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Abstract

We examine for the existence of the collateral and the bank lending channel simultaneously and compare the economic significance of the two channels. For this purpose, we identify the exogenous shock to a firm's tangible assets and a bank's net worth caused by the massive Tohoku earthquake in 2011. We obtain the following findings: (1) damage to a firm's tangible assets and to the net worth of its primary banks led to a deterioration in the firm's credit availability, providing evidence of the existence of both the collateral and the bank lending channel; (2) firms that faced a tighter credit constraint after the earthquake reduced the amount of borrowing outstanding and saw a fall in the level of production and sales activities; (3) in aggregate, the damage caused by the earthquake and transmitted through the collateral and bank lending channels substantially decreased output in the region; and (4) some of the financial support measures such as investment subsidies and earthquake insurance payouts alleviated the negative impact.

JEL classifications: E22, G18, G21, H84

Keywords: Financial intermediation, Credit constraint, Natural disaster

1. Introduction

Under asymmetric information between financial intermediaries and borrowers in the loan market, borrowers face credit constraints and often fail to obtain sufficient amounts of funds. Such credit constraints can be alleviated if borrowers hold sufficient net worth and/or intermediaries have sufficient lending capacity. That is, on the one hand, firms with sufficient assets that they can pledge as collateral can obtain loans more easily than firms without such assets, in which case the value of firms' assets affects the loans available to them, which is referred to as the "collateral channel" (Stiglitz and Weiss, 1981; Bernanke and Gertler, 1989; Hart and Moore, 1994; Kiyotaki and Moore, 1997). On the other hand, banks with a large lending capacity are able to provide larger amounts of loans than banks that have only a small lending capacity, meaning that the loans available to firms are also affected by financial intermediaries' lending capacity, which is referred to as the "bank lending channel" (Bernanke and Blinder, 1988; Stein, 1998). Of course, both channels can operate at the same time, something which Holmström and Tirole (1997) take into account by incorporating features of both the collateral and the bank lending channel in the same equilibrium framework.

Many policymakers as well as academics are concerned about how financial market imperfections affect the credit market and the real economy through the collateral and bank lending channels. As chairman of the Federal Reserve Bank, Bernanke (2007) addressed the importance of these two channels for the dynamics of the economy citing a number of articles starting with his own seminal work (Bernanke 1983). In the study, Bernanke described how the initial downturn during the Great Depression propagated through the economy through one or both of these two channels, although he did not distinguish between the two.

To date, almost all empirical studies examining the existence of these two channels have focused only on one or the other, but not on both at the same time. Regarding the collateral channel, studies have focused on fluctuations in real estate prices and examined their impact on the amount of firms' borrowing and investment (Gan, 2007a; Chaney, Sraer, and Thesmar, 2012; Cvijanović, 2014; Lin, 2015; Adelino, Schoar, and Severino, 2015; Schmalz, Sraer, and Thesmar, 2017; Wu, Gyourko, and Deng, 2015). Regarding the bank lending channel, many studies have focused on shocks to banks originating from the real estate market (Gan, 2007b; Chakraborty, Goldstein, and MacKinlay, 2017; Cuñat, Cvijanović, and Yuan, 2017), while others have concentrated on a range of other types of shocks such as those caused by monetary policy, domestic and international financial crises, and liquidity shortages (Khwaja and Mian, 2008; Schnabl, 2012; Hosono et al., 2016). These studies examine how firms are affected by such shocks to the banks they transact with.

However, none of these studies incorporate both channels in the same empirical framework. A likely reason is the identification problem arising from the characteristics of the shocks that these studies employ for analysis. The shocks to firms and banks that these studies focus on, such fluctuations in real estate prices in the case of Gan's (2007a, 2007b) studies for instance, generally consist of aggregate shocks at the regional level and are identical across firms and banks located in the same region. Hence, even if there exist stringent credit constraints after a negative shock to the economy, it is impossible to tell which channel – the collateral or the bank lending channel – is responsible for the constraint.

Further, many of the studies focusing on the impact of financial booms and busts and employing fluctuations in asset prices as a proxy for shocks are susceptible to the fact that the direction of causality is unclear or may run in both directions. If there is positive feedback between asset prices and economic activity, then, as highlighted by Kiyotaki and Moore (1997), not only will asset prices have an impact on firms' credit availability, but credit availability will also have a substantial impact on asset prices, so that estimation results on the collateral and bank lending channels will be biased.

The aim of this study is to overcome these identification issues, examine both the collateral and bank lending channels simultaneously, and compare the size of the impact of these two channels. For this purpose, we use the situation following the massive earthquake in Japan's Tohoku region in 2011, in which damage to borrowers and lenders was exogenous and heterogeneous, as a natural experiment. We construct a firm-bank matched dataset based mainly on a series of firm surveys to obtain detailed information on the damage to individual firms and banks. This allows us to separate the collateral channel, through which shocks to firms are transmitted, from the lending channel, through which shocks to banks are transmitted.

Adopting the above identification strategy, our analysis consists of the following steps. First, we estimate the impact of the damage caused by the earthquake on firms' credit constraint to examine whether we find evidence of the collateral and bank lending channels. In case we do find evidence of the two channels, we compare the size of their impact. Second, we test if a tighter credit constraint due to earthquake-related damage has a negative impact on firms' activities such as their production, sales, capital investment, and financing. This examines if the shocks caused by the earthquake through the collateral and/or bank lending channels have "real effects" on firms.

Third, based on the results of these examinations, we measure the size of the aggregate impact transmitted through both the collateral and the bank lending channel. For this purpose, we employ information on all firms located in the earthquake-affected area and on those that are located outside the affected area but have transaction relationships with banks located inside the affected area.

Fourth, we examine the effectiveness of various government measures and other arrangements in alleviating the negative impact transmitted through the collateral and bank lending channels. On the one hand, in terms of measures and mechanisms relevant for the collateral channel, there were several measures that provided firms with financial assistance. A substantial number of firms had purchased earthquake insurance policies before the earthquake, mitigating the financial impact of the earthquake. In addition, a large number of firms received government subsidies for recovery investment after the earthquake. On the other hand, in terms of measures relevant for the bank lending channel, the government provided banks with financial assistance in the form of capital injections for the purpose of restoring their lending capacity. Finally, in terms of both the collateral and bank lending channels, long-term firm-bank relationships may have successfully alleviated the negative impact transmitted through both channels. We examine the role that each of these measures or arrangements played.

Our analysis shows the following: (1) damage to a firm's tangible assets and to the net worth of its primary banks led to a deterioration in the firm's credit availability, providing evidence of the existence of both the collateral and the bank lending channel; (2) firms that faced a tighter credit constraint after the earthquake reduced the amount of borrowing outstanding and saw a fall in the level of production and sales activities; (3) in aggregate, the damage caused by the earthquake and transmitted through the collateral and bank lending channels substantially decreased output in the region, but this decrease was rather short-lived and had no substantial impact on the entire national economy; and (4) some of the financial support measures such as investment subsidies and earthquake insurance payouts helped to alleviate the negative impact.

This study contributes to the literature in the following four respects. First, this is one of the first empirical studies to examine both the collateral and the bank lending channel in a unified framework. To the best of our knowledge, the study by Jiménez et al. (2016) is the only one that is close to ours in terms of examining the relevance of both firms' and banks' balance sheets for firms' credit availability in the same study. However, our approach is different from theirs in the way the identification problem is addressed. Jiménez et al. circumvent the identification issue by controlling for firm-time and bank-time fixed effects in turn and rely on within-bank and within-firm variations. In contrast, we exploit exogenous and heterogeneous variations in the value of firms' collateral and banks' lending capacity caused by a natural disaster. As a result, we are able to examine both the collateral and the bank lending channel simultaneously and compare their economic significance.

Second, the study details the mechanism through which shocks eventually have an adverse impact on real economic activities such as production via tighter credit constraints. Most previous studies only examine the relationship between shocks and credit availability or the relationship between shocks and real activities. In contrast, employing the treatment effect regression framework, we simultaneously estimate two equations – one for a firm's credit constraint and the other for its production/sales, investment, and financing.

Third, we take the existence of discouraged borrowers into account when defining firms' loan demand. Discouraged borrowers are firms that do not apply for a loan because they expect their application to be rejected but that should be included in the estimation of credit constraints. In contrast with many previous studies that examine the impact of borrowers' credit constraints but exclude discouraged borrowers in their analysis, we include such discouraged borrowers in the sample and estimate their impact in a more comprehensive and accurate manner.

Fourth, the study contributes to the literature examining the effects of natural disasters. There are a substantial number of studies that examine the impact of and subsequent recovery from natural disasters at the firm level. Notable examples are the studies by Leiter, Oberhofer, and Raschky (2009), De Mel, McKenzie, and Woodruff (2012), Carvalho et al. (2016), Uchida et al. (2014), and Ono et al. (2014), which mainly focus on real variables such as firms' investment, production, intermediate inputs, relocation, bankruptcies, and business closures. In contrast, similar to the studies by Hosono et al. (2016), Miyakawa et al. (2017), and Uchida et al. (2014), the primary focus of the current study is on the financial aspect. We examine the relevance of financial variables in the transmission of damage caused by a disaster after controlling for other possible transmission channels such as supply chains.

The paper proceeds as follows. Section 2 provides an overview of the Tohoku earthquake. Sections 3 and 4 explain the data and the empirical approach that we use to separate the collateral channel and the bank lending channel. Next, Section 5 presents the estimation results on the existence of the collateral and bank lending channels and on the impact of credit constraints on firms' real activities. Finally, Section 6 concludes.

2. Background

2.1 The Tohoku earthquake in 2011

The Tohoku earthquake occurred on March 11, 2011 and had a magnitude of 9.0 on the Richter scale, making it the fourth strongest earthquake in the world since 1900. The earthquake hit especially the northeastern region of Japan, which was severely affected by both the tremor and the tsunami triggered by the earthquake. Table 1 provides an overview of the damage caused, including the number of casualties and the number of housing units destroyed. As shown in the table, there were more than 19,000 casualties, about 2,600 people remain unaccounted for, and about 120,000 housing units were completely and 280,000 half destroyed. The table also shows that the casualties and the destroyed housing units were concentrated in certain municipalities, which the government officially designated as "earthquake-affected municipalities." Outside these municipalities, the number of casualties and destroyed housing units was small. Furthermore, even inside the affected areas, the damage was mainly concentrated in municipalities that were hit by the tsunami following the earthquake. Outside these tsunami-hit municipalities but within the government-designated municipalities, the ratio of casualties and destroyed housing units was smaller than that in the tsunami-hit regions.

The Tohoku earthquake had a tremendous negative impact on both firms' assets and banks' lending capacity. The total loss of capital stock from the earthquake is estimated to range from 16 trillion to 25 trillion yen according to a report by the government.[2] The earthquake caused severe damage to the lending capacity of banks in the affected areas and stopped their operations as a result. Shortly after the earthquake, as many as 264 bank branches and headquarters closed and stopped their operations. Even though many resumed their operations soon after, a substantial share remained closed for more than two months after the earthquake. Another non-negligible share of damaged branches were relocated to places distant from their original location. Further, many banks reported special losses mostly caused by the earthquake in the accounting year ending in March 2011.[3]

2.2 Financial support to firms and banks

Firms and banks damaged by the Tohoku earthquake received financial support in various ways, including earthquake insurance payouts, government subsidies for reconstruction investment and government-backed loans. First, firms received insurance payouts for property damage if they had purchased earthquake insurance prior to the Tohoku earthquake. By the end of March 2017, total property insurance payouts related to the earthquake amounted to 1.27 trillion yen in total.[4] Second, qualifying firms received subsidies for their reconstruction investment after the earthquake. The central and the local government jointly introduced this subsidy program, called

[2] Note that some argue that these estimates exaggerate the true damage. Saito, Nakagawa, and Ko (2015) pointed out that incorrect assumptions by the government regarding the damage ratio both inside and outside the tsunami-hit municipalities resulted in the overestimation of the damage.

