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Physical risks from climate change faced by Japan's financial institutions: Impact of floods on real economy, land prices, and FIs' financial conditions

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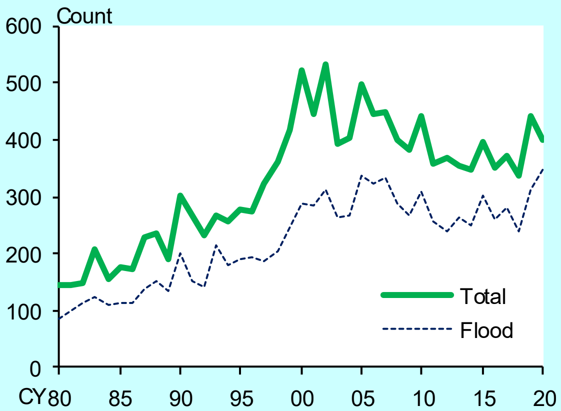
This article overviews implications of physical risks from climate change to Japan's financial institutions (FIs), focusing on the impacts of floods on the real economy, land prices and FIs' financial conditions. Floods cause massive direct damage to human lives and material resources. The empirical analyses using Japan's data suggest that the indirect effect of such damage on the real economy, land prices, and FIs' financial conditions has not been sizable over the analysis period, as the effect diminishes over time with the progress of reconstruction. The long-term simulation using a medium-scale macroeconomic model that takes into consideration possible climate changes and increases in flood damage in the future, however, suggests that the indirect effect can have a non-negligible impact on real GDP and FIs' net worth going forward. The outlook for the physical risks is extremely uncertain, varying depending on multiple factors including the pace of transition to a de-carbonized economy and interactions between the global average temperature and the frequency and scale of disasters, as well as productivity of the economy.

Introduction

Climate change has been the focus of global attention in recent years, reflecting increasing intensity of natural disasters. In particular, the number of floods[1] causing large-scale human damage has risen sharply since the 2000s (Chart 1).

[Chart 1] Number of Natural Disasters Worldwide



Note: The EM-DAT contains global catastrophes that conform to at least one of the following criteria: (1)10 or more people dead, (2) 100 or more people affected, (3) the declaration of a state of emergency, and (4) a call for international assistance. Flood includes storm, flood, and landslide disasters.
Source: EM-DAT, CRED / UCLouvain, Brussels, Belgium - www.emdat.be

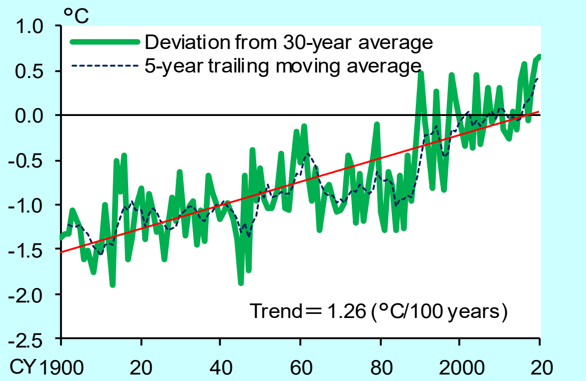
Even in Japan, where there are many mountains and few plains and therefore flood control technology has been developed over time, floods constitute more than 70 percent of all large-scale natural disasters in numbers. Based on "Hazard maps," the number of people and business facilities facing the risk of flooding, constitutes about 40 percent of the respective totals[2]. This flooding risk is easily translated to the physical risks for FIs, which extend credit to these households and firms[3].

Against this backdrop, this article discusses implications of physical risks from climate change to Japan's FIs. The remainder of the article is organized as follows. First, basic facts on developments in climate change and flood damage in Japan are provided. Next, findings about the indirect effect of flood damage and how it affects the real economy, land prices, and FIs' financial conditions, based on the empirical studies that use Japan's data, are presented[4]. The estimated impacts of possible long-term physical risks that are often discussed of late in the context of scenario analyses of climate change are also presented.

