms are subtracted from those of firms that received "rent assistance," the difference is zero. The same logic can be applied to the provisions of "temporary premise" and "lumpsum subsidy."

5. Discussion

It is necessary to measure the performance of firms until their recovery and understand the trajectory of recovery in order to evaluate the resilience of a regional economy and the factors that influence it. If government aids were not provided to favor selected firms but to support a swift recovery of firms and the regional economy in general, it is not sufficient only to evaluate the activity level at a certain point of time after the disaster, but to also examine the trajectory of recovery in order to understand the effectiveness of aid measures. The TERFS is a unique information source for such an evaluation and this paper is the first study to examine quantitatively which aid measures are effective for the recovery of production and sales.

To understand our results, the following three points deserve attention. First, TERFS does not include discontinued firms as most other firm surveys conducted after the disaster [25]. Accordingly, the impact of each kind of aid measure on the continuance/discontinuance of business cannot be measured. Secondly, in reviewing the business activity rate in this study, the weighting by the scale of firms is not conducted, so the results are not directly connected with the local macroeconomy of the region. Instead, the general trends of firms that survived are shown. Lastly, the effects of each kind of aid measure examined in this study include a "causal effect" caused by the aid measures concerned and a "selection effect" caused by the selection of firms, administrative organizations, and financial institutions. Because the aid measures are not provided randomly, it cannot be distinguished whether recovery of firm that received a certain kind of aid measure was a result of the aid measure concerned or because the firm selected was an excellent one. Indeed, causal inference analysis [17] could be conducted using a wide range of survey items of TERFS, but in this study, comprehensive effects are reviewed, including the question about the kind of firms to whom aid measures were provided.

According to the results of model 4 in **Table 2**, a robust linear mixed model, firms without physical damage recovered to the business activity rate before the earthquake within a year, while firms with physical damage operated at a lower level, corresponding to the damage rate, even in 2015. In addition to the physical damage to firms, "nuclear reputation loss" lowered the business activity rate by about 6% during the survey period. "Client damage" also lowered the business activity rate by about 2%, and the results of Brown et al. [23] can thus be confirmed. However, "supplier damage" did not have a statistically significant effect.

Aid measures to firms can be evaluated from two viewpoints: the level of business activity firms in 2015 and changes in business activity from 2012 to 2015. First, the business activity rate of recipients of "Group Subsidy" had been the highest and recovered to the level before the earthquake. In the case of a smaller damage rate, the business activity rate of recipients of "interest assistance" is highest, and this is because the recovery of the "Group Subsidy" recipients had been greater for larger damage rate. "Debt reduction" follows these aid measures, but the level of business activity rate for firms who received this measure falls below that of the no-aid firms. However, among the aforementioned aid measures, only "interest assistance" has a significantly positive difference between its business activity rate and that of the no-aid firms. The business activity rate of recipients of "debt purchase" fell significantly below that of the no-aid firms in 2015.

Second, the changes in business activity from 2012 to 2015 were largest among firms that received "debt reduction." As mentioned above, the business activity rate of recipients of this aid measure falls below that of the no-aid firms even in 2015, but the business activity rate in 2012 had been much lower than that of the no-aid firms. "Debt reduction" is thought to be provided to the firms with an especially low business activity rate but has raised the business activity rate to a similar level to that of the no-aid firms. "Group Subsidy" and "interest assistance" follow "debt reduction." The difference in the changes from 2012 to 2015 between the recipients of either of these aid measures and the no-aid firms is not significant, however. On the other hand, the changes in the business activity rate of firms that received "debt purchase" are significantly negative compared to those of the no-aid firms. It is thought that "debt purchase" could have helped financial institutions that sold the debts of firms, but there is no effect on the recovery of firms that are debtors.