[3] In a later table (Table 4), we will see that banks located in the earthquake-affected region tended to report larger special losses than those not located in the region.

[4] See page 26 in the annual report (http://www.nihonjishin.co.jp/english/2017/en_disclosure.pdf) released by the Japan Earthquake Reinsurance Co. Ltd. Note that the amount includes insurance payouts not only to firms but also to households.

the Restoration and Maintenance Subsidy Project for Facilities of Small and Medium Enterprise Groups, shortly after the earthquake. Under the program, which is still ongoing, the government screens applications and, for qualifying groups of firms, finances three-quarters of their reconstruction investment. The government allows each group to include not only firms that were directly damaged by the earthquake but those that were indirectly damaged, since it regards the recovery of the regional economy and supply chains as crucial for the recovery of individual firms that were directly damaged. By the end of 2017, the government had disbursed 501 billion yen of subsidies under this program.

Third, firms that were directly or indirectly affected by the earthquake were able to obtain two types of government-backed loans: loans provided by government-affiliated financial institutions, and loans guaranteed by public credit guarantee corporations. Special programs for both of these types of loans were introduced in the wake of the Tohoku earthquake to offer better conditions than similar programs provided nationwide. Loans by government-affiliated institutions were provided by the Japan Finance Corporation (JFC) and Shoko Chukin Bank in the case of small and medium enterprises, while the Development Bank of Japan is responsible for extending loans to large firms. By the end of June 2017, the JFC and Shoko Chukin had extended a total 6.15 trillion yen of such government loans to SMEs. Meanwhile, regarding special public credit guarantees following the earthquake, the credit guarantee corporations have provided 100% coverage for loans extended to damaged SMEs. These loans have been provided separately from their usual guarantee program offered nationwide. By the end of June 2017, the total amount of such guarantees stood at 2.73 trillion yen.

The government provided financial assistance to banks in the form of a capital injection program. It relaxed conditions for the capital injections into earthquake-affected financial institutions by revising the Act on Special Measures for Strengthening Financial Functions. From

September 2011 to December 2012, five regional banks, four *shinkin* banks, and four credit cooperatives received capital injections by the Deposit Insurance Corporation. The total sum of capital injected into these financial institutions amounted to 250 billion yen.

All of this financial support to firms and banks may have affected the extent to which shocks were transmitted through the collateral and bank lending channels. We will closely examine their impact in later sections.

3. Data

3.1 Data Sources

We employ three data sources in order to construct a firm-bank matched panel dataset. First, we use information collected through a series of firm surveys in the areas severely affected by the earthquake, the Survey on Firms after the Tohoku Earthquake (SFTE) implemented by the Center for Recovery from the Earthquake at the Graduate School of Economics of Tohoku University, as the primary source.[5] The Center implemented the survey four times (in July 2012, August-September 2013, August-September 2014, and October-November 2015).

In the first survey wave, questionnaires were sent out to 30,000 firms recorded in the database of Tokyo Shoko Research Incorporated (TSR), one of the largest private credit information companies in Japan, that were located in the three most severely-affected prefectures (Iwate, Miyagi, and Fukushima) plus the adjacent city of Hachinohe in Aomori prefecture and were chosen based on the following criteria. There were 56,101 firms in the TSR database in the area. The Center categorized these firms based on their location (located in a coastal or an inland municipality) and their size (up to 20 employees and more than 20 employees). It sent out

[5] All of the authors have participated in the SFTE since the outset in 2011 and have drafted papers (in Japanese) that summarize the surveys. See Uchida et al. (2013; in Japanese) and Ishise et al. (2013; in Japanese) for examples.

questionnaires to all firms in coastal areas and to all sizable firms (with more than 20 employees) in inland areas, while it randomly chose and sent out the questionnaire to about 18% of smaller inland firms (with up to 20 employees) in the database. The Center set these sampling ratios in order to have more accurate and comprehensive information on firms along the coast, which were more heavily damaged than those located inland. Overall, 7,119 firms returned valid questionnaires, for a response rate of 23.7%.

In the second survey wave, the Center divided the 59,880 firms in the area identified in the TSR database at the time of the second wave into two groups. The first group consisted of the firms that responded to the first wave of the SFTE in 2012 and existed at the time of the second wave. There were 6,983 such firms. The questionnaire sent to these firms asked them about their current business environment and performance but not about the damage caused by the earthquake, which is time-invariant and was already included in the questionnaire in the first wave.

The firms in the second group were those that did not respond to the first wave but were included in the TSR database. The Center categorized them based on their location and size as in the first wave but applied different extraction rates from the first wave. Specifically, it sent out the questionnaire to all sizable firms in the coastal area (1,989 firm) and inland area (3,475 firms), while it randomly chose and sent out the questionnaire to 2,324 smaller coastal firms and to 15,229 smaller inland firms. The questionnaire for these firms asked not only about their business environment and performance but also about the damage that resulted from the earthquake. 3,971 firms from the first group and 3,510 firms from the second group provided responses, for an overall response rate of 24.9%. In the third and the fourth waves, the Center sent questionnaires to firms that had responded to either the first or the second wave (or both) and received 5,713 and 4,116 responses, respectively.

We use various types of information from the SFTE for our analysis. The first type of information concerns the damage to a firm caused by the earthquake. This information includes not only direct damage to the firm itself but also indirect damage caused by damage to the firm's suppliers and customers, to public infrastructure, and to banks with which the firm transacts. It further includes information on the amount of damage to a firm's land and non-land tangible assets. The second type of information concerns the financial assistance a firm received after the earthquake such as earthquake insurance payouts, government investment subsidies, compensation for damage from the nuclear disaster, and other types of assistance by local municipalities. The third type of information concerns a firm's financing, including whether it had demand for a loan, whether it had applied for new loans and/or whether new loans had been approved, the loan conditions of any new loans, and the total loan amount outstanding. Finally, the fourth type of information consists of firms' attributes (e.g., the legal form a firm takes), activities (e.g., investment, relocation, transaction relationships with suppliers and customers), and business environment (e.g., the diffusion index of business conditions for the firm).

In order to supplement the information from the SFTE, we use our second source, the TSR database, which contains information on additional firm attributes such as a firm's geographical location, number of employees, the primary bank and the branch it transacts with, and the industry it belongs to. Our third data source are disclosure documents released by banks and a variety of media reports on damaged banks, which we use to obtain additional information on the attributes of firms' primary bank and branch. Specifically, from banks' disclosure documents, we obtain information on their profits, losses, amount of capital, and the status of each of their branches. When information on damage to a branch is unavailable, we used media reports or made enquiries directly with the bank.

3.2 Observation periods and sample selection

To investigate how the Tohoku earthquake affected firms' financial constraints and their ex-post activities through the collateral and bank lending channels, we set five observations periods: one period before the earthquake, and four after the earthquake corresponding to the waves of the SFTE. Specifically, period 1 covers the period before the earthquake, i.e., before March 11, 2011; period 2 covers the period from March 11, 2011 to July 2012 (when the first wave of the survey was conducted); period 3 covers the period from August 2012 to August-September 2013 (second wave); period 4 covers the period from September-October 2013 to August-September 2014 (third wave); and period 5 the period from September-October 2014 to October-November 2015 (fourth wave).

To select the sample firms used for analysis, we start from all the firms that responded to the SFTE. We then limit the sample to firms that had demand for new loans in each period. For this purpose, we include all firms that fall into one of the following categories: firms that obtained new loans, those that applied for new loans but were rejected, and those that wanted to apply for a loan but did not do so because they expected a rejection. This allows us to separate firms that had demand for loans but could not obtain one from those with no demand for new loans. The number of firms with demand for loans in period 2 was 2,052 firms, that in period 3 was 2,207 firms, that in period 4 was 1,437 firms, and that in period 5 was 1,190 firms. Finally, we dropped firm-year observations for which at least one of our independent variables (explained below) is missing. Our final dataset consists of 1,190 firms for period 2, 953 for period 3, 506 for period 4, and 427 for period 5.

4. Empirical approach

4.1 Empirical model employed for estimation

In order to check for the existence of the collateral and bank lending channels simultaneously and to examine how shocks to firms and banks affect firm activities ex post through these channels, we employ the following treatment regression model for each *t*=2,3,4, and 5:

$$\left.\begin{array}{l} Constrained^*{}_{it} = \lambda_1 F\_Damage_i + \lambda_2 B\_Damage_i + \mathrm{X}_{it}\delta + \epsilon_{it}, \\ Constrained_{it} = 1 \ \text{ if } \ Constrained^*{}_{it} > 0; \ = 0 \ \text{ if otherwise.} \end{array}\right\} \quad (1)$$

$$Activity_{\mathrm{it}} = \mu_1 \widehat{Constrained}_{it} + \mu_2 F\_Damage_i + \mathrm{X}_{it}\theta + \omega_{it}. \quad (2)$$

In equation (1), whether firm *i* is credit constrained ($Constrained$) is determined by the damage to its tangible assets (F_Damage), the damage to the primary bank that the firm transacts with (B_Damage), and other firm attributes (X). We employ a probit model and assume that ϵ follows the standard normal distribution. We are interested in the coefficients λ_1 and λ_2, which respectively represent the existence of the collateral channel and the bank lending channel. If the damage to firms or to banks caused by the earthquake increased the probability that a firm was credit constrained in a specific period, we expect these coefficients to be positive.

In equation (2), $Activity_{it}$ represents the level of firm activities such as production and sales, capital investment, and procurement of funds. We are interested in the coefficient on the dummy variable $Constrained_{it}$, which indicates if firm *i* was credit constrained in period *t*. To allow for the possibility that $Constrained_{it}$ is determined endogenously as shown by equation (1) and that the correlation between the disturbance terms in equations (1) and (2) is not zero, we resort to treatment effect regression using the maximum likelihood estimator. We employ the variable for bank damage (B_Damage) as an instrument which is correlated with $Constrained^*$ but not correlated with ω to extract exogenous changes in $Constrained^*{}_{it}$. We also use the same set of other firm attributes X_{it} as in equation (1).

A few remarks on the above empirical strategy with equations (1) and (2) are in order. First, we repeat cross-sectional estimations for each period *t*=2, 3, 4, and 5 rather than pooling all observations across periods and using them as a panel. The reason is that this allows us to examine the persistence of the impact of *F_Damage* and *B_Damage*, which is time-invariant, on credit constraints. If the shocks to firms and banks continue to affect firms' credit constraints through the collateral channel, the bank lending channel, or both even long after the earthquake, the coefficients λ_1 and/or λ_2 will be positive and significant in the estimations for t=3 or later. Second, we consider the possibility that firms in the sample are affected by the earthquake in many more ways other than the collateral and bank lending channels. For example, firms may be indirectly affected through the interruption of supply chains or through damage to public infrastructure nearby. In order to control for such possible impact resulting from the earthquake, we employ a number of control variables for X. Details of the variables included in each estimation will be provided in a later section. Third, note that in equation (2) we include *F_Damage* but not *B_Damage* as one of the explanatory variables for firm activities. This is because we assume that damage to firms' tangible assets may affect their activities not only through the collateral channel but also through other routes. For example, damage to a firm's fixed tangible assets may reduce the capacity for production and increase the demand for recovery investment. Hence, we include *F_Damage* in the second stage estimation in order to incorporate these possibilities.

4.2 Dependent variables

For the dependent variable in equation (1), we measure whether a firm is credit constrained using the variable $Constrained$, which takes a value of 1 if the firm replied that it was not able to obtain the desired amount of loans and 0 otherwise. We use three different variables as the dependent variable $Activity_{\mathrm{it}}$ in equation (2). The first is $Activity\_Level$, which we measure in two different ways: the level of a firm's production or the level of its sales in a particular year relative to the level in the year before the earthquake. Second, we use the ratio of tangible investment to tangible assets at the end of the previous year ($Investment$) in order to measure a firm's capital investment activities. Third, we use the ratio of a firm's loans outstanding to the amount of total assets outstanding at the end of the year ($Loans$) in order to measure firms' loan procurement status. We estimate equation (2) using each of these three variables in turn.

