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Estimation of the economic impact of urban flood through the use of big data on inter-branch office transactions

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Abstract

This paper quantitatively examines the economic impact of urban flood disasters in Tokyo on the supply chain. It accomplishes this task by using geographic information system (GIS) data on inter-firm transactions. First, we use flood simulation analysis data to identify firms that were unable to continue business operations due to flood damage. Second, we employ inter-firm transaction data to detect businesses that are related to affected firms. Subsequently, we discuss and analyze the industrial structure of the identified companies that have business associations with affected firms. Finally, we focus on the indirect economic damage caused to these companies and estimate the affected transaction amount in consideration of the magnitude of their linkages with directly affected firms. The present investigation reveals several interesting results. First, 19-29% of companies in Japan are associated with affected firms through business interests. This figure increases to nearly 50% when fifth-order firms are included: those companies connected to affected firms through the five shortest-link paths in the trading network. Many firms could thus be affected by a natural catastrophe even when they are actually located outside the core disaster area. In addition, the economic damage is estimated to be nearly 1.3% of Japan's gross domestic product (GDP).

Key words : inter-firm transaction data, supply chain, spillover effects, urban flood disaster, flood simulation

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1. INTRODUCTION

In recent years, natural disasters have become large scale, diversified, and frequent in Japan. Natural calamities such as the torrential rainfall in July 2018 in Heisei and the enormous earthquake in east Japan in 2011 have caused enormous damage and loss of human lives. The river flooded during the Heavy Rain of July, Heisei 30 (2018). Large areas were inundated and 237 people died (Cabinet Office, 2019). Examples in other countries include Hurricane Katrina (2005) and the Thailand floods (2011). On the economic side, many businesses in locations other than the affected areas have suffered indirect costs such as the halt of production because of interruptions in the inter-firm transaction network. It is thought that the incidence of various natural disasters may increase worldwide in the future (Dercon, 2005; Fachamps et al., 2003).

To reduce the economic impact of large-scale catastrophes, it is crucial for a stable inter-firm transaction network to be established so that business activities are able to continue. According to Tokyo Shoko Research Ltd. (2018), 27.7% of Japanese firms have formulated a business continuity planning (BCP) methodology that takes natural disasters into account. However, only 2.3% of companies are prepared for large-scale floods because the estimation of economic damage caused by flooding is not sufficient for the formulation of BCP, and because the magnitude of the damage has not been calculated. Therefore, it is critical to estimate the potential economic impact of large-scale flooding.

Numerous extant studies have used inter-firm transaction and statistical data (Noy, 2009; Raddatz, 2009; Strobl, 2011) to investigate the economic impact of large-scale natural disasters. Kajitani and Tatano (2018) estimated flow damage of the Great East Japan Earthquake by using the spatial computable general equilibrium (SCGE) model, which comprises comparative static equilibrium models of interregional trade and location. However, SCGE models typically use a dataset of statistical data between wide areas, such as input-output (I/O) tables, which does not cover supply chain networks between firms. Carvalho et al. (2016) developed a model based on the role of input-output to quantify the spillover effects of damage to estimate the harm caused by the Great East Japan Earthquake. This model incorporated the notion that damage would be propagated through transactional relationships of firms. Japan's total production decreased 1.2% in 2012 as a result of the earthquake of 2011. Tokui et al. (2012) estimated the damage by the Great East Japan Earthquake by approximating the gross output and damage rate of each region using statistical data such as the net capital stock of each industry sector and the total gross output. According to their calculation, the total damage exceeded 1.35% of Japan's annual GDP in 2011. Ogawa et al. (2017) applied sparse modeling by combining inter-firm transaction data and GIS microdata, and examined the sales growth and business relationships of firms outside the area affected by the tsunami before and after the Great East Japan Earthquake. The study revealed that the disaster had a significant negative impact on directly and indirectly related firms; the business partners of firms in affected areas continued to conduct new transactions. However, the inter-firm transactional data used in these studies refer to transactions between the corporate headquarters. In reality, since firms run many branch offices throughout the country, the locations of such regional divisions must also be considered along with their transactions. In addition, Ogawa et al. (2019) used varied statistics such as the transaction data of inter-branch offices and tsunami records to estimate the recovery process of firms after the Nankai Megathrust Earthquakes in Japan. Studies such as this one may be used to model other investigations pertaining to the economic impact of large-scale natural disasters that are predicted in the future. Webdawatta et al. (2012) estimated the entrepreneurial and regional - economic impacts of a specific production site in Austria by using light detection and ranging data as a source, based on flood modeling and expert judgement.

There are also many examinations of floods caused by hurricanes, heavy rain, and so on, e.g., Risk Management Solutions (2005) and Congressional Budget Office (2005). The Bureau of Labor Statistics (2006) analyzed the decline in production due to Hurricane Katrina by using statistical data from the Current Employment Statistics program and from the Quarterly Census of Employment and Wages. However, there are very few studies on the analysis of the wide-area economic impact caused by flooding, and those few investigations are limited to evaluations using statistical data such as input-output (I/O tables) tables. Further, only prefectural-level I/O tables are available throughout Japan, and these are not suitable for the analysis of the impact of narrow river basin areas that may also suffer extensive flood damage.

On the other hand, there are several examples of micro-analysis of damage caused by large-scale floods. For instance, Ikeuchi et al. (2011) estimated the potential human damage by floods in the Tokyo metropolitan area by using flooding simulation data at the building level using a death estimation model. This dataset was simulated on a 100-meter mesh basis, and had the advantage of being able to identify the location of affected firms within a narrower range and to accomplish a micro-level analysis.