The recovery curves of the business activity rate of firms that received "Group Subsidy" showed a peculiar shape (**Fig. 3**). In other words, the recovery curves fall once in 2013 but recover swiftly afterward. Although the reason for the fall in 2013 is unknown, the interruption of business during the transition period from business at temporary facilities to permanent premises may be a reason. Firms in the area affected by the tsunami operated their businesses in the confusion caused by land raising works. Assuming that the fall in business activities in

2013 had been necessary for "build back better than before," "Group Subsidy" is thought to have recovered the business activity rate rapidly after 2013 and raise it to the level before the earthquake, something that firms without aid measures could not realize.

The cross terms of "interest assistance," "temporary premise," and "lumpsum subsidy" among aid measures with the fiscal year do not have significance. Thus, it can be judged that recovery does not exceed that of the no-aid firms in these cases. Although the coefficient of "interest assistance" is significantly positive, this aid measure had been provided to firms that already had a high business activity rate in 2012, and recipients only recovered with similar tendencies to the no-aid firms. If the recipients of "interest assistance" recovered on their own, as in the case of no-aid firms, it is thought that "interest assistance" had no effect on the recovery. The coefficients of the provision of "temporary premise" and "lumpsum subsidy" are negative, and these aids are provided to firms with a low business activity rate. While these aids are assumed to influence the business continuity of the firms, these aid measures did not contribute to the recovery of the business activity rate. There was no significant effect from "rent assistance" or "tax exemption."

In summary, "debt reduction" although the business activity rate of the recipients did not recover to the level before the earthquake, this aid measure restored the business activity rate considerably. "Debt reduction" rescues firms whose recovery is delayed and restores them. The recovery curves of the recipients of "Group Subsidy" show a peculiar shape that they fall once in 2013. If this fall is considered necessary for "build back better than before," "Group Subsidy" improves the business activity rate quickly and recovers it to the level before the earthquake. The merit of the "Group Subsidy" is that this aid measure recovered the business activity rate to a pre-disaster level, even for firms with a large damage rate. The effects of these aid measures on recovery could be borne out of the selection of firms with a higher propensity to recover, but the fact that aid measures are provided to firms with better prospects of recovery and such firms did indeed recover indicates the effectiveness of these aid measures. The business activity rate of firms that received "interest assistance" is significantly higher than that of the no-aid firms, but it was already high in 2012 and its changes do not exceed that of no-aid firms. Accordingly, it is thought that "interest assistance" does not contribute to the recovery itself. "Temporary premise" and "lumpsum subsidy" are provided to firms with a low business activity rate and are thought to contribute well to the business continuity of such firms. However, these aid measures are considered not to contribute to the recovery, with the same reasoning to the case of "interest assistance." "Debt purchase" may have rescued financial institutions that were creditors, but the business activity rate of firms that are debtors were low and far from recovery.

To evaluate the difference in the performances of firms that received different kinds of aid measures, as conducted in this study, microdata from the firms is necessary. To understand the recovery trajectory of firms after a disaster, panel data are necessary. Previous studies argue that the effectiveness of the aid measures from the government after the Great East Japan Earthquake is limited [39, 40]. However, using individual data for a longer period, it is understood that some aid measures from the government do have important effects. This paper demonstrates that panel data of firms are necessary in order to understand recovery policies. Future studies should consider causal inference analysis of the aid measures to firms, analysis of the effect of aid measures on employment and industry-related issues other than business activity, and measurement of cost-effectiveness of the aid measures. Panel data from the TERFS would be indispensable in future studies.

Acknowledgements

This research is funded by KAKENHI Grant No. 16H03608. The Tohoku University Earthquake Recovery Firm Survey (TERFS) 2012–2015 dataset is provided by the Regional Innovation Research Center of the Graduate School of Economics and Management, Tohoku University. We would like to thank the anonymous reviewers for their constructive comments.