Climate change and flood damage in Japan: Some observations

Japan's average temperature has risen at a rate of 1.26 degrees Celsius per 100 years[5]. Since the 1990s in particular, the country has experienced higher-than-average temperatures many times (Chart 2). The annual average sea level along the coast of Japan has also shown a clear upward trend in recent years. These trends would affect the water cycle system, including the amount of water vapor in the atmosphere. In fact, the number of days with short-term heavy rainfalls and extreme precipitation over a whole day are on an upward trend as well.

[Chart 2] Annual Average Temperature in Japan

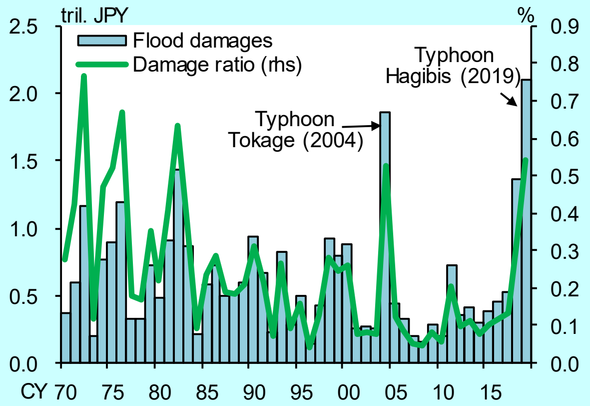


Note: 1. The vertical axis indicates the deviation from the 30-year average temperature (1991 - 2020) in Japan.
2. The dotted line indicates the 5-year trailing moving average of the green solid line, while the red solid line shows the long-term trend line.

Source: Japan Meteorological Agency

The flood damages have increased significantly over the past few years, as a large-scale flooding occurred one after another in Japan, such as the July 2018 Western Japan heavy rain and the typhoon of October 2019 (the Typhoon Hagibis) (Chart 3) [6]. The flood damage totaled 2.1 trillion yen in 2019 -- the largest since the Flood Statistics was first released, in 1961 -- , amounting to 0.54 percent of the real national income[7]. Even in 2020 and beyond, there were large-scale floods in various parts of Japan, including the heavy rain event of July 2020 that caused the flooding of the Kuma River, and that of July 2021 that caused massive landslides in Atami City in Shizuoka Prefecture[8].

[Chart 3] Flood Damages

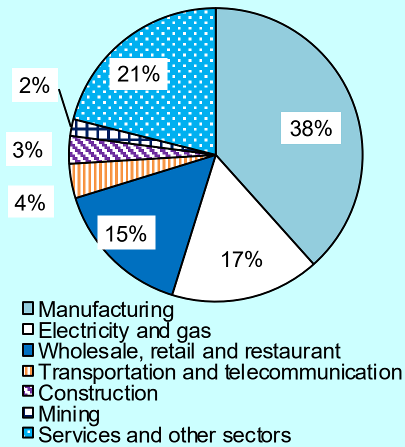


Note: 1. "Flood damages" and "Damage ratio" show flood damages measured in the 2011 price and the ratio of damages to real national income.
2. Latest data as of 2019.

Source: Ministry of Land, Infrastructure, Transport, and Tourism "Flood Statistics"

By type of damaged assets, damages to private assets such as firms' equipment and residential buildings account for about 60 percent of all losses, and the rest includes damages to social infrastructure such as river walls and roads. In terms of damages to business facilities among private assets, though flood damage has been seen across a wide range of industries, the "manufacturing," "electricity and gas," and "wholesale, retail and restaurants" industries particularly account for a large share (Chart 4), as production facilities and inventories in those industries are likely to suffer relatively large losses by floods. By prefecture, there are important variations across regions, with suburban and rural areas having experienced greater damage than three major metropolitan areas (Tokyo, Osaka, and Nagoya) over the past 10 years (Chart 5). This observation may suggest that regional financial institutions have been relatively more affected by flooding than other FIs.