Based on the above context, this study evaluates the economic impact on the supply chain by using flood analysis data and transaction data at the level of branch offices of firms. The following three points can be mentioned as the distinctive features of this paper: first, the use of flood analysis data and inter-branch offices transaction data makes it possible to scrutinize the economic impact of each region and industry at the branch office level, which is more micro; second, the drainage conditions of inundation are taken as a time series, and more accurate damage estimation can be made as the inundation and recovery periods of the affected firms are taken into account; third, a method of quantitatively identifying the firms affected by the flood and the firms that are influenced by the inter-firm transaction network is posited by this study. This proposed model also considers their degree of influence by combining the flood simulation analysis data and the transaction data of firms across the country.

The rest of this paper is organized as follows. Section 2 describes the data used in this paper. Section 3 presents the analysis and Section 4. the results. Section 5 concludes the paper.

2. DATA

2. 1 Flood simulation analysis data

The flooding area investigated in this study is the Arakawa basin located in the Tokyo metropolitan area. The Arakawa River flows through metropolitan Tokyo, the central city of the Japanese economy. It is a first-class river with a maximum width of 2,537 m in Japan. Because it is close to the central part of the city, many firms are located in its basin. If this river floods, it is likely to cause immense damage. Further, since lowlands are widely distributed in the lower reaches of the Arakawa River, areas that are inundated would take time to drain, and many firms are expected to be forced to suspend operations for a long period of time in such a situation of flooding. Thus, the initial damage caused by the primary disaster is likely to increase manifold.

The present investigation employs data for a flood on a scale of 0.001 AEP (annual exceedance probability) to analyze potential damage to firms. The data were sourced from the results of flooding simulations of the Arakawa River area provided by the Arakawa Downstream River Office, Ministry of Land, Infrastructure, Transport and Tourism (MLIT). The flooding simulation derived from this data is being conducted along the assumed Flood Inundation Area Diagram Drawing Manual (2017) created by the MLIT.

This dataset contains 335 scenarios, each with a different levee breakdown location. These data represent 100-meter-mesh figures containing information such as breakdown location and time-series (10 minutes' data for one month after the levee breakdown) data on inundation depth. This paper applies three scenarios with high damage identified by Ikeuchi et al. (2011) (**Fig. 1**). To define the features of each case, scenario Saitama encompasses the largest population in the inundation area. Scenario Tokyo comprises the possibility of inundation reaching 5 m or more in some areas near the break point such that the Soryu flows into Itabashi, Arakawa, Otemachi, Marunouchi, Ginza, and other central areas. The Koto Delta scenario envisions that the zero-meter zone is widely distributed and that there is an area with an inundation depth of more than 5 m.

2. 2 CORPORATE HEADQUARTERS AND BRANCH OFFICE DATA

These data were compiled by a major credit reporting agency of Japan, Teikoku Databank Ltd. (TDB). The dataset encompassed nearly 1.65 million corporate headquarters and 580,000 branch offices in 2015 and accounted for nearly 90% of the 1.87 million corporate enterprises in Japan including 1.62 million incorporated companies and 240,000 other firms (2016 Economic Census) in all 47 Japanese prefectures and spanning all sectors of

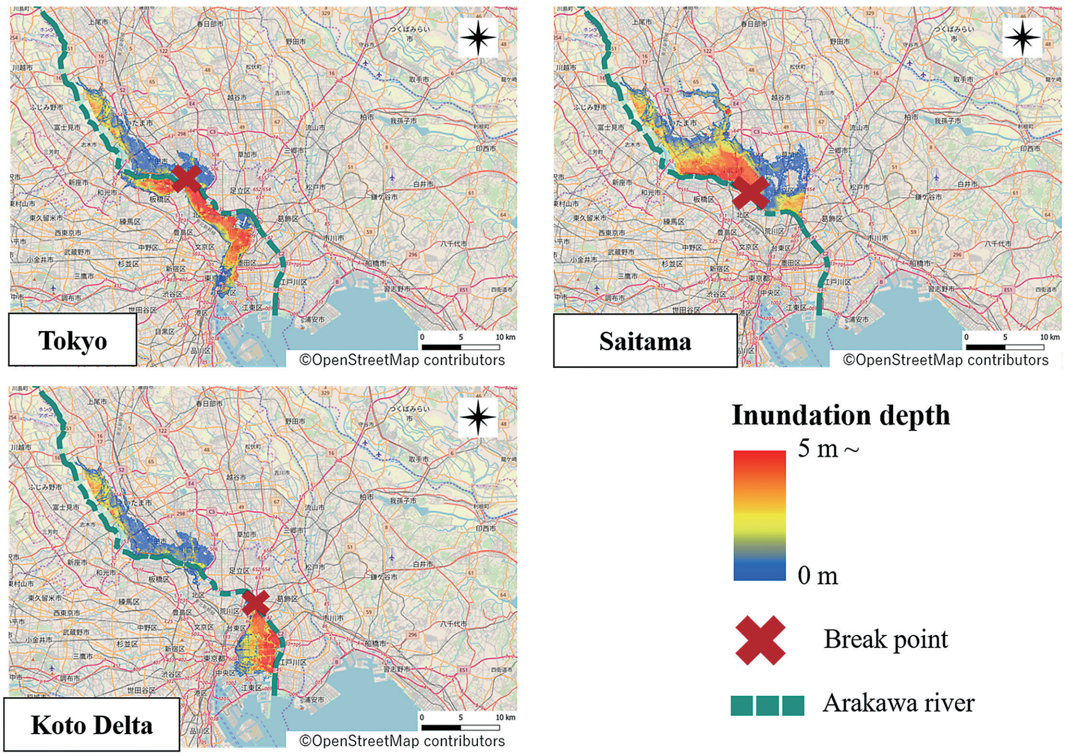

Fig. 1 Flood area and maximum inundation depth in the three scenarios

the economy. The resulting information is highly comprehensive and includes the firms' codes, addresses, industry type, and sales amounts.