4.3 Explanatory variables

We use three groups of explanatory variables: variables that measure damage to a firm's tangible assets; variables that measure damage to banks and bank branches that a firm transacts with; and other variables. We explain each group of variables below.

4.3.1 Damage to a firm's tangible assets

In order to examine for the existence and size of impact transmitted through the collateral channel, we use the information on whether a firm experienced damage to its tangible assets and how much. In the SFTE, each firm reports whether it experienced damage to its fixed tangible assets and, if so, it reports the amount of damage to non-land tangibles and to land separately. For non-land tangibles, the firm measures the amount of damage in terms of repurchase prices or in terms of repair costs, while for land it reports the amount of losses in appraisal values. We divide these two variables by the firm's total amount of assets before the earthquake and construct the variables $F\_Damage\_Tangibles$ and F_Damage_Land.

4.3.2 Damage to a firm's primary banks and their branches

In order to examine for the existence and size of impact through the bank lending channel, we use balance sheet information of the bank with which a firm transacts as the primary bank. The primary bank for a firm is the bank that had extended the largest amount of loans outstanding to the firm before the earthquake. We use the special losses reported by a primary bank divided by its total amount of assets to construct the variable $B\_Special\_Losses$. The variable measures the extent of damage to the bank's fixed tangible assets caused by the earthquake resulting in a reduction in the net worth of the bank. As an alternative, we use another variable, $dB\_CapRatio$, which measures the change in the risk weighted capital ratio from one year prior to the earthquake to the year of the earthquake.

Further, we use information on the damage to bank branches in order to examine if the bank's lending capacity at the branch level is important. The earthquake damaged the structures, equipment, and human resources of a number of bank branches, and many of these branches closed or relocated somewhere else. We collect this information from the disclosure documents of the banks and through direct inquiries to bank officials to construct two variables, B_Branch_Reloc and B_Branch_Closed. The former takes a value of 1 if the bank branch relocated from its original location after the earthquake and 0 otherwise, while the latter takes a value of 1 if the branch remained closed for at least one day after the earthquake and 0 otherwise. Also, we aggregate the branch relocation and closure information at the bank level to construct another set of variables, $B\_Branch\_Reloc\_sum$ and $B\_Branch\_Closed\_sum$. We use all five variables on bank or bank branch damage to examine how the shocks caused by the earthquake were transmitted through the bank lending channel.

4.3.3 Other types of damage to a firm

We also include a vector of other variables in the estimation. In order to control for other types of adverse impacts caused by the earthquake apart from those through the collateral and bank lending channels, we use a number of variables proxying for various kinds of negative impact. First, we employ two variables that proxy for the damage transmitted through supply chains. Cus_Damage and Sup_Damage respectively take a value of 1 if a firm is indirectly affected through damage to their customers or suppliers and 0 otherwise. Second, we use three different variables regarding a firm's location in the earthquake-affected areas in order to represent different types of shocks caused by the earthquake. $Damaged\_Area$ takes a value of 1 if a firm is located in an area designated by the Act on Special Financial Support to Deal with Extremely Severe Disasters. Of the three geographical definitions of the earthquake-affected area, this is the broadest one. Next, $Tsunami\_Area$ takes a value of 1 if a firm is located in an area that was inundated by the tsunami. In those areas, the tsunami caused much larger damage to structures and equipment than the tremor of the earthquake. Finally, $Evacuation\_Area$ takes a value of 1 if a firm was located within a radius of 20 kilometers from the Fukushima Dai-ichi Nuclear Power Plant, the area that was evacuated following the nuclear meltdown at the plant. Although not all firms located in this area were forced to relocate outside the area, there are certain restrictions on the way firms have been able to operate in the area. Moreover, firms have suffered reputational damage linked to fears that their products may have been exposed to high radiation. These three variables control for the different types of impact caused by the earthquake.

4.3.4 Financial support and firm-bank relationships

In order to examine factors that may have alleviated the adverse shocks transmitted through the collateral and bank lending channels, we introduce several variables. The first two variables represent financial assistance to firms damaged by the earthquake. $Insurance$ takes a value of 1 if a firm had taken out earthquake insurance before the earthquake, while $Subsidy$ takes a value of 1 if a firm received subsidies for recovery investment. Although these two variables are similar in that they represent the provision of funds to firms, the way insurance payouts and subsidies alleviate credit constraints differs. Insurance payouts are determined based on the amount firms spent on property, plant, and equipment in the past, while investment subsidies were proportional to the amount firms were planning to invest after the earthquake. Therefore, receiving the insurance payout directly alleviated firms' credit constraints by increasing their net worth, while receiving investment subsidies reduced the costs of investment and alleviated the extent to which firms were constrained in financing recovery investment projects. We include each of these two variables and their interaction terms with $F\_Damage\_Tangibles$.

Second, we employ one variable that represents financial assistance to banks in the form of capital injection by the government. $Injection$ takes a value of 1 if the primary bank of a firm received a capital injection after the earthquake. Since the capital injections were aimed at restoring the lending capacity of damaged banks, they alleviated the extent to which the bank was unable to supply sufficient funds to firms due to the damage to its net worth. We include this variable and its interaction term with one of the six bank damage variables ($B\_Special\_Loss$).

Third, we employ two variables that may possibly be related to the extent of the impact through the collateral and bank lending channels. These are Num_bank, which represents the number of banks a firm used to transact with before the earthquake, and $Duration\_bank$, which represents the number of years a firm had transacted with the primary bank. Firms that have a close long-term relationship with their banks, in which case Num_bank is small and $Duration\_bank$ is large, may have been more likely to obtain bank loans than those that had no such relationships even when they were damaged by the earthquake.

4.3.5 Control variables

We use several variables to control for firm attributes. $Employment$ measures the number of employees, which we employ as a proxy for firm size. $Leverage$ is the ratio of liabilities to total assets, which is a proxy for a firm's riskiness. $Business\_Conditions$ is a subjective measure of the current business conditions of a firm ranging from 1 (very good) to 5 (very bad). Finally, we also use industry dummies.

5. Estimation results

5.1 Baseline results of the credit constraint estimation

In the baseline estimation, we focus on equation (1) in period 2, which measures the instantaneous impact of damage to firms and to banks on firms' credit constraint shortly after the earthquake. By employing different variables for F_Damage and B_Damage, we examine whether damage to firms or banks had a significant impact on firms' credit availability. Specifically, the variables we use are the two variables to represent the damage to a firm's fixed tangible and land assets ($F\_Damage\_Tangibles$ and F_Damage_Land), the two variables to represent the damage to a bank's lending capacity ($B\_Special\_Losses$ and $dB\_CapRatio$), the two variables to represent the damage to a bank branch that a firm transacted with (B_Branch_Reloc and B_Branch_Closed), and the two variables to represent the damage to the branch network of a bank that a firms transacted with ($B\_Branch\_Reloc\_Sum$ and $B\_Branch\_Closed\_Sum$). The estimation results are shown in Table 5(a).

We start by looking at the coefficients on the variables that we are most interested in. For the F_Damage variables, we find that the coefficients on both $F\_Damage\_Tangibles$ and F_Damage_Land are positive and statistically significant. The coefficients on $F\_Damage\_Tangibles$ are smaller in size but more significant than that on F_Damage_Land. One possible reason for the relatively low statistical significance of the coefficient on F_Damage_Land is measurement errors in land value losses. Unless land owners actually sell their land, it is difficult for them to know the exact amount of losses in land value caused by the earthquake, since they can only rely on its appraisal value. Taking this into consideration, we will solely employ $F\_Damage\_Tangibles$ for the damage to firms' tangible assets in later estimations.

Turning to the bank damage variables constructed from banks' balance sheet information ($B\_Special\_Losses$ and $dB\_CapRatio$), we find that the coefficients on $B\_Special\_Losses$ are significant and positive, while that on $dB\_CapRatio$ is significant and negative. Since larger special losses reduce the bank's capital ratio, both of these coefficients indicate that the reduction in banks' lending capacity caused by losses from the earthquake leads to a tightening in firms' credit constraint. It should be emphasized that the coefficients on these bank damage variables are substantially larger than those on the firm damage variables, even though we constructed both sets of damage variables in the same manner (by dividing the amount of damage by the amount of total assets). The size of the coefficients indicates that a one percentage point decline in the net worth of a bank that a firm transacts with increased the probability of the firm being credit constrained more than 80 times as much as a one percentage point decrease in the firm's own net worth. Note that we will use $B\_Special\_Losses$ rather than $dB\_CapRatio$ in later estimations, since the former variable more directly represents the damage caused by the earthquake than the latter, which may be confounded by other factors.

Using the above results, we compare the economic significance of the impact of shocks transmitted through the collateral and the bank lending channel, respectively. On the one hand, taking the mean value of the firm damage variable $F\_Damage\_Tangibles$ (0.1541 from Table 3) and multiplying it by the marginal effect on the variable (0.1662 calculated from Column (1) in Table 5), we obtain the increase in the probability that a firm is credit constrained, which is 2.56 percentage points. This represents the size of the impact of the damage to a firm's tangible assets caused by the earthquake transmitted through the collateral channel. On the other hand, taking the mean value of bank damage variable $B\_Special\_Losses$ (0.0037 from Table 4) and multiplying it by the marginal effect (13.4988 calculated from Column (1) of Table 5), we obtain the increase in the probability that a firm is credit constrained, which is 4.99 percentage points. This represents the size of the impact transmitted through the bank lending channel. These results suggest that the impact through the bank lending channel is larger and economically more significant than that through the collateral channel.

Turning to the variables on the closure and relocation of bank branches, B_Branch_Reloc and B_Branch_Closed, we examine if the damage to a bank branch rather than to a bank as a whole had a negative impact on a firm's credit availability. We find that the coefficients on these variables are negative but insignificant. On the other hand, the coefficients on $B\_Branch\_Reloc\_sum$ and $B\_Branch\_Closed\_sum$ (the ratio of branches relocated or closed to all the branches of a bank), are positive but again insignificant. All these results suggest that the damage to a bank branch that a firm transacted with had no economically significant impact.

Next, we examine the coefficients on the variables that measure damage to suppliers and customers of a firm and damage to the local area where the firm is located. Of the five variables, only $Tsunami\_Area$ has a marginally significant coefficient, which is positive, indicating that firms located in a *tsunami*-affected area were marginally more likely to face credit constraints. Having examined the impact of both direct and indirect damage in the baseline estimation, we find that only damage to firms' assets and damage to the net worth of a bank that firms transact with seem to have had a statistically significant negative impact on firms' credit availability.

Finally, we look at the coefficients on the firm control variables and find that several have significant coefficients. Specifically, we find statistically significant coefficients on $Employment$, $Business\_Conditions$, and $Leverage$, indicating that firms with a smaller number of employees, facing worse business conditions, and/or with higher leverage were more likely to be credit constrained.

5.2 Credit constraint estimation for later periods

Following the baseline estimation, we implement the estimation of equation (1) for the later periods 3, 4, and 5 to see how persistent the impact of damage to firms and banks through the collateral and bank lending channels was. From the specifications shown in Table 5(a) in the previous subsection, we employ the one in Column (1) and implement the estimation for each of the three later periods. While the variables on damage to firms and banks are time invariant, not only the dependent variables but also some of the explanatory variables such as $Business\_Conditions$ and $Leverage$ vary over time. Note that one explanatory variable ($Evacuation\_Area$) is dropped in periods 4 and 5 since the variable perfectly predicts the dependent variable in these periods. The results of this estimation are shown in Table 5(b).