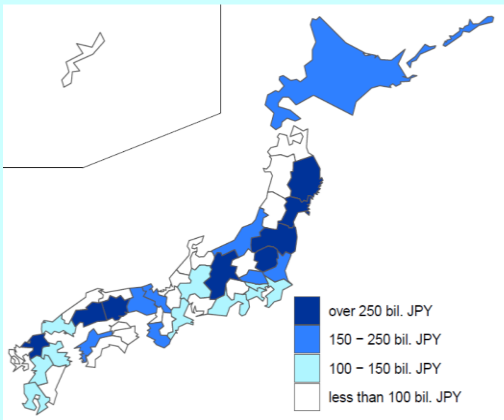
[Chart 4] Damages to Business Facilities by Sector



Note: Total flood damages from 2010 to 2019 with respect to business facilities, consisting of depreciable and inventory assets (based on 2011 real price).

Source: Ministry of Land, Infrastructure, Transport, and Tourism "Flood Statistics"

[Chart 5] Flood Damages by Prefecture



Note: Total flood damages from 2010 to 2019 (based on the 2011 real price).

Source: Ministry of Land, Infrastructure, Transport, and Tourism "Flood Statistics"

Indirect effect of flood damage on real GDP, land prices, and FIs' financial conditions: Mechanism

As described above, floods cause direct losses of human lives and material resources. Theoretically, these direct losses are considered to have the second-round effects on the real economy, land prices, and FIs' financial conditions through the two channels explained below.

The first channel is damage to private firms' production facilities, which directly hamper production activities. The other channel is a decline in productivity of production inputs. Local economic activities can cease to function when floods deteriorate the social capital, including bridges and roads (accounting for about 40 percent of all flood losses in the statistics as documented above), or disrupt the supply chain of firms, which is captured as productivity declines in terms of the macroeconomy as a whole.

The production decline due to the disruptions to firms' production facilities and lower productivity dampen the private demand, such as the aggregate consumption, and worsen firms' financial conditions. Meanwhile, insurance against flood damage is considered to curb the adverse effects from an income perspective.

Once the real economies are depressed by flooding, the expected returns of the affected areas are expected to fall and the risk perception of the residents regarding possible flooding in the area may be altered, leading to a decline in land prices.

Consequently, FIs located in the affected areas may see a worsening of their financial conditions, including those shown in credit costs, ROA, and non-performing loan ratios, through a deterioration in their borrowers' financial conditions or a fall in the collateral value due to land price declines.

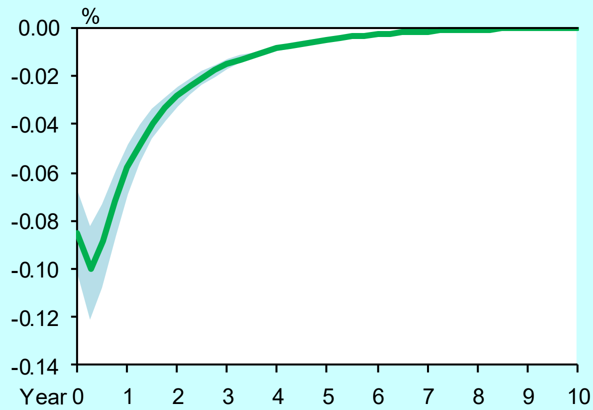
Admittedly, the downward pressure from floods diminishes as the economic recovery progresses. In the longer run, the economy is considered to return to the level that would be reached if no floods take place[9].

Indirect effects of flood damage on real GDP, land prices, and FIs' financial conditions: Empirical analyses

Impact of flood damage on the real economy

First, the impact of flood damage on the real economy is studied. Based on the simulation using an estimated medium-scale macroeconomic model, which specifies flood damage as a shock to the capital depreciation rate and the total factor productivity, flood damage reduces real GDP in the short run by depressing capital stocks, lowering the productivity, and deteriorating firms' financial conditions. In the simulation, the size of flood damage is set to the size equivalent to that seen in the 2019 Typhoon Hagibis, the largest case in recent decades (Chart 6)[10]. The downward pressure on real GDP starts to diminish gradually as the investment spending starts to increase, restoring once-depressed capital stocks. The negative impact almost disappears 5-6 years after the flood. The decline in real GDP is about 0.1 percent at maximum[11].