2. 3 INTER-BRANCH OFFICE TRANSACTION DATA

Many firms have multiple branch offices. Since these data were compiled from transactions among headquarters, it was not possible to ascertain transactions between branch offices. Therefore, the authors of this paper used nearly 332 million transaction observations at both headquarters and branch offices as developed by Ogawa et al. (2018). Transaction amounts were distributed to each branch office based on the gravity model that uses the distances between offices and number of employees. Nearly 5 million inter-firm transaction observations were compiled in 2016 from the TDB headquarters transaction data. These data include transaction information between headquarters, such as the company codes of suppliers and clients, transaction items, and estimated transaction amounts. As shown in **Fig. 2**, the firm's code enables network analysis to be performed in association with data pertaining to the company and its branch offices.

A comparison of the transaction amounts of these data with inter-regional transactions based on I/O tables evinces a high correlation of R=0.9, indicating that it is adequate for a comprehensive grasp of production activities. In addition, there is a flow of goods and money in the transaction data between firms, and the transaction network is evaluated as a directed graph.

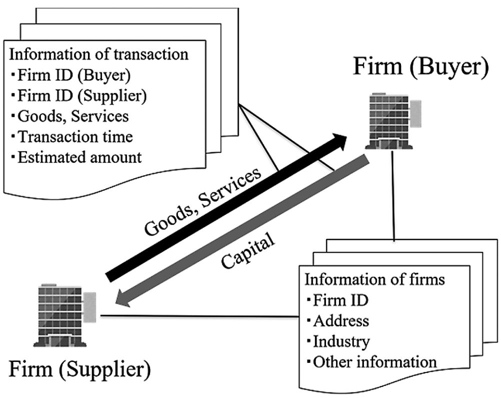

Fig. 2 Attribute of inter-firm transaction data

3. METHOD

First, latitudinal and longitudinal information was used from the Arakawa River flood simulation analysis data and the data on firms and branch offices to identify the affected firms based on the spatial join. The definition of an affected firm in the case of a large-scale flood is an enterprise whose business activities may be suspended for one of many reasons including power outage and stagnation of supplies.

This paper focuses on employees and assumes that business activities cannot be continued if employees cannot go to work. However, we do not take into account the inundation situation of employees' homes or the roads used for commuting. According to the Guidance on Analysis of Flood Damage Index (2013) of the MLIT Water and Disaster Management Bureau, it is difficult for people to walk on foot if the flooding depth exceeds 0.5 m. If the flooding depth reaches 0.3 m, cars will also be unable to move. Therefore, we define the firms in areas with a maximum inundation depth exceeding 0.3 m as affected firms. Next, we identify the business partners of the affected firms through the transaction data on inter-branch offices and the compiled data on firms and branch offices.

3. 1 SPILLOVER EFFECTS

According to Albert and Barabasi (2002), many networks exhibit complex structures with distinguishing features that define them as scale-free or small-world networks. It is said that everyone in the world is connected by a maximum of six degrees of separation. If the structure of this "small-world" network known in sociology is also valid for trading networks between companies, the disaster area would actually extend to include other regions that are not directly affected and many firms are likely to be affected through their business relationships. Ohnishi et al. (2010) demonstrate that the inter-firm transaction network also indicates the structure of the small-world network, implying that economic impact will indirectly spread throughout the country through inter-firm transaction networks. This paper assumes that all firms are linked to each other at the sixth transaction based on the concept of six degrees of separation.

First, let the affected firms be zero-order firms (Tier 0), and the business partners of the affected firms be first-order firms (Tier 1). Similarly, the business partners of nth-order firms (Tier n) are set as (n + 1)th-order firms (Tier n + 1) (**Fig. 3**).

The number of zero-order firms will be the number of directly affected firms, and the number of first-order firms will be the number of business partners of those directly affected firms. Similarly, the second to fifth orders are obtained by sequential calculation. However, in order to avoid duplication in the identification of firms, Tier n cannot become Tier n + 1 or beyond. For example, if a Tier n − 1 customer is Tier n, then, even if it has a business relationship with a Tier n + 1 firm or beyond, it does not become a Tier n + 1 firm or beyond.

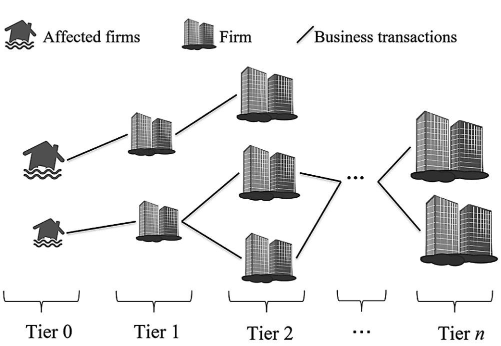

Fig. 3 Inter-firm transaction network of affected firms

Next, the proportion of Tier 0 to Tier 5 firms is sought for all firms in each prefecture and industry, respectively. The number of firms in industry p in prefecture q shall be F_{pq}. The number of firms in Tier n in industry p and prefecture q can be written as $F_{pq,\,Tier_n}$ and the proportion of Tier n in the firms of industry p, prefecture q, $R_{pq,\,Tier_n}$ is given by equation (1):

$$R_{pq,Tier_n} = \frac{F_{pq,Tier_n}}{F_{pq}}. \tag{1}$$

Moreover, there is a flow of objects in the transaction. Each company can thus be considered as a node and the transaction network can be regarded as a directed graph if the transaction is a link. For the purposes of this paper, the direction in which goods and services flow is downstream, and the opposite direction is upstream.

3. 2 AFFECTED TRANSACTION AMOUNT

Estimation of the amount of damage caused by disasters is important in determining the budget for disaster recovery and expediting damage insurance payments. In general, damage is calculated by assessing direct and indirect monetary loss. This study attends to indirect damage and uses inter-branch office transaction data to estimate the transaction amounts of affected firms. In addition, the affected amount is considered to be the quantum of transactions lost during the period when the economic activities of affected firms are suspended.