We start by looking at coefficients on the variables that represent damage to a firm's fixed tangibles and damage to a bank's lending capacity. We find that the coefficient on $F\_Damage\_Tangibles$ is positive and significant in period 2 but becomes successively smaller and statistically less significant thereafter. Thus, damage to a firm's tangible assets had an adverse impact on its credit availability through the collateral channel for about one year and four months after the earthquake, but this negative effect subsequently dissipated. On the other hand, the coefficient on $B\_Special\_Losses$ is positive and significant in both periods 2 and 3 but becomes insignificant in periods 4 and 5. In other words, damage to a bank's lending capacity negatively affected credit availability for its borrower firms at most for two-and-a-half years after the earthquake. The coefficients on the bank branch damage variable, $B\_Branch\_Reloc,$ are negative but insignificant for all periods, and those on $B\_Branch\_Reloc\_Sum$ are also always insignificant. In sum, the impact through the collateral and bank lending channels was rather short-lived and did not last more than three years. However, the impact through the bank lending channel appears to have persisted longer than that through the collateral channel.

Next, we examine the coefficients on other damage variables in later periods. The only significant coefficient is the negative coefficient on Cus_Damage in period 3, while all other coefficients on firm damage variables are insignificant in all periods. The significant negative coefficient on Cus_Damage in period 3 implies that firms whose customers suffered damage were less likely to be credit constrained. One possible explanation is that creditworthy firms that were less likely to be credit constrained had so many customers that at least one of them was damaged by the earthquake.

Finally, looking at the coefficients on the firm control variables, we find that their signs and statistical significance are similar across periods. $Employment$, $Business\_Conditions$, and $Leverage$ all have statistically significant coefficients in all periods, with the only exception being the coefficient on $Leverage$ in period 3.

5.3 The role of financial support and firm-bank relationships

The next issue we examine is the effect of various types of financial support and the role of firm-bank relationships in alleviating the negative impact of the earthquake. For this purpose, we use the five variables introduced in Section 4.3.4, namely $Insurance$ and $Subsidy$ for financial support to firms, $Injection$ for financial support to banks, and Num_Bank and $Duration\_Bank$ for close firm-bank relationships. We add these five variables along with their interaction terms with the firm or bank damage variable to the explanatory variables employed in the baseline specification. The results are shown in Table 5(c).

Starting with the variables on financial support to firms, we find that the way earthquake insurance and subsidies for recovery investment affects firms' credit constraint differs.

Specifically, the insurance variable has a negative and significant coefficient, while its interaction term with firm damage has a statistically insignificant coefficient. The result suggests that insurance payouts increased a firm's net worth and reduced the probability that a firm was credit constrained. However, the maximum insurance payout was predetermined and the amount was not necessarily correlated with the amount of damage caused by the earthquake. Therefore, while insurance payouts themselves alleviated credit constraints, the amount of damage had no significant impact on the extent insurance money reduced credit constraints. In contrast, the coefficient on $Subsidy$ is insignificant, but its interaction term with $F\_Damage\_Tangibles$ has a marginally significant negative coefficient, indicating that the subsidies helped to alleviate the negative impact of the damage to a firm's tangible assets on its credit availability. The result is consistent with the fact that the scheme provided subsidies in proportion to the amount of recovery investment undertaken, which, in turn, likely reflects the amount of damage suffered by a firm.

Turning to the results for the variables on financial support to banks, the coefficients on both $Injection$ and its interaction term with the amount of bank damage are statistically insignificant. Regarding the variables on firm-bank relationships, we find a marginally negative coefficient on the interaction term between Num_Bank and $F\_Damage\_Tangibles$. We interpret this as indicating that multiple relationships with banks enabled firms to find alternative funding sources and alleviated the negative impact caused by the damage to the value of their collateral.

To summarize the above results, one type of financial support to firms (earthquake insurance) reduced the probability of firms being credit constrained, while the other type of support to firms (investment subsidies) alleviated the impact of shocks transmitted through the collateral channel. Also, multiple bank relationships marginally alleviated the extent to which shocks transmitted through the collateral channel. In contrast, we found no statistically significant evidence that the capital injections to banks alleviated the impact of shocks transmitted through the bank lending channel.

5.4 The impact on firm activities

So far, our examination has focused on the impact of the damaged caused by the earthquake on firms' credit constraints via the collateral and bank lending channels. In this section, our attention shifts to the impact that such credit constraints had on firms' real activities, in particular their sales and production, investment, and financing. We employ the treatment effect estimation procedure described in Section 4.1, which consists of the following two equations: equation (1) for the credit constraint estimation, which we examined in the previous three subsections, and equation (2) for the estimation of the impact on firm activities. In order to control for the endogenous nature of credit constraints, we estimate these two equations simultaneously. In this system of equations, we include the bank damage variable $B\_Special\_Losses$ in equation (1) only, since we assume that the variable affects firms' real activities only through firms' credit constraints. On the other hand, we include the variable for the damage to firms tangible assets, $F\_Damage\_Tangibles$, in both equations (1) and (2), since we assume that this variable affects firms' real activities not only via credit constraints but also through a number of other routes. For example, one possibility is that substantial damage to a firm's tangible assets impaired its production capacity; another is that the damage increased the demand for recovery investment.

With these considerations in mind, we implement treatment effect regressions using the three firm activity variables as the dependent variable in equation (2) in turn. The explanatory variables are almost the same as those in equation (1) in the baseline estimation. We exclude the variables on damage to bank branches from the set of explanatory variables, since all of their coefficients were insignificant in the baseline estimation. We also implement a simple ordinary least squares (OLS) estimation of equation (2) for each of the firm activity variables and compare the results with those using the treatment regression model.

We start with Table 6(a), which presents the results when we employ $Activity\_Level$ as the outcome variable. Column (1) in the table shows the coefficients from the first-stage estimation using a dummy indicating whether a firm was credit constrained or not as the dependent variable. The results are quite similar to those obtained in the baseline credit constraint estimation in Table 5(a). Column (2) shows the results of the second-stage estimation. The coefficient that we are most interested in is that on $Constrained$, which is negative and significant. Next, Columns (3) and (4) show the results when we employ simple OLS estimation. As can be seen, the coefficients on $Constrained$ in this case are also negative but much smaller in size and either insignificant or only marginally significant. The other variable we are interested in is $F\_Damage\_Tangibles$. This has a significant negative coefficient in Column (2), which indicates that the damage to a firm's tangible assets had a direct impact on its activity level through the impairment of capital inputs.

Next, Table 6(b) shows the results when we employ $Investment$ as the outcome variable. Column (1) shows that the coefficients from the first stage estimation are more or less similar to those obtained in the baseline credit constraint estimation in Table 5(a). Note, however, that some variables, such as $F\_Damage\_Tangibles$, now have an insignificant coefficient, presumably due to the small sample size. In Column (2), the coefficient on $Constrained$ is positive but not significant. This differs from the results of the simple OLS estimation in Columns (3) and (4), where the coefficients are positive and significant. These results indicate that if $Constraint$ is not instrumented, the variable is contaminated by confounding factors such as the demand for recovery investment, potentially giving rise to significant upward bias in the coefficient estimates.

The other variable of interest, $F\_Damage\_Tangibles$, has a positive coefficient, which indicates that damage to a firm's tangible assets had a direct impact on its investment for recovery.

Finally, Table 6(c) shows the results when we employ $Loan\_Ratio$ as the outcome variable. Column (1) shows that the coefficients again are quite similar to those obtained in the baseline credit constraint estimation in Table 5. Next, Column (2) indicates that the coefficient on $Constrained$ is negative and significant, implying that firms that faced a tighter credit constraint reduced their amount of borrowing. This contrasts with the result in Columns (3) and (4) obtained using simple OLS estimation, where the coefficients are positive. The other variable of our interest, $F\_Damage\_Tangibles$, has a positive coefficient, which indicates that damage to a firm's tangible assets increased its loan demand for reconstruction and resulted in a larger loan amount outstanding.

To summarize, we find that the tighter credit constraints caused by the damage to banks' lending capacity and by damage to firms' tangible assets had a negative impact on some firm activities, such as their production and sales as well as their financing.

5.5 Aggregate impact on the economy

In the previous subsections, we showed that the earthquake had an adverse impact not only on firms' credit availability but also on their production and sales activities through the collateral and bank lending channels. However, the scope of this analysis was limited to firms in our sample, which we constructed from the SFTE. Showing that the mechanisms examined affected the activities of firms in the sample does not necessarily mean that they were of significance for the wider economy, for the following two reasons. First, our results may overestimate the impact on the economy of the region included in our analysis, since our sample is limited only to firms that had demand for new loans. Since there were a substantial number of firms that did not require a loan, a simple extrapolation of our results to the entire population of firms in the region may exaggerate the extent of the negative impact. Second, our estimations do not include firms located outside the earthquake-affected area that may have been adversely affected by the damage to banks inside the area through bank-firm relationships. Therefore, excluding firms located outside the earthquake-affected area from the sample may result in underestimation of the impact transmitted through the bank lending channel.

Given these possible biases, we attempt to measure the aggregate impact of the Tohoku earthquake on the entire Japanese economy transmitted through the two channels. For this purpose, we use information for all the firms in the TSR database introduced in Section 3.1, while in the previous section we used information only for firms that responded to the SFTE. The TSR database provides information on the geographical location of the headquarters, the number of employees, the amount of sales, and the identity of the primary bank for about 2.38 million firms throughout Japan. Given that, according to firm censuses by the government, there are about 4 million firms in the country, this means that the TSR database covers a substantial portion of the total population of firms. Further, to simplify the analysis, we make the following assumptions: (1) only firms in the region covered by the SFTE suffered substantial damage to their tangible assets, so that the collateral channel is confined to firms located in the area covered by the SFTE; and (2) the extent of the impact transmitted through the bank lending channel is the same inside and outside the areas covered by the SFTE. Details of the procedures for calculating the aggregate impact are provided in the Appendix.

The results of the calculation are shown in Table 7 and indicate that the size of the impact transmitted through the two channels is economically sizable in the region covered by the SFTE. Looking at the impact transmitted through the collateral channel, the number of credit constrained firms is 1,122, and the reduction in sales due to credit constraints is 131 billion yen. Turning to the impact through the bank lending channel in the survey region, the number of credit constrained firms is 2,737, and the reduction in sales due to credit constraints is 351 billion yen. These figures combined indicate that the total number of constrained firms after the earthquake was 3,859, which was 3.7% of the number of firms in the region, and the sales reduction due to the constraints amounted to 482 billion, which was equivalent to 1.1% of the total sales amount in the region.

However, it would be difficult to argue that this adverse regional impact through these channels was long-lasting or large in relation to the national economy overall. The reasons are as follows. First, the results in Table 5(b) indicate no statistically significant impact through the collateral channel two-and-a-half years after the earthquake and no statistically significant impact through the bank lending channel after three-and-a-half years. Hence, the negative impact through both channels decayed rather quickly. Second, when we measure the impact on the national economy in terms of the ratio of the number of credit constrained firms and in terms of the ratio of the sales reduction caused by the constraints, both were quite small. We see from Table 7 that the number of credit constrained firms following the earthquake was 4,726 firms, accounting for only 0.2% of the total number of firms; similarly, the reduction in sales amounted to 716 billion yen, which is equivalent to only 0.04% of the total amount of sales in the economy as whole.

6. Conclusion

This study simultaneously examined for the existence of the collateral and the bank lending channel and compared the economic significance of each channel. For this purpose, we employed a unique firm-bank matched panel dataset and measured the damage to individual firms and banks caused by the massive Tohoku earthquake in 2011. We obtained the following findings: (1) damage to firms' tangible assets and to the net worth of their primary bank led to a deterioration in firms' access to credit, providing evidence of the existence of both the collateral and the bank lending channel; (2) firms that faced a tighter credit constraint after the earthquake experienced a reduction in their amount of borrowing and their level of production and sales; (3) in aggregate, the damage caused by the earthquake and transmitted through the collateral and bank lending channels substantially decreased the sales and production of firms located in the region, but the effect was rather short-lived and had no substantial impact on the national economy overall; and (4) some of the financial support received by affected firms such as investment subsidies and earthquake insurance payouts alleviated the negative impact.

Appendix: Procedures used for calculating the aggregate impact on the economy overall

This appendix presents details of the procedure we employed to calculate the aggregate impact through the collateral and bank lending channels on the economy overall. We first calculate the aggregate impact through the collateral channel, followed by the calculation of the impact through the lending channel.