[Chart 6] Response of Real GDP to Flood Damage: Estimates using a Medium- -scale Macroeconomic Model

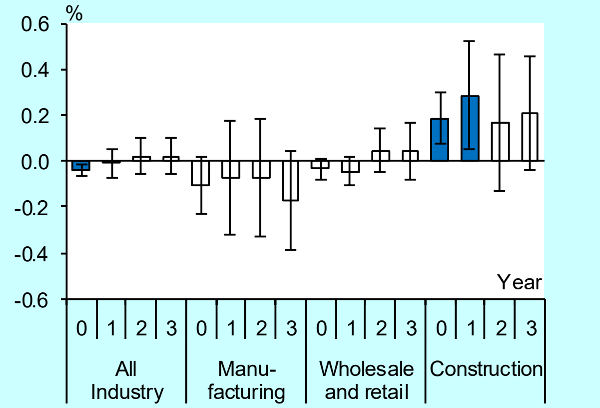


Note: The vertical axis indicates deviation from the steady state (%). The green solid line and shaded area represent point estimates and the 10th-90th percentile ranges of impulse response function.

Source: Hashimoto and Sudo (2022)

In addition to the macroeconomic model, the panel estimation using the data from 47 prefectures in Japan is executed. The similar results are obtained. That is, flood damage reduces real GDP, though the decline in GDP is modest possibly due to the reconstruction demand (Chart 7)[12]. By industry, the value added is pushed down in the manufacturing and wholesale and retail industries for which business facilities are more damaged than others, as shown in Chart 4. By contrast, in the construction industry, for which damage is relatively moderate and the reconstruction demand can be expected, the value-added tends to rise following floods. These results indicate that flood damage has an aspect of adverse sectoral shocks.

[Chart 7] Response of Real GDP to Flood Damage: Prefecture-level Panel Analysis



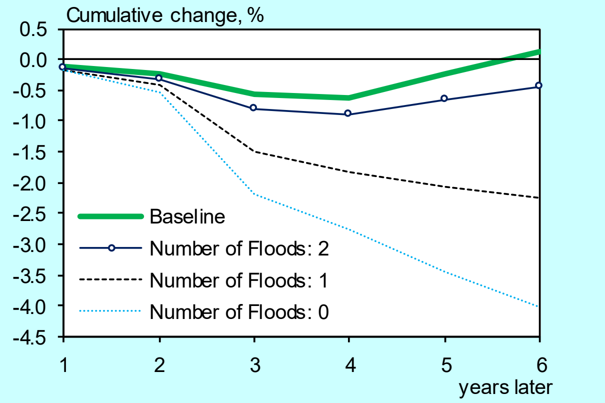
Note: 1. Illustrates the response when flood damage amounts to 2% of real GDP (average damage of the sample).
2. The dark blue bar indicates 95% statistical significance. The error band shows the 90% confidence interval.

Source: Ashizawa, Sudo and Yamamoto (2022)

Impact of flood damage on land prices

Next, the impact of flood damage on land prices is studied. Specifically, the response of land prices in "Land Market Value Publication" -- which are widely referred to when FIs value their collateral -- to the occurrence of floods is estimated by using panel data (Chart 8)[13]. The results indicate that flood damage reduce land prices of the affected area for 3-4 years following the flood. As reconstruction proceeds, however, the downward pressure decays and within 5-6 years land prices recover to a level before the flood on the whole. Changes in land prices are modest, however, even when the magnitude of the direct flood damage that triggers the land price change is considerably large[14].

[Chart 8] Response of Land Prices to Flood Damage



Note: "Baseline" is the estimate based on pooled observations, while the other categories is the estimate based on a setting that allow the parameters to differ depending on the number of floods experienced in the past 10 years, which is counted at the prefectural level.