Yang et al. (2018) attempted to calculate the affected transaction amount using the sales of one of the annual transactions between branch offices. However, it is also necessary to consider the frequency of transactions conducted during the period of business outage due to disasters. Therefore, the average annual transaction frequency of firm i is determined by dividing total sales S_i for one year by the sum of the amount of one transaction that the firm has traded with each customer. Next, assume that the transaction between firm i (Tier n) and its downstream firms i' is $L_{ii'}$, and firms i' are denoted by {1, 2, 3, ..., I'}. One year has 365 days, and the average daily transaction amount with downstream firms i' of the firms i, $y_{ii'}$ is given by equation (2):

$$y_{ii'} = L_{ii'} \cdot \frac{S_i}{\sum_{i'=1}^{I'} L_{ii'}} \cdot \frac{1}{365}. \quad (2)$$

In addition, the inundation depth changes in the time series, and the degree of impact on the company also differs depending on the degree of inundation. The inundation period is referenced as a daily unit and termed "inundation time."

After being flooded, the company will carry out recovery activities until it can resume its business. During this period, the company loses 100% of its trade because it cannot conduct any production activities. This period is called "business interruption time." Even when the companies are ready to resume their business and can engage in production activities, the production capacity is only 50% of that before the disaster. This period is called "business stagnation time." However, the flooding analysis data only lasts 28 days. Scenario Tokyo and Koto Delta do not envisage draining even after one month, and there are areas where flooding is likely to continue even longer. The inundation period of those firms is set as 28 days for the purposes of the present computation.

In this paper, the affected time is calculated according to the business interruption time and business stagnation time of the establishments according to the flooding depth as seen in **Table 1** based on the Flood Control Economic Survey Manual (2005).

In addition, business interruption time is taken to be the period in which the entirety of dealings of the period is lost. The business stagnation time supposes the loss of half the quantum of the transactions within the period.

Next, the affected time shall be the sum of the business interruption time and half the business stagnation time and the inundation time (depth of inundation exceeds 0.3 m). Let $T_i^{(iundation)}$ be the inundation time of affected firm i, $T_i^{(interruption)}$ be the business interruption time, and $T_i^{(stagnation)}$ be the business stagnation time. Period of economic damage $T_i^{(affected)}$ is referred to as "affected time," which is given by equation (3):

$$T_i^{(affected)} = T_i^{(inundation)} + T_i^{(interruption)} + \frac{T_i^{(stagnation)}}{2}. \quad (3)$$

In addition, indirect damage spreads through the trading network but, as the degree of trading increases, the impact is considered to be less significant. For Tier 0 firms, it is assumed that the transaction amount loss is multiplied by the average daily transaction amount by the number of s days. However, for Tier 1 and later, the impact is smaller, so spillover effect coefficient K is set as a factor that indicates how much production is dependent on the affected firms. The value obtained by multiplying this amount by the economic damage can be calculated by multiplying the production amount by K. For example, affected companies will undergo 100% impact, as 100% production will stop during the affected time. Spillover effect coefficient of affected firm i, $K_{i,Tier_o}$ is given by equation (4):

Table 1 Impact on firms by inundation depth classification

Inundation depth (m)	Business interruption time (days)	Business stagnation time (days)
0-0.5	4.4	8.8
1.5-0.99	6.3	12.6
1-1.99	10.3	20.6
2-2.99	16.8	33.6
3-	22.6	45.2

$$K_{i,Tier_0} = T_i^{(affected)}. \tag{4}$$

The impact on Tier 1 firms is the loss in the share of purchase transactions with affected firms; so, for Tier 1 firms, the spillover effect coefficient is the ratio of the transaction amount with affected firms to total purchasing transactions.

For Tier 1 firms, let K be the ratio of the transaction amount of a particular company vis-à-vis the affected firms to the total transaction amount. Assume that the supplier firm of firm i is i'' and that its transaction with firm i is $y_{ii''}$, and firms i'' are denoted by {1, 2, 3, ..., I''}. The affected time of firm i'' *is* $T_{i''}^{(affected)}$, and spillover effect coefficient $K_{i,Tier_1}$ can be expressed by equation (5):

$$K_{i,Tier_1} = \frac{\sum_{i''=1}^{I''} y_{ii''} \cdot T_{i''}^{(affected)}}{\sum_{i''=1}^{I''} y_{ii''}}. \tag{5}$$

For Tier 2 and beyond, the impact on firm i in Tier n is its transaction with Tier n-1, which has a business relationship with the affected firms. The spillover effect coefficient is the ratio of transactions with Tier 1, which is affected by damage to all purchasing transactions. For Tier 2 and beyond, Tier n firm i, let the ratio of the sum of the value of transactions with each Tier n − 1 firm i'' multiplied by spillover effect coefficient $K_{i,Tier_{n-1}}$ of Tier n − 1 firm i'' to the total transaction value of Tier n firm i be firm i's spillover effect coefficient $K_{i,Tier_n}$, which can be expressed by equation (6):

$$K_{i,Tier_n} = \frac{\sum_{i''=1}^{I''} y_{ii''} \cdot k_{i'',Tier_{n-1}}}{\sum_{i''=1}^{I''} y_{ii''}}. \tag{6}$$

Based on the above, affected transaction amount Δy_i of firm i can be expressed by equation (7):

$$\triangle y_i = \sum_{i'=1}^{I'} y_{ii'} \cdot k_i. \tag{7}$$

4. RESULTS

4. 1 COMPARISON OF THE THREE SCENARIOS

Fig. 4 shows the number of affected firms in each scenario, the inundation time for each industry, the business stagnation time, and the business interruption time. A total of 44,210 firms are affected in the Tokyo scenario and the average affected time is 57 days. The service industry accounts for the major percentage in comparison to the other scenarios. A total of 20,218 affected firms are calculated for the Koto Delta simulation, with an average of 50 days of being affected. Scenario Saitama estimates 16,001 affected firms, with an average of