A1. Aggregate impact through the collateral channel

We start by using the coefficient estimate for $F\_Damage\_Tangibles$ obtained in Column (1) of Table 5(a) (0.467) to calculate the average marginal effect for firms located in each of the seven regions (Hachinohe, Coastal Iwate, Inland Iwate, Coastal Miyagi, Inland Miyagi, Coastal Fukushima, and Inland Fukushima), which we denote by a_i, where i stands for the region. Next, we multiply the average marginal effects for firms in each region by the ratio of firms that had loan demand (b_i) and the average amount of damage to their tangible assets (c_i) to obtain the marginal increase in the probability that firms were credit constrained (d_i). The marginal increase in the probability that firms were credit constrained varies across regions from 0.0064 (Inland Fukushima) to 0.0259 (Coastal Miyagi). Finally, multiplying the marginal increase in each region by the total number of firms in the region recorded in the TSR database (e_i), we obtain the total number of firms that became credit constrained through the collateral channel (h_i). Further, multiplying the number of constrained firms by a firm's average sales (f_i) and the average rate of sales decrease taken from the coefficient on $Constraint$ in Column (2) of Table 6(a) (-27.74% and denoted by g), we obtain the amount of sales decline caused by the impact transmitted through the collateral channel (k_i). Table A1 shows the values used and obtained in the various steps of the calculation.

As can be seen in the table, the total number of credit constrained firms is 1,122 firms, while the sales decrease caused by credit constraints amounts to 131 billion yen. Note that the above calculation measures the impact for one-and-a-half years after the earthquake and that the impact of the earthquake transmitted through the collateral channel became insignificant after that.

A2. Aggregate impact through the bank lending channel

To calculate the aggregate impact through the bank lending channel, we start by using the coefficient on $B\_Special\_Losses$ in the estimation in Column (1) of Table 5(a) (37.91) to calculate the average marginal effect for firms located in each of the seven regions (a_i, where i stands for the region). For the five areas that are not included in the surveys (Aomori except for Hachinohe, Hokkaido, the rest of Tohoku, Kanto, and the rest of Japan), we use the average marginal effect for the entire sample.[6] We multiply each of these effects with the ratio of firms with demand for loans (b_i). The values of the above two variables are shown in Table A2.

Next, we employ bank and bank-region level information: the extent of special losses of a bank (c_j, where j stands for the bank) and the number of firms in each region with which a bank transacts (d_{ij}). We find many firms that were located outside the earthquake-affected area but transacted with banks located inside the area. We present these variables in Table A3. By multiplying all these variables – the marginal effect of a bank's special losses (a_i), the extent of a bank's special losses (c_j), the number of firms that transact with the bank (d_{ij}), and the ratio of firms with demand for loans (b_i) – we obtain the number of firms that were credit constrained due to the shock transmitted through the bank lending channel (h_{ij}). Moreover, by multiplying h_{ij} with the average sales amount of a firm (f_i) and with the average rate of sales decrease caused by credit constraints (-27.74% and denoted by g), we obtain the amount of sales decline through the

[6] Similarly, for b_i and g we take the average values for the survey region and use these for regions outside the survey region.

bank lending channel (k_{ij}). We sum h_{ij} and k_{ij} across the regions covered by the SFTE, across the regions not covered by the survey, and across the entire country. The results are presented in Table A4.

The above calculations suggest that there were a total of 3,604 constrained firms and the sales decrease caused by credit constraints amounted to 585 billion yen. These figures include not only firms located in the survey region (2,737 firms, accounting for a sales decrease of 351 billion yen), but also firms outside the survey region (867 firms, 234 billion yen). That is, although these firms did not suffer any direct damage from the earthquake, they were still affected indirectly through the damage suffered by their primary bank.

Note that the above calculation measures the impact for one-and-a-half years after the earthquake and that the impact in later periods became smaller. The impact of the earthquake transmitted through the bank lending channel became about 20% smaller in the next period (from July 2012 to August/September 2013). By replacing the marginal effect of 37.91 (in Column (1) of Table 5(b)) with 30.75 (in Column (2) of the same table) and otherwise following the same procedure described in the preceding paragraphs, the number of constrained firms and the resulting sales reduction are 2,220 firms and 284 billion yen in the survey region and 703 firms and 190 billion yen outside the region, respectively. Note further that there is no statistically significant negative impact of the earthquake transmitted through the bank lending channel after this period.

A3. Aggregate impact through the two channels

The above calculations show that the adverse impact of the earthquake transmitted through the collateral channel and the bank lending channel was non-negligible one-and-a-half years after the earthquake and that the impact through the bank lending channel was non-negligible two-and-a-half years after the earthquake. Next, we evaluate the economic significance of the negative impact transmitted through the collateral and bank lending channels on the regional and on the national economy.

Given the number of firms in the survey region and their annual sales amount (100,000 firms and 45 trillion yen, respectively), the impact in terms of leading firms to be credit constrained one-and-a-half years after the earthquake was sizeable, since 3.7% of firms became credit constrained. The impact on sales was also substantial, with sales being reduced by about 1.1%. The impact was still sizable two-and-a-half years after the earthquake, with the ratio of credit constrained firms being 2.1% of the total number of firms and the resulting decline in sales 0.6% of the total sales in the region.

In contrast, given the number of firms in the entire country and their annual sales (2.38 million firms and 2,037 trillion yen), the impact in terms of credit constraints was not economically sizable, with only 0.2% of firms being credit constrained as a result one-and-a-half years after the earthquake. The impact on sales also was not economically substantial, since the reduction amounted to only 0.04% of total sales.

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Table 1: Overall damage of the Tohoku (Great East Japan) earthquake

	Deaths	People missing	Houses completely destroyed	Houses half destroyed	Houses partially destroyed	Area in square kilometers	Number of residents	Dead+missing/population	Completely destroyed houses/100 residents	Completely+ half destroyed houses/100 residents	Completely+ half+partially destroyed houses/100 residents
Total	19,575	2,577	121,776	280,326	744,269	92,641	55,555,668	0.0004	0.2192	0.7238	2.0635
Non-designated municipalities	44	0	361	2,964	147,718	57,337	43,854,049	0.0000	0.0008	0.0076	0.3444
Designated+non-tsunami affected municipalities	354	13	7,876	65,369	286,411	22,832	7,619,719	0.0000	0.1034	0.9613	4.7201
Designated+tsunami-affected municipalities	19,177	2,564	113,539	211,993	310,140	12,472	4,081,900	0.0047	2.7815	7.9750	15.5729
Most severely damaged municipalities in terms of houses completely destroyed											
Onagawa	615	258	2,924	349	661	66	10,051	0.0869	29.0916	32.5639	39.1404
Otsuchi	854	422	3,579	588	208	201	15,276	0.0835	23.4289	27.2781	28.6397
Minami-sanriku	620	211	3,143	178	1,204	164	17,429	0.0477	18.0332	19.0544	25.9625
Rikuzen-takata	1,602	203	3,806	240	3,985	232	23,300	0.0775	16.3348	17.3648	34.4678
Yamada	687	148	2,762	405	202	263	18,617	0.0449	14.8359	17.0113	18.0964
Yamamoto	700	18	2,217	1,085	1,138	64	16,704	0.0430	13.2723	19.7677	26.5805
Higashi-matsushi	1,132	23	5,519	5,558	3,504	102	42,903	0.0269	12.8639	25.8187	33.9860
Ishinomaki	3,552	425	20,041	13,048	19,948	556	160,826	0.0247	12.4613	20.5744	32.9779
Kesennuma	1,216	215	8,483	2,571	4,761	333	73,489	0.0195	11.5432	15.0417	21.5202
Kamaishi	993	152	2,957	699	1,048	441	39,574	0.0289	7.4721	9.2384	11.8866

"Total" covers all municipalities that experienced damage to humans or structures.

Table 2: Definition of variables

Variable	Definition	Winsorized
Credit constraint variables		
Constrained	1: the firm did not obtain a sufficient amount of funds, 0: it obtained a sufficient amount of funds	No
Firm activity variables		
Activity_Level	Level of a firm's activities in a particular year relative to the level in the year before the Tohoku earthquake. 100% if it was the same as in the pre-earthquake year.	Yes
Investment	Amount of tangible investment (including land and structures) in a year/amount of tangible assets outstanding at the end of the previous year	Yes
Loan_Ratio	Amount of loans outstanding / amount of total assets outstanding at the end of the year	Yes
Variables on damage		
To a firm's tangible assets		
F_Damage_Tangibles	Amount of damage to a firm's non-land tangible assets / total amount of the firm's assets before the earthquake. The damage is measured in terms of the replacement costs.	Yes
F_Damage_Land	Amount of damage to a firm's land assets / total amount of the firm's assets before the earthquake. The damage is measured in terms of the loss in the appraisal value of land.	Yes
To a bank or a bank branch that a firm transacted with		
B_Special_Losses	Special losses of a firm's primary bank in fiscal 2010 / total assets of the bank at the end of the fiscal year. A firm's primary bank is the bank that has extended the largest amount of loans to the firm.	No
dB_CapRatio	Change in the capital ratio of a firm's primary bank from fiscal 2009 to 2010. For the ratio, the amount of capital is divided by the amount of risk assets.	No
B_Branch_Reloc	1: the branch of the primary bank that a firm used to transact with before the earthquake was relocated, and 0: otherwise	No
B_Branch_Reloc_Sum	Number of relocated branches of the primary bank / total number of branches of the bank	No
B_Branch_Closed	1: the branch of the primary bank that a firm used to transact with before the earthquake remained closed for at least one day, and 0: otherwise	No
B_Branch_Closed_Sum	Number of closed branches of the primary bank / total number of branches of the bank	No
To a firm's transaction partners		
Cus_Damage	1: the firm was indirectly affected by damage to its customers, and 0: otherwise	No
Sup_Damage	1: the firm was indirectly affected by damage to its suppliers, and 0: otherwise	No
To specific areas		
Damaged_Area	1: the firm was located in an area designated by the Act on Special Financial Support to Deal with Extremely Sever Disasters, and 0: otherwise	No
Tsunami_Area	1: the firm was located in an area inundated by the tsunami, and 0: otherwise	No
Evacuation_Area	1: the firm was located in an area within a 20km radius from the Fukushima Dai-ichi Nuclear Power Plant, and 0: otherwise	No
Variables on financial support and firm-bank relationship		
Injection	1: the primary bank of a firm received a capital injection from the government after the earthquake, and 0: otherwise	No
Insurance	1: the firm had taken out earthquake insurance, and 0: otherwise	No
Subsidy	1: the firm received subsidies for recovery investment from the government, and 0: otherwise	No
Num_Bank	Number of banks a firm used to transact with before the earthquake	No
Duration_Bank	Number of years the firm had transacted with its primary bank	No
Control variables		
Employment	The firm's number of employees	No
Business_Conditions	The firm's assessment of its current business conditions. 1: very good, 2: good, 3: fair, 4: bad, and 5: very bad	No
Leverage	Amount of liabilities in the previous year / amount of total assets in the previous year	Yes
Industry dummies	1: Construction (default), 2: Manufacturing, 3: Utilities, IT, and transportation, 4: Wholesale, 5: Retail sales, and 6: Services and other industries	No