References:

[1] E. Cavallo and I. Noy, "Natural disasters and the economy – A survey," Int. Review of Environmental and Resource Economics, Vol.5, No.1, pp. 63-102, 2011.
[2] N. V. Loayza, E. Olaberría, J. Rigolini, and L. Christiaensen, "Natural disasters and growth: Going beyond the averages," World Development, Vol.40, Issue 7, pp. 1317-1336, 2012.
[3] J. Klomp and K. Valckx, "Natural disasters and economic growth: A meta-analysis," Global Environmental Change, Vol.26, pp. 183-195, 2014.
[4] J. M. Albala-Bertrand, "Natural disaster situations and growth: A macroeconomic model for sudden disaster impacts," World Development, Vol.21, Issue 9, pp. 1417-1434, 1993.
[5] M. Skidmore and H. Toya, "Do natural disasters promote long-run growth?," Economic Inquiry, Vol.40, Issue 4, pp. 664-687, 2002.
[6] A. Popp, "The effects of natural disasters on long run growth," Major Themes in Economics, Vol.8, pp. 61-82, 2006.
[7] H. Toya and M. Skidmore, "Economic development and the impacts of natural disasters," Economic Letters, Vol.94, Issue 4, pp. 20-25, 2007.
[8] J. C. Cuaresma, J. Hlouskova, and M. Obersteiner, "Natural disasters as Creative Destruction? Evidence from developing countries," Economic Inquiry, Vol.46, Issue 2, pp. 214-226, 2008.
[9] A. M. Leiter, H. Oberhofer, and P. A. Raschky, "Creative disasters? Flooding effects on capital, labour and productivity within European firms," Environmental and Resource Economics, Vol.43, Issue 3, pp. 333-350, 2009.
[10] S. Hallegatte and P. Dumas, "Can natural disasters have positive consequences? Investigating the role of embodied technical change," Ecological Economics, Vol.68, Issue 3, pp. 777-786, 2009.
[11] C. Raddatz, "The wrath of god: Macroeconomic costs of natural disasters," World Bank Policy Research Working Paper, Report Number WPS5039, 2009.
[12] P. Guimaraes, F. L. Hefner, and D. P. Woodward, "Wealth and income effects of natural disasters: An econometric analysis of hurricane Hugo," Review of Regional Studies, Vol.23, pp. 97-114, 1992.
[13] W. DuPont and I. Noy, "What happened to Kobe? A reassessment of the impact of the 1995 earthquake in Japan," Economic Development and Cultural Change, Vol.63, No.4, pp. 777-812, 2015.
[14] S. Hallegatte, "An adaptive regional input-output model and its application to the assessment of the economic cost of Katrina," Risk Analysis, Vol.28, Issue 3, pp. 779-799, 2008.
[15] G. Felbermayr and J. Gröschl, "Naturally negative: the growth effects of natural disasters," J. of Development Economics, Vol.111, pp. 92-106, 2014.
[16] Y. Kajitani and H. Tatano, "Applicability of a spatial computable general equilibrium model to assess the short-term economic impact of natural disasters," Economic Systems Research, Vol.30, Issue 3, pp. 289-312, 2017.