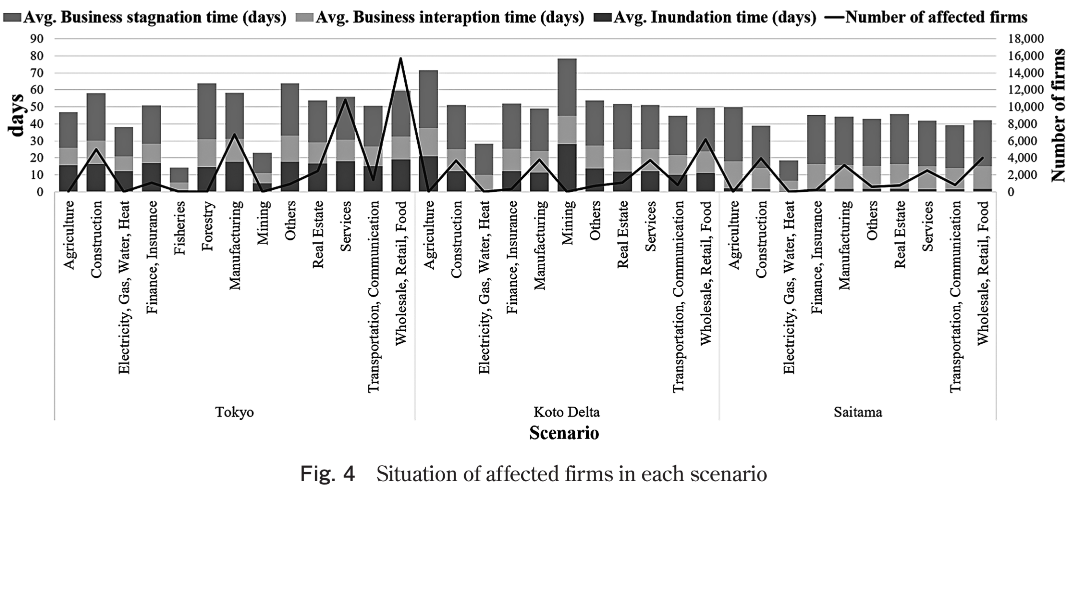

Fig. 4 Situation of affected firms in each scenario

41 days of impact.

The results reveal similar trends for all three scenarios (**Fig. 5**). The proportion of affected firms up to Tier 1 is 20-30% of the total. The figure for scenario Saitama is the lowest at 20% and the number for scenario Tokyo is the highest at 32%. It is assumed that the majority of business enterprises are located on the Tokyo side of the Arakawa River.

Additionally, although there is a significant difference between the three scenarios up to Tier 1, the figure for all scenarios after Tier 3 is approximately 51%. Similar results were obtained for distribution by region and industry. Therefore, the impact caused by the flooding of Arakawa differs depending on the scenario for companies with direct dealings with affected firms, but the difference is not as significant for indirectly related companies.

Also, the evaluation of the spillover effect by transaction direction yields the outcome whereby the figure is between 11% and 20% when firms up to Tier 1 are included. Once again, scenario Tokyo reports the largest effect at 20%. The number increases to 31-36% up to Tier 2 and to 40-41% when companies up to Tier 5 are included. In addition, the downstream impact is estimated to be greater than upstream because firms tend to have more sellers than suppliers.

Fig. 6 shows the affected amount in each scenario. Scenario Tokyo shows the highest affected transaction amount at 7,424 billion JPY when companies up to Tier 4 are included. A major difference in the affected transaction amount is recorded between the other scenarios and the Tokyo calculations. For the Saitama and Koto Delta scenarios, the affected amount is about 4,000 billion JPY. However, the difference between the Saitama and Koto Delta projections is small. In terms of tier, the Tokyo scenario posits a heavier amount of Tier 0 to 1 compared to the other two scenarios. However, for the other two scenarios, the weight of Tier 0 to 1 is small, and Tier 2 is found to be the most affected.

This projection seems valid because many large firms would be affected by the Tokyo scenario and their transactions are many. Their transaction amount is also very sizeable. In the other two scenarios, the affected firms are mostly small and medium-sized, and they do not have as many business partners as the larger companies. A rise in the number of transactions also signals an increase in the volume of money that is transacted by enterprises.

With regard to industries (**Fig. 7**), the wholesale, retail, food, and manufacturing sectors are significant for the Saitama and the Koto Delta sce-