Table 3: Summary statistics

	N	mean	sd	min	p25	p50	p75	max
Credit constraint variables								
Constrained	1190	0.4933	0.5002	0	0	0	1	1
Firm activity variables								
Activity_Level	958	93.4438	30.1284	0	80	96	100	300
Investment	504	0.2509	0.4807	0	0.0179	0.0686	0.2719	4.5320
Loan_Ratio	995	0.5978	0.7004	0	0.2336	0.4603	0.7018	5
Damage variables								
F_Damage_Tangibles	1190	0.1541	0.3932	0	0	0.0188	0.1133	3.2787
F_Damage_Land	1190	0.0198	0.0841	0	0	0	0	0.6093
B_Special_Losses	1190	0.0037	0.0033	0.0000	0.0008	0.0027	0.0083	0.0090
dB_CapRatio	1176	-0.0054	0.0102	-0.0291	-0.0160	-0.0040	-0.0002	0.0671
B_Branch_Closed	1190	0.3387	0.4735	0	0	0	1	1
B_Branch_Closed_Sum	1190	0.2330	0.2228	0	0.0734	0.2027	0.3451	1
B_Branch_Reloc	1190	0.1420	0.3492	0	0	0	0	1
B_Branch_Reloc_Sum	1190	0.1021	0.1248	0	0.0690	0.0789	0.1197	0.6667
Cus_Damage	1190	0.4782	0.4997	0	0	0	1	1
Sup_Damage	1190	0.3782	0.4851	0	0	0	1	1
Damaged_Area	1190	0.8319	0.3741	0	1	1	1	1
Tsunami_Area	1190	0.2059	0.4045	0	0	0	0	1
Evacuation_Area	1190	0.0118	0.1079	0	0	0	0	1
Financial support and firm-bank relationship variables								
Injection	1190	0.3924	0.4885	0	0	0	1	1
Insurance	1190	0.2815	0.4499	0	0	0	1	1
Subsidy	1190	0.2370	0.4254	0	0	0	0	1
Num_Bank	1088	2.5983	1.8493	0	1	2	3	19
Duration_Bank	1067	30.9428	15.9727	0	20	30	40	100
Control variables								
Employment	1190	33.6370	71.8974	1	8	18	35	1637
Business_Conditions	1190	3.2101	1.0709	1	2	3	4	5
Leverage	1190	0.8647	0.6623	0.0002	0.5749	0.7979	0.9657	6.5
Ind=1 (Construction)	1190	0.3025	0.4593	0	0	0	1	1
=2 (Manufacturing)	1190	0.1714	0.3769	0	0	0	0	1
=3 (Utilities, IT, and transportation)	1190	0.0840	0.2774	0	0	0	0	1
=4 (Wholesale)	1190	0.1437	0.3508	0	0	0	0	1
=5 (Retail)	1190	0.1294	0.3357	0	0	0	0	1
=6 (Services)	1190	0.1689	0.3747	0	0	0	0	1

Table 4: Damage to banks

Bank name	Bank category	Bank code	B_Special_Losses	dB_CapRatio	B_Branch_Closed_Sum	B_Branch_Reloc_Sum	Injection
Fukushima	Second-tier regional	513	0.00900	-0.014	0.2364	0.0727	0
77	Regional	125	0.00825	-0.016	0.3451	0.1197	1
Tohoku	Regional	124	0.00695	-0.0106	0.1379	0.0690	1
Kitanihon	Second-tier regional	509	0.00538	-0.006	0.1235	0.0864	0
Ishinomaki	*Shinkin*	1172	0.00412	-0.0077	1	0.6667	1
Sendai	Second-tier regional	512	0.00411	-0.0185	0.1690	0.1268	1
Iwate	Regional	123	0.00273	-0.0002	0.0734	0.0734	0
Daito	Second-tier regional	514	0.00264	0.0031	0.1111	0.0794	0
Iwaki	Credit cooperative	2092	0.00199	-0.002	0.6842	0.2632	1
Sen-nan	*Shinkin*	1174	0.00168	0.0005	0.0625	0.0625	0
Kesennuma	*Shinkin*	1175	0.00167	-0.0291	0.9167	0.6667	1
Morinomiyako	*Shinkin*	1170	0.00163	0.0025	0.2667	0.2667	0
Soso	Credit cooperative	2095	0.00150	-0.0065	0.8750	0.5000	1
Ishinomaki shoko	Credit cooperative	2061	0.00147	0.0134	0.2500	0.1667	0
Miyako	*Shinkin*	1152	0.00144	-0.004	0.7778	0.6667	1
Aizu shoko	Credit cooperative	2096	0.00109	0.0016	0	0	0
Sukagawa	*Shinkin*	1185	0.00108	-0.0008	0.0769	0.0769	0
Kirayaka	Second-tier regional	508	0.00098	-0.0104	0.0339	0.0254	1
Himawari	*Shinkin*	1186	0.00096	-0.0001	1	0.0625	0
Asuka	Credit cooperative	2060	0.00096	0.0009			0
Toho	Regional	126	0.00075	-0.0004	0.3070	0.0789	0
Aoimori	*Shinkin*	1105	0.00072	0.0113	0.0137	0	0
Ichinoseki	*Shinkin*	1153	0.00067	0.0076	0	0	0
Development bank of Japan	Government-affiliated	9930	0.00063	0.0142	0	0	0
Miyagi Dai-ichi	*Shinkin*	1171	0.00055	0.0024	0.0769	0	0
Aomori	Regional	117	0.00040	-0.0097	0	0	0
Nihonmatsu	*Shinkin*	1189	0.00037	0.0014	0	0	0
Japan Finance Corporation	Government-affiliated	9932	0.00037				0
Fukushimaken Shoko	Credit cooperative	2090	0.00028		0.0625	0	0
Fukushima	*Shinkin*	1190	0.00025	0.0028	0.0385	0	0
Ashikaga	Regional	129	0.00024		0	0	0
Yamanashi Chuo	Regional	142	0.00024	0.0076	0	0	0
Akita	Regional	119	0.00022	-0.0013	0	0	0
Senhoku	Credit cooperative	2063	0.00021	-0.0071	0	0	0
Joyo	Regional	130	0.00019	-0.0001	0.0400	0.0057	0
Mitsubishi-Tokyo-UFJ	City	5	0.00018	0.0027	0	0	0
Michinoku	Regional	118	0.00017	-0.0103	0	0	0
Risona	City	10	0.00015	0.0074	0	0	0
Norinchukin	Agricultural	3000	0.00014	0.0671	0	0	0
Shonai	Regional	121	0.00012	0.0257	0.1059	0.0471	0
Daishi	Regional	140	0.00011	-0.0084	0	0	0
Shokochukin	Government-affiliated	2004	0.00011	0.0097	0	0	0
Morioka	*Shinkin*	1150	0.00010	-0.0051	0	0	0
Yamagata	Regional	122	0.00008	0.0049	0.0500	0	0
Mitsui-Sumitomo	City	9	0.00008	0.0317	0	0	0
Mizuho	City	1	0.00007	0.0266	0	0	0
Tokyo Tomin	Regional	137	0.00007	-0.0053	0	0	0
Koriyama	*Shinkin*	1182	0.00007	0.0077	0.0526	0.0526	0
Shirakawa	*Shinkin*	1184	0.00006	-0.0036	0	0	0
Mizuho Corporate	City	16	0.00005	0.0205	0	0	0
Mizusawa	*Shinkin*	1156	0.00004	0.0073	0	0	0
Kitakami	*Shinkin*	1154	0.00004	0.0001	0	0	0
Aizu	*Shinkin*	1181	0.00003	0.0077	0	0	0
Yokohama	Regional	138	0.00003	0.0006	0	0	0
Aomori-ken	Credit cooperative	2030	0.00001		0	0	0
Hanamaki	*Shinkin*	1155	0.00001	0.0093	0	0	0
Kanagawa	Second-tier regional	530	0.00001	0.0038	0	0	0
Abukuma	*Shinkin*	1188	0.00001	0.0018	0.4286	0.2143	1
Furukawa	Credit cooperative	2062	0.00000		0	0	0

Table 5: Credit constraint estimation

(a) Baseline

	(1)	(2)	(3)	(4)
	Dependent variable=Constrained			
VARIABLES	Probit model estimation			
F_Damage_Tangibles	0.467***		0.450***	0.479***
	(0.128)		(0.127)	(0.126)
F_Damage_Land		0.992*		
		(0.509)		
B_Special_Losses	37.91***	38.47***		40.18***
	(12.04)	(11.99)		(12.22)
dB_CapRatio			-12.35***	
			(4.077)	
B_Branch_Reloc	-0.0883	-0.0361	-0.0710	
	(0.123)	(0.121)	(0.123)	
B_Branch_Reloc_Sum	0.211	0.318	0.102	
	(0.336)	(0.332)	(0.344)	
B_Branch_Closed				-0.0554
				(0.0943)
B_Branch_Closed_Sum				-0.0917
				(0.193)
Cus_Damage	-0.0952	-0.0872	-0.0786	-0.0969
	(0.0838)	(0.0835)	(0.0844)	(0.0839)
Sup_Damage	0.0790	0.0698	0.0807	0.0738
	(0.0832)	(0.0829)	(0.0836)	(0.0831)
Damaged_Area	0.0605	0.0812	0.0552	0.0743
	(0.106)	(0.106)	(0.107)	(0.107)
Tsunami_Area	0.151	0.194*	0.176*	0.166
	(0.104)	(0.103)	(0.105)	(0.104)
Evacuation_Area	-0.0210	-0.159	-0.0243	-0.0152
	(0.363)	(0.368)	(0.363)	(0.362)
Employment	-0.00372***	-0.00381***	-0.00349***	-0.00379***
	(0.000956)	(0.000958)	(0.000943)	(0.000965)
Business_Conditions	0.280***	0.284***	0.282***	0.277***
	(0.0378)	(0.0377)	(0.0381)	(0.0377)
Leverage	0.281***	0.299***	0.274***	0.285***
	(0.0636)	(0.0634)	(0.0634)	(0.0635)
Manufacturing	0.103	0.117	0.117	0.0963
	(0.119)	(0.119)	(0.120)	(0.120)
Utilities, IT, and transportation	-0.0789	-0.0704	-0.108	-0.0905
	(0.154)	(0.153)	(0.156)	(0.154)
Wholesale	-0.217*	-0.224*	-0.212	-0.226*
	(0.129)	(0.128)	(0.129)	(0.128)
Retail	-0.207	-0.194	-0.224*	-0.207
	(0.129)	(0.128)	(0.130)	(0.129)
Services	-0.0245	-0.0210	-0.0313	-0.0286
	(0.118)	(0.117)	(0.119)	(0.118)
Constant	-1.269***	-1.298***	-1.201***	-1.232***
	(0.182)	(0.182)	(0.179)	(0.182)
Number of observations	1,190	1,190	1,176	1,190

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

(b) Different periods

		(1)	(2)	(3)	(4)
		Dependent variable = Constrained			
		Probit model estimation			
VARIABLES	period=	2	3	4	5
		March 2011-July 2012	July 2012-Aug/Sep 2013	Oct 2013-Aug/Sep 2014	Oct 2014-Oct/Nov 2015
F_Damage_Tangibles		0.467***	0.0877	-0.0613	0.0928
		(0.128)	(0.109)	(0.131)	(0.177)
B_Special_Losses		37.91***	30.75**	7.373	-21.64
		(12.04)	(13.29)	(19.36)	(21.77)
B_Branch_Reloc		-0.0883	-0.0892	-0.260	-0.146
		(0.123)	(0.159)	(0.213)	(0.250)
B_Branch_Reloc_Sum		0.211	0.103	-0.0792	0.619
		(0.336)	(0.473)	(0.612)	(0.934)
Cus_Damage		-0.0952	-0.207**	-0.0650	0.0140
		(0.0838)	(0.0924)	(0.132)	(0.144)
Sup_Damage		0.0790	0.120	-0.0510	-0.0289
		(0.0832)	(0.0917)	(0.129)	(0.139)
Damaged_Area		0.0605	-0.0894	-0.0921	0.183
		(0.106)	(0.0986)	(0.144)	(0.151)
Tsunami_Area		0.151	0.0572	0.00790	0.0841
		(0.104)	(0.141)	(0.194)	(0.209)
Evacuation_Area		-0.0210	0.379		
		(0.363)	(0.601)		
Employment		-0.00372***	-0.00355***	-0.0103***	-0.00667***
		(0.000956)	(0.00101)	(0.00212)	(0.00193)
Business_Conditions		0.280***	0.315***	0.398***	0.344***
		(0.0378)	(0.0418)	(0.0674)	(0.0761)
Leverage		0.281***	0.0869	0.447***	0.284**
		(0.0636)	(0.0551)	(0.121)	(0.111)
Manufacturing		0.103	-0.0749	0.182	0.122
		(0.119)	(0.133)	(0.201)	(0.205)
Utilities, IT, and transportation		-0.0789	0.0450	0.260	0.371
		(0.154)	(0.186)	(0.254)	(0.287)
Wholesale		-0.217*	-0.361**	-0.0252	-0.193
		(0.129)	(0.145)	(0.199)	(0.222)
Retail		-0.207	0.0346	0.0230	0.0459
		(0.129)	(0.141)	(0.219)	(0.228)
Services		-0.0245	0.0631	-0.129	-0.103
		(0.118)	(0.131)	(0.188)	(0.196)
Constant		-1.269***	-0.974***	-1.341***	-1.361***
		(0.182)	(0.170)	(0.270)	(0.295)
Number of observations		1,190	953	506	427