Source: Koide, Nishizaki and Sudo (2022)

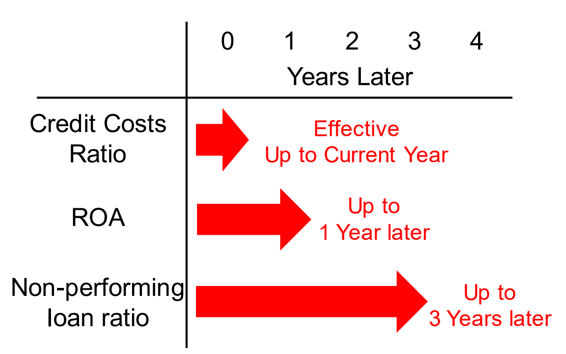
In addition, it is seen that municipalities tend to see milder impacts of floods on land prices if they are located in prefectures that have experienced more flooding in the past. One interpretation for this is that the residents in areas that experience floods more frequently are more prepared, making the regional economy more resilient to floods[15]. Another interpretation is that the risk of floods has already been incorporated into the residents' risk perception and therefore these residents do not change their perception further in the wake of additional floods. In any case, the response of land prices to floods seems to largely depend on the past experience of floods in the area.

Impact of flood damage on FIs' financial conditions

Lastly, the impact of flood damage on FIs' financial conditions is studied. As described above, economic activities of the borrowers of FIs are hampered by floods, but there is no data available regarding how severely the borrowers are economically affected due to flood damage for each FI. Following the existing study using U.S. data, a flood damage index[16] -- the ratio of the flood-affected lending to all loans outstanding -- is constructed. The flood-affected lending is calculated as the product of the loans outstanding and the size of flood damage for each municipality in Japan[17]. While this index is constructed from an approximated value of the actual municipal level loans outstanding and income, it still provides a useful metric regarding the size of flood damage the borrowers face for each FI. By type of FIs, regional FIs score higher than other types of FIs, possibly reflecting the fact that the recent floods damage has been concentrated in local areas, as shown in Chart 5[18].

A close examination of the relationship between the flood damage index and FIs' financial variables shows that flood damage has a significant adverse impact on the flow variables, such as credit costs and ROA, as well as stock variables, such as non-performing loan ratios. However, this adverse impact becomes insignificant in two years for the flow variables and in 3 years for the stock variable (Chart 9). It is also notable that even the largest adverse impact on the credit cost ratios among FIs is at about 2 basis points[19]. These results are generally consistent with the estimates of the direct effects of floods on the real economy and land prices described above.

[Chart 9] Effect of Flood Damage on Financial Indicators of FIs



Note: 1. Effects are estimated by regressing each of the financial indicators of 345 FIs on the flood damage index between 2005 and 2018. FIs' fixed effects and time fixed effects are considered.
2. The length of arrows indicates the period of time during which flood damage causes a statistically significant deterioration in financial conditions.

Physical risks from long-run perspective

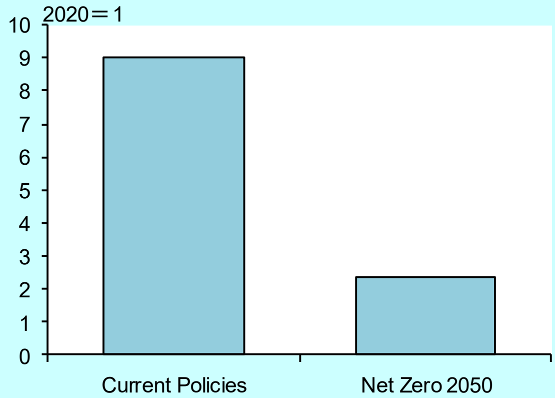
Physical risks of floods from long-run perspective

The results of these empirical studies that use the time series data over the past 15-40 years are summarizes as follows. First, while flood damage poses an adverse indirect effect on the real economy, land prices, and FIs' financial conditions, the impact is short-lived, dissipating in the medium term as reconstruction progresses. Second, these indirect effects are not necessarily devastatingly large as far as floods that occurred in the analysis period are concerned.