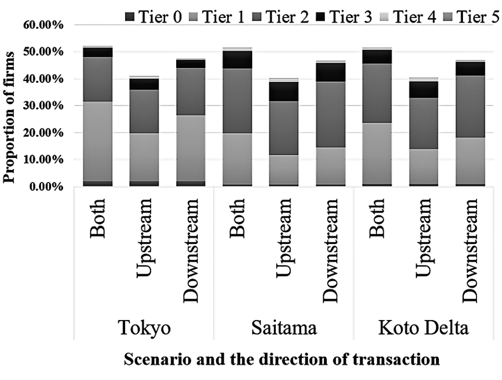

Fig. 5 Proportion of affected firms in each scenario

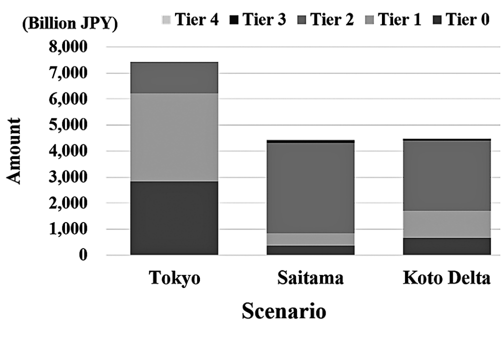

Fig. 6 Affected amount for each tier in each scenario

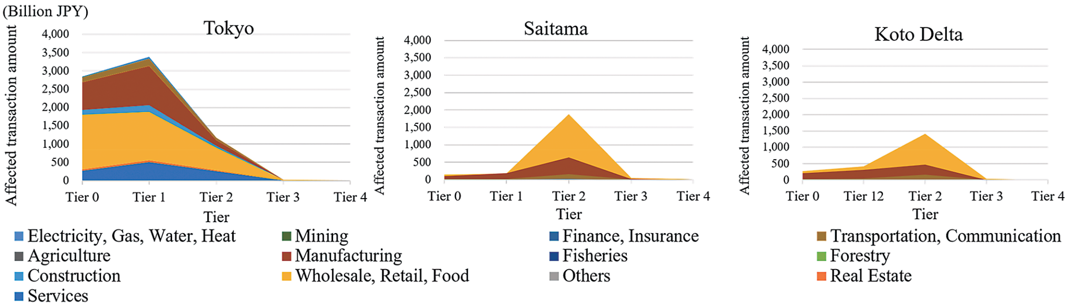

Fig. 7 Affected amount for each industry in each scenario

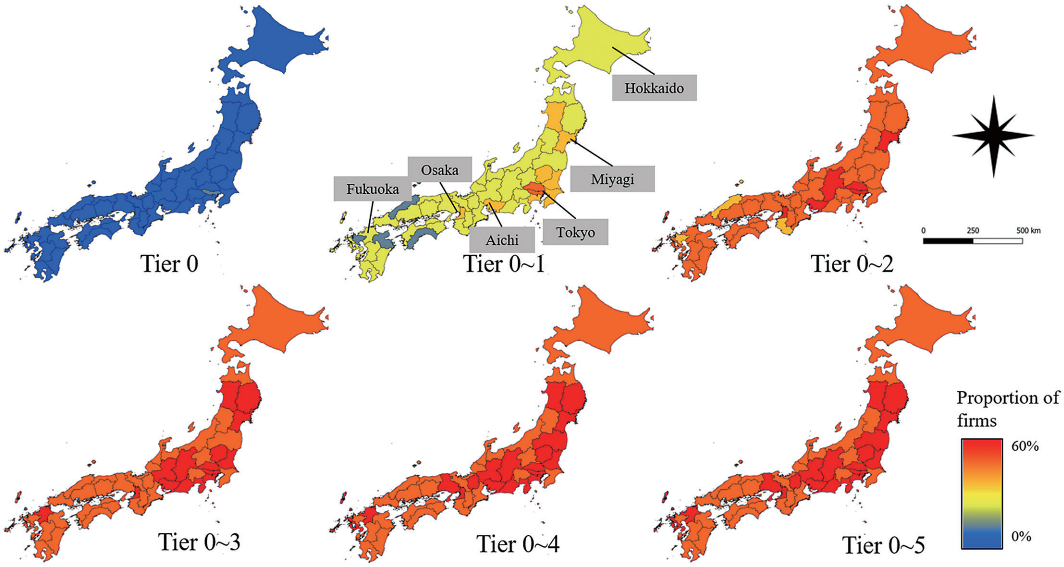

Fig. 8 Proportion of firms by prefecture in each tier in the Tokyo scenario

narios and account for the major part of the transactions. However, the proportion of the service industry is also observed to be high for the Tokyo scenario because the service industry is concentrated in the downtown Tokyo area and more transactions are associated with them here compared to scenario Saitama and Koto Delta.

4. 2 SCENARIO TOKYO

Of the three scenarios, the impact is the largest in the Tokyo simulation. A detailed analysis of scenario Tokyo is presented below. First, looking at prefectures (**Fig. 8**), Tier 0 accounts for about 2% of the total, but the inclusion of Tier 1 takes the figure to 31%. It can be seen that the ratio of firms up to Tier 1 is higher in locations closer to the projected disaster area such as Chiba, Saitama, and Gunma Prefectures. In addition, the percentage of impact in major cities in each area such as Osaka, Aichi, Miyagi Prefectures, etc. is high, and the influence on these areas is considered to be larger than in other locations. When connections up to Tier 3 are included, the figure increases to 51% of the total, but changes only minimally after

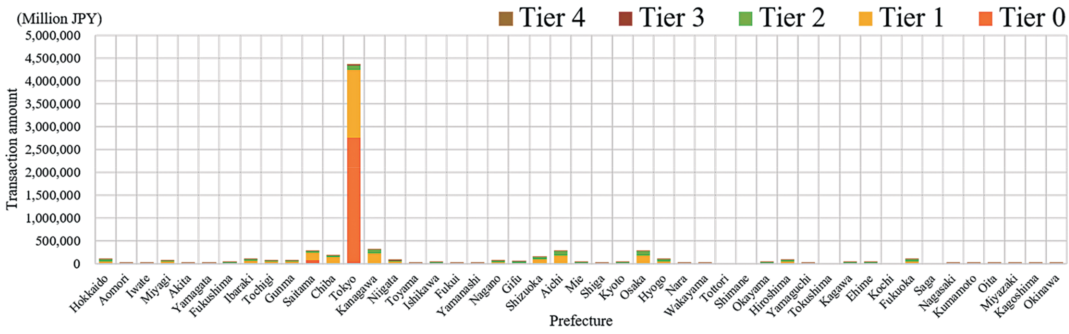

Fig. 9 Affected transaction amount in each prefecture in the Tokyo scenario

this tier, with about 51% of firms and branch offices being affected up to the inclusion of Tier 5 transactions. The remaining firms, or 49% of the total, are thought to form a large network that is external to this inter-firm transaction network.

Fig. 9 shows the affected amount in each prefecture. The affected transaction amount is 7,424 billion JPY when companies up to Tier 5 are included in the Tokyo scenario. It can be seen that amounts are relatively high in prefectures located in areas close to the affected areas such as Chiba, Saitama, and in other major cities in other areas such as Osaka, Aichi, and Miyagi Prefectures.

Next, in terms of industry, over 50% of the firms up to Tier 2 are engaged in the finance, insurance, electricity, gas, water, or heating sectors (**Fig. 10**). It is noteworthy that these two types of businesses are prevalent across regions. The next-highest sectors are transportation, communication, and manufacturing, with the number of firms up to Tier 5 in these industries representing nearly 70% of the total. The real estate industry is the lowest, with the number of firms up to Tier 5 representing less than 30% of the total. In this case, it is pertinent that the real estate industry often transacts with local firms. The agriculture, forestry, and fisheries sectors account for less than 40% of the total number of firms up to Tier 5, indicating that the impact on these industries is relatively small.