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

(c) Effects of financial support

	(1)	(2)	(3)	(4)	(5)
	Dependent variable = Constrained				
VARIABLES	Probit model estimation				
F_Damage_Tangibles	0.470***	0.401***	0.883***	0.952***	0.240
	(0.128)	(0.141)	(0.277)	(0.290)	(0.294)
B_Special_Losses	50.63**	39.88***	38.00***	42.97***	43.92***
	(23.81)	(12.11)	(12.07)	(12.56)	(12.65)
B_Branch_Reloc	-0.0894	-0.0720	-0.0699	-0.0817	-0.0539
	(0.123)	(0.124)	(0.126)	(0.129)	(0.130)
B_Branch_Reloc_Sum	-0.0135	0.209	0.199	0.301	0.199
	(0.424)	(0.339)	(0.338)	(0.356)	(0.352)
Cus_Damage	-0.0937	-0.0925	-0.0977	-0.0473	-0.0264
	(0.0840)	(0.0844)	(0.0842)	(0.0883)	(0.0892)
Sup_Damage	0.0823	0.0832	0.0916	0.114	0.0888
	(0.0833)	(0.0834)	(0.0836)	(0.0874)	(0.0885)
Damaged_Area	0.0612	0.0594	0.0598	0.0464	0.0376
	(0.108)	(0.106)	(0.107)	(0.110)	(0.112)
Tsunami_Area	0.155	0.151	0.152	0.170	0.157
	(0.105)	(0.105)	(0.107)	(0.111)	(0.111)
Evacuation_Area	-0.0633	0.00245	-0.0389	-0.124	-0.0725
	(0.365)	(0.364)	(0.367)	(0.390)	(0.401)
Employment	-0.00372***	-0.00370***	-0.00358***	-0.00367***	-0.00367***
	(0.000957)	(0.000958)	(0.000949)	(0.00102)	(0.00103)
Business_Conditions	0.280***	0.275***	0.284***	0.269***	0.262***
	(0.0379)	(0.0379)	(0.0379)	(0.0397)	(0.0399)
Leverage	0.277***	0.283***	0.280***	0.252***	0.223***
	(0.0638)	(0.0636)	(0.0638)	(0.0655)	(0.0650)
Manufacturing	0.104	0.0877	0.117	0.0988	0.0839
	(0.119)	(0.120)	(0.120)	(0.123)	(0.124)
Utilities, IT, and transportation	-0.0743	-0.0889	-0.0682	-0.0431	-0.0646
	(0.154)	(0.154)	(0.154)	(0.166)	(0.171)
Wholesale	-0.212*	-0.234*	-0.211	-0.217	-0.283**
	(0.129)	(0.129)	(0.129)	(0.133)	(0.136)
Retail	-0.209	-0.206	-0.213	-0.238*	-0.296**
	(0.129)	(0.129)	(0.130)	(0.137)	(0.139)
Services	-0.0280	-0.0463	-0.0292	0.00897	-0.0390
	(0.118)	(0.118)	(0.118)	(0.122)	(0.123)
Injection	0.224				
	(0.240)				
B_Special_Loss*Injection	-38.02				
	(38.84)				
Insurance		-0.215**			
		(0.0958)			
F_Damage_Tangibles*Insurance		0.283			
		(0.304)			
Subsidy			-0.0470		
			(0.111)		
F_Damage_Tangibles*Subsidy			-0.520*		
			(0.310)		
Num_Bank				0.0266	
				(0.0238)	
F_Damage_Tangibles*Num_Bank				-0.216*	
				(0.112)	
Duration_Bank					-0.00426
					(0.00284)
F_Damage_Tangibles*Duration_Bank					0.00740
					(0.00899)
Constant	-1.283***	-1.203***	-1.295***	-1.353***	-1.059***
	(0.184)	(0.185)	(0.183)	(0.200)	(0.213)
Number of observations	1,190	1,190	1,190	1,088	1,067

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 6: Firm activity estimation

(a) Production and sales activity level

	(1)	(2)	(3)	(4)
Dependent variable:	Constrained	Activity_Level	Activity_Level	Activity_Level
Esimation method:	Treatment regression		OLS	OLS
	First stage	Second stage		
Constrained		-27.74***	-3.087	-3.540*
		(8.464)	(1.892)	(1.831)
F_Damage_Tangibles	0.383***	-5.167**	-7.562***	
	(0.114)	(2.506)	(2.109)	
B_Special_Losses	37.28***			
	(12.07)			
Cus_Damage	0.0223	-2.717	-2.717	-3.251*
	(0.0889)	(2.066)	(1.947)	(1.948)
Sup_Damage	-0.00370	-0.656	-0.202	0.184
	(0.0885)	(2.041)	(1.931)	(1.942)
Damaged_Area	0.0439	0.0364	-0.718	-1.241
	(0.110)	(2.589)	(2.444)	(2.296)
Tsunami_Area	0.135	-2.673	-5.085**	-6.633***
	(0.106)	(2.538)	(2.310)	(2.302)
Evacuation_Area	-0.139	-17.04*	-14.97*	-14.55
	(0.424)	(9.252)	(8.782)	(9.040)
Employment	-0.00353***	-0.00709	0.0121	0.0109
	(0.000976)	(0.0144)	(0.0123)	(0.0125)
Business_Conditions	0.262***	-4.946***	-7.501***	-7.742***
	(0.0395)	(1.219)	(0.869)	(0.856)
Leverage	0.273***	3.285**	0.639	-0.0378
	(0.0654)	(1.595)	(1.328)	(1.214)
Manufacturing	0.115	-9.320***	-10.21***	-8.989***
	(0.130)	(3.015)	(2.852)	(2.762)
Utilities, IT, and transportation	0.0291	-8.314**	-8.044**	-6.610*
	(0.168)	(3.861)	(3.673)	(3.630)
Wholesale	-0.271**	-12.07***	-10.29***	-9.042***
	(0.137)	(3.295)	(3.023)	(2.964)
Retail	-0.121	-10.44***	-8.510***	-8.056***
	(0.138)	(3.246)	(3.045)	(2.973)
Services	0.0406	-8.935***	-8.854***	-7.580***
	(0.121)	(2.810)	(2.650)	(2.534)
Constant	-1.233***	130.3***	129.2***	129.7***
	(0.188)	(4.115)	(3.868)	(3.690)
athrho		0.540***		
		(0.192)		
lnsigma		3.411***		
		(0.0537)		
Observations	1,037	1,037	1,050	1,174
R-squared			0.146	0.127

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 6: Firm activity estimation

(b) Investment

	(1)	(2)	(3)	(4)
Dependent variable:	Constrained	Investment	Investment	Investment
Estimation method:	Treatment regression		OLS	OLS
	First stage	Second stage		
Constrained		0.169	0.130***	0.168***
		(0.129)	(0.0451)	(0.0475)
F_Damage_Tangibles	0.151	0.395***	0.403***	
	(0.164)	(0.0575)	(0.0558)	
B_Special_Losses	52.15***			
	(18.12)			
Cus_Damage	-0.0754	0.00241	0.00217	0.00405
	(0.123)	(0.0445)	(0.0457)	(0.0498)
Sup_Damage	-0.104	-0.0437	-0.0520	-0.0431
	(0.122)	(0.0439)	(0.0450)	(0.0490)
Damaged_Area	-0.00289	0.109**	0.112**	0.177***
	(0.150)	(0.0541)	(0.0561)	(0.0573)
Tsunami_Area	0.371**	-0.0298	-0.0358	0.0428
	(0.147)	(0.0567)	(0.0543)	(0.0577)
Evacuation_Area	-0.212	0.139	0.137	0.0874
	(0.631)	(0.217)	(0.225)	(0.251)
Employment	-0.00316***	-0.000524	-0.000618**	-0.000753**
	(0.00112)	(0.000324)	(0.000308)	(0.000335)
Business_Conditions	0.285***	-0.0229	-0.0265	-0.0151
	(0.0545)	(0.0228)	(0.0201)	(0.0216)
Leverage	0.268***	-0.0446	-0.0447	-0.0303
	(0.0899)	(0.0306)	(0.0291)	(0.0321)
Manufacturing	0.121	0.00137	0.0115	-0.0346
	(0.180)	(0.0653)	(0.0675)	(0.0702)
Utilities, IT, and transportation	0.112	0.0883	0.0965	0.0351
	(0.222)	(0.0799)	(0.0830)	(0.0895)
Wholesale	-0.315	0.0759	0.0735	0.00903
	(0.205)	(0.0736)	(0.0751)	(0.0794)
Retail	-0.0384	-0.0219	-0.0144	-0.0537
	(0.198)	(0.0716)	(0.0741)	(0.0803)
Services	0.107	0.0103	0.0283	-0.0141
	(0.170)	(0.0624)	(0.0636)	(0.0657)
Constant	-1.337***	0.177**	0.205**	0.180**
	(0.252)	(0.0855)	(0.0878)	(0.0912)
athrho		-0.0639		
		(0.158)		
lnsigma		-0.738***		
		(0.0307)		
Observations	552	552	563	621
R-squared			0.147	0.063

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 6 Firm activity estimation

(c) Loan ratio

	(1)	(2)	(3)	(4)
Dependent variable:	Constrained	Loan_Ratio	Loan_Ratio	Loan_Ratio
Estimation method:	Treatment regression		OLS	OLS
	First stage	Second stage		
Constrained		-0.808***	0.0631	0.116***
		(0.0570)	(0.0400)	(0.0404)
F_Damage_Tangibles	0.469***	0.571***	0.468***	
	(0.101)	(0.0601)	(0.0503)	
B_Special_Losses	25.49***			
	(9.520)			
Cus_Damage	0.0283	-0.0400	-0.0500	-0.0374
	(0.0848)	(0.0496)	(0.0414)	(0.0432)
Sup_Damage	0.0342	-0.0170	-0.0351	-0.0416
	(0.0850)	(0.0496)	(0.0415)	(0.0435)
Damaged_Area	0.0707	-0.0104	-0.0225	0.0392
	(0.104)	(0.0614)	(0.0516)	(0.0501)
Tsunami_Area	0.107	0.111*	0.0566	0.155***
	(0.103)	(0.0602)	(0.0502)	(0.0518)
Evacuation_Area	-0.637	-0.215	0.00602	-0.0149
	(0.493)	(0.281)	(0.237)	(0.255)
Employment	-0.00317***	-0.00154***	-0.000387	-0.000546
	(0.000837)	(0.000425)	(0.000348)	(0.000365)
Business_Conditions	0.268***	0.152***	0.0625***	0.0723***
	(0.0385)	(0.0226)	(0.0188)	(0.0192)
Leverage	0.247***	0.553***	0.482***	0.474***
	(0.0602)	(0.0341)	(0.0286)	(0.0272)
Manufacturing	-0.0400	0.0863	0.0818	0.0400
	(0.125)	(0.0730)	(0.0614)	(0.0627)
Utilities, IT, and transportation	-0.0682	-0.0378	-0.0150	-0.0396
	(0.156)	(0.0922)	(0.0772)	(0.0785)
Wholesale	-0.197	0.0528	0.131**	0.0997
	(0.132)	(0.0768)	(0.0642)	(0.0652)
Retail	-0.186	0.130*	0.185***	0.130**
	(0.132)	(0.0768)	(0.0642)	(0.0654)
Services	0.00395	0.0653	0.0626	0.0503
	(0.113)	(0.0670)	(0.0559)	(0.0560)
Constant	-1.130***	-0.0214	-0.114	-0.137*
	(0.179)	(0.101)	(0.0843)	(0.0834)
athrho		0.998***		
		(0.0592)		
lnsigma		-0.302***		
		(0.0295)		
Observations	1,075	1,075	1,087	1,225
R-squared			0.310	0.245