When assessing the physical flood risks, however, it is essential to consider a possibility that the frequency of occurrence increases or the scale becomes larger due to climate change, from a long-term point of view.

In this regard, the NGFS (Network for Greening the Financial System), the international climate change forum hosted by central banks and financial authorities, provides estimates of Japan's flood damages in 2100, using General Circulation models (Chart 10)[20]. The NGFS estimates show that Japan's flood damages in 2100 would become ninefold of that in 2020 if the transition to the de-carbonized economy stalls (known as the "Current Policies" scenario), while it would be limited to around twofold if the smooth transition is achieved (the "Net Zero 2050" scenario).

[Chart 10] Estimates of Flood Damages in Japan in 2100 by NGFS

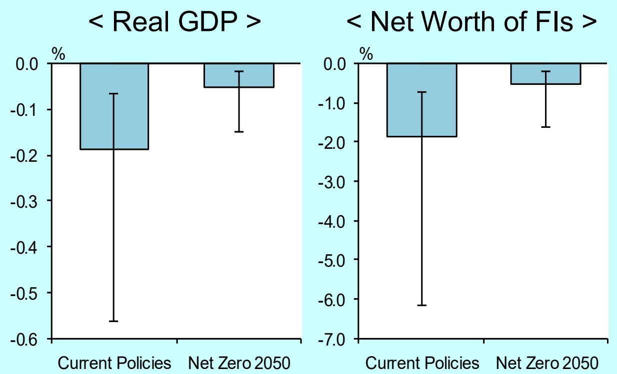


Note: Median value for each scenario is presented. NGFS calculates the median value and 5th-95th confidence interval for each scenario using the combination of parameters for temperature trajectory and General Circulation Models.

Source: NGFS "Climate Impact Explorer"

Using the medium-scale macroeconomic model used in Chart 6, a projection up to 2100 is conducted to calculate the long-term impact of a future increase in flood damage on the real economy and FIs' financial conditions (Chart 11). The time path of the future capital depreciation rate and the productivity are estimated based on the trajectory of flood damage in each NGFS scenario ("Current Policies" and "Net Zero 2050") and fed into the model so as to obtain the future impacts of the damage on real GDP and FIs' net worth. The results indicate that the impact of flood damage on real GDP and FIs' net worth is modest even in 2100 if the smooth transition is achieved. On the other hand, if the transition is delayed, flood damage reduces real GDP in 2100 by up to about 0.6 percent and the real market value of FIs' net worth by about 6 percent, respectively.[21]

[Chart 11] Estimates of Indirect Effects of Flood Damage on Real Economy using a Medium-scale Macroeconomic Model



Note: 1. Deviation from the steady state in 2100 estimated using NGFS climate change scenarios.
2. Bar and error bar indicate the median value and 90% confidence interval, respectively.

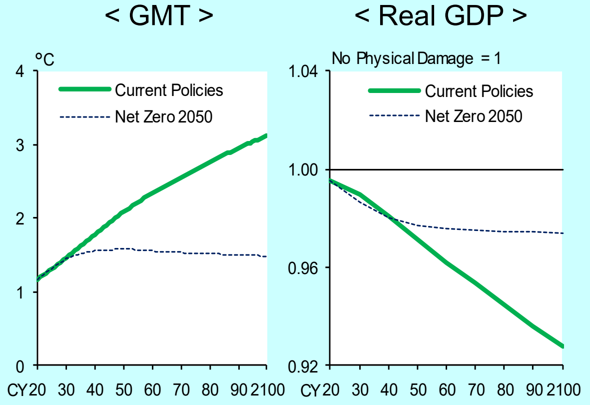
Source: Hashimoto and Sudo (2022)

Physical risks including other acute and chronic risks

The physical risks are not limited to floods -- the primary focus of this paper -- rather, it also comprises other acute risks, such as droughts and wildfires, and chronic risks such as a steady decrease in people's flow and labor productivity caused by an increase in the global mean temperature (GMT).