[17] E. Cavallo, S. Galiani, I. Noy, and J. Pantano, "Catastrophic natural disasters and economic growth," Review of Economics and Statistics, Vol.95, Issue 5, pp. 1549-1561, 2013.
[18] Y. Kajitani and H. Tatano, "Estimation of lifeline resilience factors based on surveys of Japanese industries," Earthquake Spectra, Vol.25, No.4, pp. 755-76, 2009.
[19] S. L. Cutter, C. G. Burton, and C. T. Emrich, "Disaster resilience indicators for benchmarking baseline conditions," J. of Homeland Security and Emergency Management, Vol.7, Issue 1, doi: 10.2202/1547-7355.1732, 2010.
[20] A. Rose and E. Krausmann, "An economic framework for the development of a resilience index for business recovery," Int. J. of Disaster Risk Reduction, Vol.5, pp. 73-83, 2013.
[21] K. J. Tierney, "Business impacts of the Northridge earthquake," J. of Contingencies and Crisis Management, Vol.5, Issue 2, pp. 87-97, 1997.
[22] G. R. Webb, K. J. Tierney, and J. M. Dahlhamer, "Business and disasters: Empirical patterns and unanswered questions," Natural Hazards Review, Vol.1, Issue 2, pp. 83-90, 2000.
[23] C. Brown, J. Stevenson, S. Giovinazzi, E. Seville, and J. Vargo, "Factors influencing impacts on and recovery trends of organisations: Evidence from the 2010/2011 Canterbury earthquakes," Int. J. of Disaster Risk Reduction, Vol.14, pp. 56-72, 2015.
[24] M. Battisti and D. Deakins, "The relationship between dynamic capabilities, the firm's resource base and performance in a post-disaster environment," Int. Small Business J., Vol.35, Issue 1, pp. 78-98. 2017.
[25] S. Sydnor, L. Niehm, Y. Lee, M. Marshall, and H. Schrank, "Analysis of post-disaster damage and disruptive impacts on the operating status of small businesses after Hurricane Katrina," Natural Hazards, Vol.85, Issue 3, pp. 1637-1663, 2017.
[26] L. Huang, L. Wang, and J. Song, "Post-disaster business recovery and sustainable development: A study of 2008 Wenchuan earthquake," Sustainability, Vol.10, No.3, doi: 10.3390/su10030651, 2018.
[27] Y. Kajitani, S. E. Chang, and H. Tateno, "Economic Impacts of the 2011 Tohoku-Oki Earthquake and Tsunami," Earthquake Spectra, Vol.29, No.S1, pp. S457-S478, 2013.
[28] T. Hayashi, "Daisaigai no Keizaigaku (Economics of Large-scale Disaster)," PHP Interface, 2011 (in Japanese).
[29] Y. Harada, "Shinsai Fukkou, Giman no Kozu (Revitalization from Earthquake Disaster, a Composition of Deceptions)," Shinchosha, 2012 (in Japanese).
[30] M. Saito, "Shinsai Fukkou no Seiji Keizaigaku (Political Economy of Revitalization from Earthquake Disaster)," Nippon Hyoron sha Co., Ltd., 2015 (in Japanese).
[31] Y. Honda and Y. Nakazawa, "Higashi Nihon Dai Shinsai karano Chiiki Keizai Fukkou (Revitalization of Regional Economy from the Great East Japan Earthquake)," Minerva Shobo, 2016 (in Japanese).
[32] S. Tokunaga and M. Okiyama, "Daishinsai karano Fukkou to Chiiki Saisei no Moderu Bunseki (Revitalization from the Great Earthquake Disaster and Model Analysis)," Bunshin-do, 2014 (in Japanese).
[33] H. Uchida, D. Miyakawa, K. Hosono, A. Ono, T. Uchino, and I. Uesugi, "Natural disaster and natural selection," RIETI Discussion Paper, 14-E-055, 2014.
[34] Y. Todo, K. Nakajima, and P. Matous, "How do supply chain networks affect the resilience of firms to natural disasters? Evidence from the Great East Japan Earthquake," J. of Regional Science, Vol.55, Issue 2, pp. 209-229, 2015.