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 7: Aggregate impact of the earthquake through the collateral and bank lending channels

		Impact through collateral channel	Impact through bank lending channel	Sum
Firms located in the survey area	Number of constrained firms	1122	2737	3859
	Reduction of sales (billion yen)	131	351	482
Firms located outside the survey area	Number of constrained firms		867	867
	Reduction of sales (billion yen)		234	234
Sum	Number of constrained firms	1122	3604	4726
	Reduction of sales (billion yen)	131	585	716

Table A1: Aggregate impact through the collateral channel

	Hachinohe	Coastal Iwate	Inland Iwate	Coastal Miyagi	Inland Miyagi	Coastal Fukushima	Inland Fukushima	Sum
Average marginal effect (a_i)	0.1717	0.1684	0.1638	0.1647	0.1662	0.1668	0.1645	0.1659
Ratio of firms that had demand for new loans (b_i)	0.5886	0.5916	0.5584	0.6042	0.5450	0.6115	0.7022	0.6047
Average amount of damage to tangible assets to total tangible assets (c_i)	0.0933	0.2397	0.0228	0.2603	0.0682	0.1346	0.0551	0.1541
Ratio of firms that are credit constrained due to damage to their tangible assets (d_i=a*b*c)	0.0094	0.0239	0.0021	0.0259	0.0062	0.0137	0.0064	0.0155
Number of firms in the TSR database (e_i)	4602	4716	17456	18991	21669	9740	26785	103959
Average sales amount of firms in the TSR database (thousand yen) (f_i)	4.07E+05	2.23E+05	3.81E+05	4.53E+05	6.05E+05	3.02E+05	4.17E+05	4.37E+05
Decline in sales due to credit constraint to total sales (g)	0.2774	0.2774	0.2774	0.2774	0.2774	0.2774	0.2774	0.2774
Number of firms that are credit constrained due to damage (h_i=d*e)	43	113	36	492	134	134	170	1122
Amount of sales reduction among these firms (thousand yen) (k_i=f*g*h)	4900412	6982012	3849323	61873204	22481031	11208293	19734611	131028886

Table A2: Region-level variables for measuring the impact through the bank lending channel

Region (i)	Hachinohe	Aomori not Hachinohe	Coastal Iwate	Inland Iwate	Coastal Miyagi	Inland Miyagi	Coastal Fukushima	Inland Fukushima	Hokkaido	Rest of Tohoku	Kanto	Rest of Japan
i=	21	22	31	32	41	42	71	72	100	200	300	400
Average marginal effect of a bank's special losses (a_i)	13.96625	13.49148	13.6937	13.3169	13.3918	13.5132	13.56814	13.37406	13.49148	13.49148	13.4915	13.49148
Ratio of firms that had demand for new loans (b_i)	0.5886	0.6047	0.5916	0.5584	0.6042	0.5450	0.6115	0.7022	0.6047	0.6047	0.6047	0.6047
Average sales amount of firms in the TSR database (thousand yen) (f_i)	4.1E+05	3.1E+05	2.2E+05	3.8E+05	4.5E+05	6.1E+05	3.0E+05	4.2E+05	3.7E+05	3.0E+05	1.5E+06	5.8E+05
Decline in sales due to credit constraint to total sales (g)	0.2774	0.2774	0.2774	0.2774	0.2774	0.2774	0.2774	0.2774	0.2774	0.2774	0.2774	0.2774

Table A3: Bank-region-level variables for measuring the impact through the bank lending channel

Bank name	B_Special _Losses (c_j)	Number of firms that transact with the bank (d_ij)												
		Hachinohe	Aomori not Hachinohe	Coastal Iwate	Inland Iwate	Coastal Miyagi	Inland Miyagi	Coastal Fukushima	Inland Fukushima	Hokkaido	Rest of Tohoku	Kanto	Rest of Japan	Total
		i=21	22	31	32	41	42	71	72	100	200	300	400	
Fukushima	0.00900				1	32	36	849	2777			161	5	3861
77	0.00825	1	2	1	78	8937	11032	601	119	45	92	126	30	21064
Tohoku	0.00695	148	16	634	2826	320	163		1	1	81	21	3	4214
Kitanihon	0.00538	159	161	838	2739	489	196		90	0	164	55	1	4892
Ishinomaki	0.00412					833	46							879
Sendai	0.00411				4	1786	2919	25	25		3	19	4	4785
Iwate	0.00273	184	33	2139	6797	322	116			6	15	38	4	9654
Daito	0.00264	1				1	2	731	2841	1	1	93		3671
Iwaki	0.00199					1		930	1			2		934
Sen-nan	0.00168					228	649					2		879
Kesennuma	0.00167			113	6	545	4							668
Morinomiya	0.00163				1	1286	1210					2		2499
Soso	0.00150							252	4					256
Ishinomaki s	0.00147					791	74							865
Miyako	0.00144			386	4									390
Aizu shoko	0.00109								520	5				525
Sukagawa	0.00108								900			2		902
Kirayaka	0.00098			2	1	182	209		94	1	6535	112	246	7382
Himawari	0.00096							1075	2			8	2	1087
Asuka	0.00096	4	6		2	16	21	3	6	21	3	175	1	258
Toho	0.00075					108	63	2844	10022		7	341	41	13426
Aoimori	0.00072	1136	2199	3								2		3340
Ichinoseki	0.00067			1	629	2	59					1	3	695
Developmen	0.00063	2	2	1	3	7	11	4	3	39	7	229	234	542
Miyagi Dai-i	0.00055					519	491					1		1011
Aomori	0.00040	1377	7766	3	33	13	40			195	128	27		9582
Nihonmatsu	0.00037							1	559			3		563
Japan Finan	0.00037	47	212	30	45	124	84	48	112	424	81	2061	3439	6707
Fukushimako	0.00028								711			1	1	713
Fukushima	0.00025					1	2	1	1784	1		4	3	1796
Ashikaga	0.00024				1	3	14	1	174	1	2	21218	44	21458
Yamanashi C	0.00024								1	1		611	10453	11066
Akita	0.00022	71	120	3	51	83	68	98	275	250	10450	62	22	11553
Senhoku	0.00021					8	180							188
Joyo	0.00019		1			116	142	813	714	2	3	19809	28	21628
Mitsubishi-T	0.00018	9	19	4	28	221	383	21	55	695	51	1E+05	84193	188904
Michinoku	0.00017	914	5976	108	224	24	55	1		780	281	56	6	8425
Risona	0.00015		5	1	7	57	122	4	11	228	7	29638	28745	58825
Norinchukin	0.00014	8	19	11	22	47	26	12	20	73	57	407	571	1273
Shonai	0.00012					36	74	1	33		4211	19	11	4385
Daishi	0.00011						1		93	128	1	257	16483	16963
Shokochukin	0.00011	51	57	4	41	197	117	20	56	319	180	3115	5350	9507
Morioka	0.00010			34	1082						1	2		1119
Yamagata	0.00008				2	95	174	2	49	5	8233	148	9	8717
Mitsui-Sumi	0.00008	5	9	8	22	199	325	18	47	607	32	83060	64583	148915
Mizuho	0.00007	11	155	6	174	164	347	155	598	1384	287	97107	26534	126922
Tokyo Tomin	0.00007	1			3		1	1	3			7466	11	7486
Koriyama	0.00007					1		30	1060			3		1094
Shirakawa	0.00006								728			68	1	797
Mizuho Corp	0.00005	3	1	5	1	11	22	7	10	37	14	2247	524	2882
Mizusawa	0.00004				508							2	1	511
Kitakami	0.00004				524		1			1	1	1		528
Aizu	0.00003								834				1	835
Yokohama	0.00003		3		5	2	3	4	5	2	5	23474	105	23608
Aomori-ken	0.00001	53	1246											1299
Hanamaki	0.00001				377									377
Kanagawa	0.00001						1					1941	3	1945
Abukuma	0.00001					21		577	4			1	1	604
Furukawa	0.00000					1	329							330

Table A4: Aggregate impact through the bank lending channel

Bank name	Number of firms that were credit constrained due to damage (h_j)			Amount of sales decrease among these firms (thousand yen) (k_j)		
	Firms in the survey area	Firms outside the survey area	Total	Firms in the survey area	Firms outside the survey area	Total
Fukushima	303	12	315	33200750	4920062	38120812
77	1323	20	1343	192761806	4653624	197415430
Tohoku	216	7	223	22274910	981141	23256050
Kitanihon	187	17	203	19139175	2205808	21344983
Ishinomaki	29	0	29	3725013	0	3725013
Sendai	150	1	151	22532227	292183	22824410
Iwate	199	2	201	19263782	467144	19730926
Daito	87	2	89	9525966	828842	10354808
Iwaki	15	0	15	1288014	13317	1301332
Sen-nan	11	0	11	1734426	11240	1745666
Kesennuma	9	0	9	1039676	0	1039676
Morinomiyako	32	0	32	4588472	10965	4599437
Soso	3	0	3	269037	0	269037
Ishinomaki sh	10	0	10	1318710	0	1318710
Miyako	5	0	5	284382	0	284382
Aizu shoko	5	0	5	613900	4602	618502
Sukagawa	9	0	9	1054298	7225	1061524
Kirayaka	4	55	59	534871	4994396	5529267
Himawari	9	0	9	719200	28271	747471
Asuka	0	2	2	53750	585985	639736
Toho	90	2	92	9850748	906672	10757420
Aoimori	7	13	20	757255	1119984	1877239
Ichinoseki	3	0	3	380692	4879	385571
Development	0	3	3	19702	697964	717666
Miyagi Dai-ich	4	0	4	619047	1828	620875
Aomori	5	27	31	549604	2343363	2892966
Nihonmatsu	2	0	2	226500	3745	230245
Japan Finance	1	19	20	177030	4435199	4612230
Fukushimaken	2	0	2	214312	1295	215607
Fukushima	4	0	4	488743	4580	493323
Ashikaga	0	42	43	51688	17440426	17492114
Yamanashi Ch	0	21	21	257	3742575	3742832
Akita	1	19	21	140235	1655188	1795423
Senhoku	0	0	0	48332	0	48332
Joyo	3	30	33	304340	12370170	12674509
Mitsubishi-To	1	277	278	145237	82542161	82687398
Michinoku	2	10	12	203205	914231	1117436
Risona	0	73	73	34936	20912364	20947299
Norinchukin	0	1	1	19312	307058	326370
Shonai	0	4	4	19409	344296	363705
Daishi	0	16	16	11567	2565436	2577003
Shokochukin	0	8	8	53776	1922324	1976100
Morioka	1	0	1	85593	728	86321
Yamagata	0	5	5	28203	465249	493452
Mitsui-Sumito	0	91	92	52480	27535961	27588441
Mizuho	1	76	77	111919	26940790	27052709
Tokyo Tomin	0	4	4	610	1801212	1801822
Koriyama	1	0	1	79866	684	80551
Shirakawa	0	0	0	44885	13004	57889
Mizuho Corpo	0	1	1	3229	443148	446376
Mizusawa	0	0	0	17101	343	17444
Kitakami	0	0	0	15047	178	15224
Aizu	0	0	0	27751	40	27791
Yokohama	0	6	6	542	2389621	2390163
Aomori-ken	0	0	0	415	7436	7851
Hanamaki	0	0	0	2111	0	2111
Kanagawa	0	0	0	9	46178	46186
Abukuma	0	0	0	2732	30	2762
Furukawa	0	0	0	934	0	934
Total	2737	867	3604	350711719	233885144	584596863