The NGFS offers simple estimates for the two climate change scenarios above to assess physical damage on real GDP stemming from the broader classes of physical risks (Chart 12)[22]. The NGFS assumes that country level labor productivity follows a non-linear function of GMT and calculates the physical damage for each country using the maximum decline in labor productivity in the Integrated Assessment Models[23, 24, 25]. According to the estimates in the "Current Policies" scenario, the adverse impact of physical damage on real GDP will be contained until around 2030, when the estimated GMT increases is only less than 1.5 degrees compared to the GMT in the second half of the last century. The adverse impact, however, grows non-linearly as the GMT increases further. Real GDP falls by about 3 percent in 2050 when the estimated increase of the GMT is about 2 degrees, and falls by 7 percent in 2100 when the estimated increase of the GMT is about 3. Even in the "Net Zero 2050" scenario, the estimated GMT increase is more than 1.5 degrees and physical damage becomes larger over the period. In this case, however, the damage to real GDP will be contained by less than 3 percent in 2100, as the estimated GMT increase is smaller than the "Current Policies" scenario.

[Chart 12] GMT and Physical risks in 2100 by NGFS Release



Note: 1. The left chart shows the median value of deviation of the global mean temperature from the long-term average (1850-1900) in NGFS climate scenarios.

2. The right chart shows NGFS estimates for physical damage in Japan (95 percentile value) in each climate scenario. Physical damage is scaled by real GDP (1 if no physical damage happens).

Source: NGFS

The NGFS estimates imply that physical risks from climate change will likely to increase as the GMT rises. However, the extent and pace of the increase in physical risks is extremely uncertain as they depend on various deciding factors, such as the pace of transition to a de-carbonized economy and linkages between the GMT and the frequency and scale of disasters, as well as the productivity of the economy.

Conclusion

This paper provides an overview of physical risks from climate change faced by Japan's FIs, focusing on the impacts of floods on the real economy, land prices, and FIs' financial conditions.

Floods cause the loss of human lives and material resources. Our empirical analyses based on Japanese historical data, suggest that the indirect effects of flood damage on the real economy, land prices, and FIs' financial conditions have not been necessarily large over the analysis periods and tended to dissipate in the medium-to-long run with the reconstruction process.

When assessing the physical risks associated with floods, however, it is necessary to take the future impacts of possible climate changes into account. In this regard, our tentative results based on the simulation using the macroeconomic model indicate a possibility that these risks may have a non-negligible impact on real GDP and net worth of FIs' as a whole.

It is also important to keep in mind that the outlook for these risks is extremely uncertain, as it depends on various factors including the pace of transition to a de-carbonized economy, interactions between the global average temperature and the frequency and scale of disasters, and the productivity of the economy. The Bank of Japan's Financial System and Bank Examination Department will continue conducting research and analyses for better understanding of the nature of physical risks faced by Japanese financial institutions, with the help of, for example, the greater usage of highly granular data, taking into account developments in international discussions.

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[1] The term "flood" in this paper indicates overall water-related disasters.

[2] See Chart 1 of Koide et al. (2022). Koide, Y., K. Nishizaki, and N. Sudo, "Flood Risk Perception and its Impact on Land Prices in Japan," BOJ Working Paper Series, forthcoming.

[3] Climate-related financial risks consist not only of physical risks, which are the risks of losses incurred because of physical phenomena, as argued in this paper, but also the transition risks, which are the risks of losses incurred by the changes in the transition process to a de-carbonized economy. For the concept of climate-related financial risks, also see Shibakawa et al. (2020). Sibakawa, T., T. Naka, and S. Kobayashi, "International Developments of Issues around Climate-related Financial Risks: A New Discussion on Financial Stability," Bank of Japan Review Series, No. 20-J-16, December 2020 (available only in Japanese).

[4] Following Cavallo and Noy (2011), the direct effect refers to that on human lives and physical damage caused by a flood, and the indirect effect refers to the damage derived from it. Cavallo, E., and Noy, I. "Natural disasters and the economy – a survey, " *International Review of Environmental and Resource Economies*, 5(1), 63-102.