[35] J. Tokui, K. Kawasaki, and T. Miyagawa, "The economic impact of supply chain disruptions from the Great East-Japan earthquake," Japan and the World Economy, Vol.41, pp. 59-70, 2017.
[36] N. Nakatani, O. Murao, K. Meguro, and K. Terumoto, "Business recovery conditions of private enterprises after the 2011 Great East Japan Earthquake and issues on business continuity measures for large-scale disaster management – A case study of small and medium-sized enterprises in Miyagi –," IEICE Trans. on Fundamentals of Electronics, Communications and Computer Sciences, Vol.E99.A, Issue 8, pp. 1539-1550, 2016.
[37] Y. Kashiwagi, Y. Todo, and P. Matous, "Propagation of Shocks by Natural Disasters through Global Supply Chains," RIETI Discussion Paper Series, 18-E-041, 2018.
[38] A. Masumura, A. Kubota, "Analysis of Damage and Survival of Business in the Tsunami Affected Area Caused by the Great East Japan Earthquake Using Economic Census Individual Data," Summaries of Technical Papers of Annual Meeting, Architectural Institute of Japan 2019, pp. 865-867, 2019.
[39] N. Hamaguchi, "Higashi Nihon Dai Shinsai Hisai Chiiki Seizougyou Kigyou no Fukkou Katei no Bunseki (Analysis of the Process of Revitalization of Manufacturing Firm is the Regions Affected by the Great East Japan Earthquake)," REITI Discussion Paper Series, 15-J-044, 2015 (in Japanese).
[40] M. A. Cole, R. J. R. Elliott, T. Okubo, and E. Stroble, "The effectiveness of pre-disaster planning and post-disaster aid: examining the impact on plants of the Great East Japan Earthquake," REITI Discussion Paper Series, 15-E-097, 2015.
[41] H. Uchida and S. Nakanishi, "Higashi Nihon Dai Shinsai ni okeru Chusho Kigyou Shiensaku (Aid measures to Small and Medium Enterprises during the Great East Japan Earthquake)," Rippo to Chosa, No.318, pp. 32-45, 2011 (in Japanese).
[42] J. Kamata, M. Dateoka, and S. Nakanishi, "Higashi Nihon Dai Shinsai Go no Chusho Kigyo Shien to Kongo no Kadai (Aids to Small and Medium Enterprises after the Great East Japan Earthquake and Future Challenges)," Rippo to Chosa, No.330, pp. 36-57, 2012 (in Japanese).
[43] S. Masuda, "Sangyo Saisei to Fukkou Machizukuri (Industrial recovery and revitalization town planning)," Joint Editorial Committee for the Report on the Great East Japan Earthquake Disaster (Ed.), "Report on the Great East Japan Earthquake Disaster: Building Series Vol.11, Building Legislation/Urban Planning and Design," Architectural Institute of Japan, pp. 196-206, 2019 (in Japanese).
[44] Board of Audit of Japan, "Kaikei Kensain Ho Dai 30 Jo no 3 no Kitei ni Motuzuku Houkokusho (Report based on the Board of Audit Act 30-3: the Result of Audit on Implementation Status of Projects for Revitalization from the Great East Japan Earthquake)," 2017 (in Japanese).
[45] Chiiki Sangyo Fukkou Chosa Kenkyu Project (Ed.), "Higashi Nihon Dai Shinsai Kenkyu I (the Great East Japan Earthquake Research I)," Kahoku Shinpo Shuppan Center, 2012 (in Japanese).
[46] Chiiki Sangyo Fukkou Chosa Kenkyu Project (Ed.), "Higashi Nihon Dai Shinsai Kenkyu V (the Great East Japan Earthquake Research V)," Nanboku-sha, 2016 (in Japanese).
[47] P. Kennedy, "A Guide to Econometrics," 5th edition, MIT Press, 2003.
[48] R. Andersen, "Modern Methods for Robust Regression," Sage Publications, 2008.