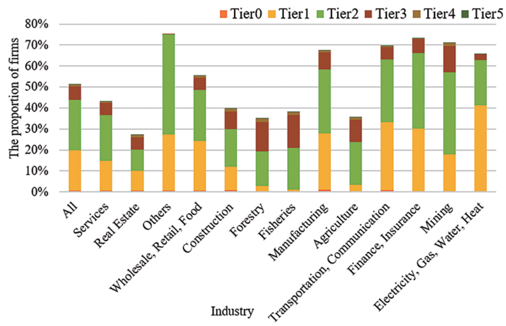

Fig. 10 Proportion of affected firms in each industry in the Tokyo scenario

4. 3 COMPARISON WITH THE RESULTS OF PREVIOUS STUDIES

The Japan Society of Civil Engineers (2018) estimates the economic damage of a large-scale flood in metropolitan Tokyo using the flood analysis data simulated from the conditions of flood hazard maps (2016). The levee break point is assumed to be the same as the one presumed for this research: the 21-kilometer Arakawa right bank. The scenario envisaged by the Japan Society of Civil Engineers is also similar to the circumstances described in this paper, and it also targets the flood with a scale of 0.001 AEP.

The above investigation empirically estimated the economic damage caused by stagnation of economic activity based on the damage situation of past floods and computed the damage to the production facilities and the transportation infrastructure. Specifically, using the spatial computable general equilibrium (SCGE) model, previous studies estimated the amount of decrease in GDP in the affected area due to disasters. The results projected that economic damage of 26 trillion JPY would be incurred in 14 months.

The amount is very large compared to the estimated amount in this study. The reasons for the following differences between the research methods used by the present study and previous studies are considered. The first is that the dataset used is different. Previous studies have used the SCGE model, which uses a social accounting matrix with two regions and two household-income levels as the database. It is built to estimate the benefit of each region and household level from traffic infrastructure investment. In other words, the data used are statistical data between wide areas. In this paper, inter-branch office transaction data are used, and analysis is conducted on a branch-office basis. Flood damage is different depending on the location of the damage; by grasping the damage amount for each company, it can be accurately estimated.

Second, in previous studies, the directly affected area was considered as the area of analysis. In this paper, not only the directly affected area but the whole of Japan is taken as the affected area. Thus, the indirectly affected branch offices in Japan are taken into consideration up to the fifth level of business partners of directly affected firms, making it possible for the present investigation to determine indirect damage more accurately. In addition, in previous studies, the period of economic damage is set to 14 months with reference to the past disaster. However, it does not specify the basis for the choice of this time span, and no further references are provided. In this paper, the affected period is determined according to the Flood Control Economic Survey Manual (2005). It is regarded as beginning from the actual time of the direct effect on companies up to the full resumption of work processes. The affected period for the three scenarios considered in this paper is about two months on average up to approximately three months.

5. CONCLUSION

This paper used GIS data on inter-branch office transactions and flooding analysis data to estimate the economic impact of urban flooding in Tokyo on the supply chain. The investigation revealed the following results. First, many firms and branch offices in areas close to the affected areas have business relationships with the affected firms, so the impact on the area is significant. Second, firms connected to the directly affected firms account for 51% of the total if business partners up to Tier 5 are included; thus, many firms might be indirectly affected even if they do not report an apparent business relationship with the directly affected firms; also, in industries such as finance, insurance, electricity, gas, etc., nearly 70% of firms are related to affected firms, suggesting that the impact on the entire industry is significant. In addition, the impact is projected to be greater on downstream firms than on upstream firms in terms of transactional direction; further, among the three scenarios, the Tokyo scenario is the most affected in economic terms at 7,428 billion JPY, which corresponds to about 1.3% of the Japanese GDP.

Future scholarly work by the authors of this paper will incorporate three additional considerations. First, the roles of indirectly affected firms in each area will be examined by using the concept of centrality, including betweenness centrality. Second, only human factors were set as a condition for the cessation of business activities in this paper. However, the halting of work may depend on a variety of factors in reality. In order to better estimate the economic impact, it is thus necessary to consider disaster conditions based on past floods. For example, physical distribution of goods may be severely affected by the damage or congestion of a road or a lifeline. Third, the impact of the return rate of employees on the production value will be evaluated using population distribution data.

The present study contributes to extant scholarship by presenting a method of estimating the economic damage of a natural disaster at the micro level by combining inter-branch office transaction data and flood simulation analysis data. This model may also be successfully applied to cases other than the Arakawa scenario described in this paper. By establishing a method of analyzing the spillover effects of the economic damage caused by floods using micro-level transaction data between firms and branch offices, the present investigation enables a detailed scrutiny that takes regional characteristics into consideration. Firms and branch offices may use the calculations made by this paper as basic data when considering their BCP for flood damage.

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REFERENCES

Albert, R., A.-L. Barabási, 2002. Statistical mechanics of complex networks, Reviews of Modern Physics, Vol.74, 47–97.

Bureau of Economic Analysis, 2005. Damages and Insurance Settlement from the Third-quarter Hurricanes.

Bureau of Economic Analysis, 2005. Damages and Insurance Settlement from the Third-quarter Hurricanes.

Bureau of Labor Statistics, 2006. Hurricane Katrina's effects on industry employment and wages, Monthly Labor Review.

Cabinet Office, Government of Japan, 2019. The damage situation by heavy rain in July, http://www.bousai.go.jp/updates/h30typhoon7/index.html, accessed April 5, 2019.

Carvalho, V.M., Nirei, M., Saito, Y.U., Tahbaz–salehi, A., 2016. Supply chain disruptions: Evidence from the Great East Japan Earthquake, PRI Discussion Paper Series, No. 16A–15.