[5] The statement of this paragraph basically refers to the Ministry of Education, Culture, Sports, Science and Technology and the Japan Meteorological Agency (2020). Ministry of Education, Culture, Sports, Science and Technology and Japan Meteorological Agency, "Climate Change in Japan 2020: Report on assessment of observed/projected climate change relating to the atmosphere, land and oceans," December 2020.

[6] In addition to such property damage, the number of people who died or are missing due to floods has been on the rise in recent years.

[7] This figure is based on the 2011 real prices.

[8] The number of requests for financial measures to deal with water-related disasters, which the Bank of Japan makes with the government authorities, has increased over this period.

[9] There may exist a case where the impact of a disaster becomes long-lived when the scale of that disaster is extremely large.

[10] For details of the analysis, see Hashimoto and Sudo (2020). Hashimoto, R., and N. Sudo, "Transmission of Flood Damage to the Real Economy and Financial Intermediation: Simulation Analysis using a DSGE Model," BOJ Working Paper Series, forthcoming.

[11] Here, the "maximum" means the maximum decrease in the point estimates over the simulation period of 10 years.

[12] For details of the analysis, see the following paper. Ashizawa, T., N. Sudo, and H. Yamamoto, "How Do Floods Affect the Economy? An Empirical Analysis using Japanese Floods Data," BOJ Working Paper Series, forthcoming.

[13] For the details of the analysis, see Koide et al. (2022).

[14] Figures in Chart 8 are calculated in the case where the amount of flood damages per capita corresponds to the 99th percentile from samples taken in 2001-2019 by each municipality.

[15] In this respect, Yamamoto and Naka (2021) point out that firms located in areas that experience floods more frequently than other areas have less of an impact from floods on their financial conditions. Yamamoto, H., and T. Naka, "Quantitative analysis of the impact of floods on firms' financial conditions," BOJ Working Paper Series, No.21-E-10, July 2021.

[16] The methodology of compiling the flood damage index refers to Noth and Schüwer (2018). Noth, F. and U. Schüwer, "Natural Disaster and Bank Stability: Evidence from the U.S. Financial System," SAFE Working Paper No.167, April 2018.

[17] As no Japanese municipality level data exist on loans outstanding and value-added-based income, these numbers are estimated by dividing prefecture level data proportionally by the number of FIs' branches or that of households located in each municipality.

[18] Looking at the "flood-affected credits" in 2018 by type of FI, which is the numerator of the flood damage index, regional FIs account for more than 90 percent of total flood-affected credits.

[19] The figure is calculated based on the results shown in Chart 9. The "maximum" here means the maximum impact of the 90th percentile from the flood damage index over the simulation period of 10 years.

[20] The estimation results are available at http://climate-impact-explorer.climateanalytics.org/.

[21] The "maximum" here means the 95th percentile.

[22] The estimation results are available at https://data.ene.iiasa.ac.at/ngfs/.

[23] Integrated Assessment Models (IAMs) can be referred to as models that describe the interaction between economic activity and climate change. They are generally used when calculating the impact of paths of future greenhouse gas emissions on GDP and carbon prices. For more details on IAMs, see the Institute for Monetary and Economic Studies of the Bank of Japan (2021). Institute for Monetary and Economic Studies of the Bank of Japan, "Special Volume: Economics of Climate Change (1) – Capturing the Relationship between Climate Change and Macroeconomics –DICE Model," IMES Newsletter, October 2021 (available only in Japanese).

[24] The "maximum" decline here means the 95th percentile of the estimates. The NGFS has also published the median of the estimates of physical damage.

[25] The numbers of physical damage provided by the NGFS conceptually includes damages to private firms' equipment and capital stocks due to floods. However, there may be limitation regarding the extent to which they can well capture the size of acute risks quantitatively, as they are derived from a reduced-form non-linear relationship between the labor productivity and the global average temperature.

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