Name:
Yuzuru Isoda

Affiliation:
Earth Science Division, Graduate School of Science, Tohoku University

Address:
6-3 Aramaki-aza-Aoba, Aoba, Sendai, Miyagi 980-8578, Japan

Brief Career:
2002 D.Sc., Graduate School of Science, Tohoku University
2003- Lecturer, Ritsumeikan University
2006- Lecturer, Risumeikan Asia Pacific University
2011- Associate Professor, Graduate School of Science, Tohoku University

Selected Publications:
• Y. Isoda et al., "Strengths of Exaggerated Tsunami-Originated Placenames: Disaster Subculture in Sanriku Coast, Japan," ISPRS Int. J. of Geo-Information, Vol.8, Issue 10, doi: 10.3390/ijgi8100429, 2019.
• T. Nakaya et al., "Virtual Kyoto project: Digital diorama of the past, present, and future of the historical city of Kyoto," Culture and Computing, Lecture Notes in Computer Science, Vol.6259, pp. 173-187, 2010.
• Y. Isoda, "Migration to and from Greater London: An irregular escalator?," Geographical Review of Japan, Series A, Vol.73, pp. 44-55, 2000.

Academic Societies & Scientific Organizations:
• Association of Japanese Geographers (AJG)
• GIS Association of Japan (GISA)
• Population Association of Japan (PAOJ)
• Tohoku Geographical Association (TGA)
• Human Geographical Society of Japan (HGSJ)

Name:
Satoru Masuda

Affiliation:
Professor, Graduate School of Economics and Management, Tohoku University

Address:
27-1 Kawauchi, Aoba, Sendai, Miyagi 980-8576, Japan

Brief Career:
1987 Ph.D., Graduate School of Engineering, The University of Tokyo
1987- Researcher, Mitsubishi Research Institute
1989- Lecturer, College of General Education, Tohoku University
1993- Associate Professor, Graduate School of Information Sciences, Tohoku University
2000- Professor, Graduate School of Economics and Management, Tohoku University
2013- Concurrent Professor, International Research Institute of Disaster Science (IRIDeS), Tohoku University

Selected Publications:
• A. Okabe and S. Masuda, "Qualitative Analysis of Two-dimensional Urban Population Distributions in Japan," Geographical Analysis, Vol.16, Issue 4, pp. 301-312, 1984.
• T. Sato, S. Masuda, Y. Murayama, A. Shibayama, M. Motosaka, and A. Mano, "Proposal of Regional Safety Factors for Balance in Risk-Response Ability of Local Voluntary Disaster Prevention Organizations and Their Application to Sendai City, Japan," J. of Natural Disaster Science, Vol.32, Issue 1, pp. 23-38, 2010.
• Y. Araki, A. Hokugo, and S. Masuda, "The Great East Japan Earthquake and Tsunami: Lessons for Land Use," M. Banba and R. Shaw (Eds.), "Land Use Management in Disaster Risk Reduction: Practice and Cases from a Global Perspective," Springer Japan, pp. 325-351, 2017.

Academic Societies & Scientific Organizations:
• City Planning Institute of Japan (CPIJ)
• Architectural Institute of Japan (AIJ)
• Association of Japanese Geographers (AJG)
• Japan Society for Urbanology (JSU)

Name:
Shin-Ichi Nishiyama

Affiliation:
Professor, Graduate School of Economics, Kobe University

Address:
2-1 Rokkodai-cho, Nada, Kobe, Hyogo 657-8501, Japan

Brief Career:
2002-2005 Economist, Bank of Japan
2005-2010 Senior Analyst, Bank of Canada
2011-2017 Associate Professor, Tohoku University
2017- Professor, Kobe University

Selected Publications:
• R. Kato and S. Nishiyama, "Optimal Monetary Policy When Interest Rates are Bounded at Zero," J. of Economic Dynamics and Control, Vol.29, pp. 97-133, 2005.
• S. Nishiyama, "The Cross-Euler Equation Approach to Intertemporal Substitution in Import Demand," J. of Applied Econometrics, Vol.20, Issue 7, pp. 841-872, 2005.
• I. Christensen, P. Corrigan, C. Mendicino, and S. Nishiyama, "Consumption, Housing Collateral, and the Canadian Business Cycle," Canadian J. of Economics, Vol.49, Issue 1, pp. 207-236, 2016.

Academic Societies & Scientific Organizations:
• American Economic Association (AEA)
• Canadian Economic Association (CEA)
• Japanese Economic Association (JEA)
• Japan Society of Monetary Economics (JSME)