Congressional Budget Office, 2005. TESTIMONY: Macroeconomic and Budgetary Effects of Hurricanes Katrina and Rita.

Dercon, Stefan, ed., 2005. Insurance against Poverty, Oxford: Oxford University Press.

Fafchamps, M., Rural, P., 2003. Risk and Development, Cheltenham: Edward Elgar.

Ikeuchi, K., Ochi, S., Yasuda, G., Okamura, J., Aono, M., 2011. Inundation patterns and fatality analysis on large-scale flood, Journal of Japan Society of Civil Engineers, ser. B1 (Hydraulic Engineering) Vol. 67, No. 3, 133–144.

Japan Society of Civil Engineers, 2018. Technical examination report about huge disaster measures bringing "National hardship," http://committees.jsce.or.jp/chair/node/21, accessed April 5, 2019.

Kajitani, Y., Tatano, H., 2018. Applicability of a spatial computable general equilibrium model to assess the short-term economic impact of natural disasters, Economic Systems Research, Vol. 30.

Ministry of Land, Infrastructure, Transport and Tourism Water and Disaster Management Bureau, 2013. Guidance on Analysis of Flood Damage Index.

Ministry of Land, Infrastructure, Transport and Tourism, 2005. Flood Control Economic Survey Manual, http://www.mlit.go.jp/river/basic_info/seisaku_hyouka/gaiyou/hyouka/hyouka.html, accessed April 5, 2019.

Ministry of Land, Infrastructure, Transport and Tourism, 2015. Flood Hazard Map Manual, http://www.mlit.go.jp/river/bousai/main/saigai/tisiki/syozaiti/, accessed April 5, 2019.

Ministry of Land, Infrastructure, Transport and Tourism, 2017. Flood Inundation Area Diagram Drawing Manual, http://www.mlit.go.jp/river/shishin_guideline/, accessed April 5, 2019.

Moel, H. D., van Alphen, J. and Aerts, J. C. J. H., 2009. Flood maps in Europe - Methods, availability and use–, Natural Hazards and Earth System Sciences, Vol. 9, 289–301.

Noy, I., 2009. The macroeconomic consequences of disasters, Journal of Development Economics, Vol. 88(2), pp. 221–231.

Ogawa, Y., Akiyama, Y., Shibasaki, R., 2017. Development of loss and recovery model of corporate transactions for earthquake disaster based on the Great East Japan Earthquake and Tsunami, CUPUM2017 Conference Proceedings, CD-ROM.

Ogawa, Y., Akiyama, Y., Shinohara, G., Shibasaki, R., Sekimoto, Y., 2018. Estimation inter–firm transaction data between branch offices using head office transaction data, Proceedings of the 27th Geographical Information System Society Research Paper Proceedings of the Geographical Information System Association, CD-ROM.

Ogawa, Y., Akiyama, Y., Yokomatsu, M., Sekimoto, Y., Shibasaki, R., 2019. Estimation of supply chain network disruption of companies across the country affected by the Nankai Trough Earthquake Tsunami in Kochi City, Journal of Disaster Research, Vol. 14, No. 3.

Ohnishi, T., H. Takayasu, M. Takayasu, 2010. Network motifs in inter-firm network, Journal of Economic Interaction and Coordination, Vol. 5, No. 2, 171–180.

Raddatz, C., 2009. The wrath of God: Macroeconomic costs of natural disasters, World Bank Policy Research Working Paper Series 503.

Risk Management Solutions, 2005. Combines Real-time Reconnaissance with Risk Models to Estimate Katrina Losses.

Smith, D.I., 1994. Flood damage estimation—A review of urban stage–damage curves and loss functions, Water SA, Vol. 20(3), 231–238.

Strobl, E., 2011. The economic growth impact of Hurricanes: Evidence from U.S. coastal counties, Review of Economics and Statistics, Vol. 93(2), 575–558.

Tokui, J., Arakawa N., Kawasaki, K., Miyagawa, O., Fukao, K., Arai S., Edamura, K., Kodama N., Noguchi, N., 2012. Economic impact of the Great East Japan Earthquake - Comparison with past disasters, supply chain shredding effects, power supply constraints-, RIETI Policy Discussion Paper, No. 12–P–004.

Tokyo Shoko Research Ltd, 2018. Questionnaire survey on disaster prevention measures.

Webdawatta, G., Ingirige, B., Proverbs, D., 2012, Small businesses and flood impacts: The case of the 2009 flood event in Cockermouth, Journal of Flood Risk Management Vol. 7, Issue 1.

Yang, S., Ogawa, Y., Akiyama, Y., Shibasaki, R. Ikeuchi, K., 2018. Estimation of the economic impact of large-scale flooding in the Tokyo metropolitan area, 2018. IEEE International Conference on Big Data (Big Data) Proc., 3190–3199.

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要　旨

本稿では，東京都に位置する荒川の流域において大規模水害が発生した場合に，大規模な企業間取引のGISデータを用いて，水害がサプライチェーンに与える経済的影響を定量的に推定した。まず，荒川流域の氾濫シミュレーション解析データを用いて，被害を受けて事業継続ができない被災企業を特定した。次に，大規模取引ネットワークデータを用いて被災企業と取引関係によって繋がっている企業を特定し，その産業構造についてネットワーク分析した。最後に，被災区域及び被災区域外の取引先の影響される取引金額について，被災企業の浸水期間（被災期間）や，被災企業の取引先の次数が増加するにつれ影響が小さくなることを考慮し，推計を行った。分析の結果，被災地の企業の取引先は全体の20～30％であり，５次取引先までを含めると全体の約50％であり，被災地以外でも多くの企業が影響を受ける可能性があることがわかった。

地域別では，東京や大阪などの大都市の受ける影響が大きく，産業別では，金融，運輸業への影響が大きく，農林水産業への影響が小さいことが明らかになった。また，生産額に関しては全国で最大で GDP の約1.3 %の取引金額に影響を与える可能性があるとわかった。