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Financial System Report – Annex

The Financial Macro-econometric Model (FMM, March-2020 Version): Overview and Recent Developments

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Background

The Bank of Japan's *Financial System Report* has two main objectives: to assess the stability of Japan's financial system from a macroprudential perspective and to communicate with all related parties on any tasks and challenges ahead in order to ensure the system's stability.

The *Financial System Report* provides a comprehensive assessment of the financial system twice a year and is occasionally supplemented by the *Financial System Report Annex Series,* which provides more detailed analysis and insight on specific topics. In this paper we explain the Financial Macro-econometric Model (FMM) and its recent revisions and uses. Developed by the Bank of Japan's Financial System and Bank Examination Department, the FMM is used to conduct the macro stress testing, the results of which are regularly reported in the *Financial System Report*.

Abstract

The Bank of Japan developed the Financial Macro-econometric Model (FMM) in 2011. The FMM is employed to conduct macro stress testing for comprehensive quantitative analyses of the stress resilience of Japan's financial institutions, and the results are published twice a year in the *Financial System Report*. The FMM is continually being developed to ensure that the Bank's macro stress testing can capture the key issues when assessing the stability of the financial system by appropriately incorporating the transmission mechanisms of shocks. Recently, macro stress testing results based on the FMM have been employed in new areas: in the Bank's dialogue with individual financial institutions during its on-site examinations and off-site monitoring; and in the comparative examinations in supervisory simultaneous stress testing which are based on common scenarios and conducted jointly with the Financial Services Agency of Japan.

In this paper we present the basic framework of the FMM and the macro stress testing based on the FMM, and explain five major enhancements of the model that have been made in recent years. We have improved the loan function by taking nonlinearity into account; and refined the credit cost model using granular data. We have developed a new framework of a medium- to long-term simulation of financial institutions' profits and stress testing that assumes a stress event in the medium- to long-term future. We have refined the model to take into account the room held by securities investment for locking in gains, and we have incorporated the effect of increases in foreign-currency funding costs in times of stress. Finally, we describe caveats in the use of the FMM and consider some issues for its use in the future.

I. Introduction[1]

The Bank of Japan conducts macro stress testing regularly in order to assess the stability of Japan's financial system, publishing the results twice a year in the *Financial System Report* (hereafter, FSR). Specifically, the Bank first assumes that macroeconomic tail risks unexpected in the standard outlook, such as a severe economic downturn or a sharp fall in asset prices, have materialized. Then, using a model which describes the financial institutions' risk characteristics, the Bank analyzes the impact on their losses and capital adequacy ratios that such an event would cause. Third, the Bank quantitatively examines from a macroprudential perspective whether financial institutions have sufficient capacity to absorb losses, and whether, in the event of stress, the financial system would continue to perform its financial intermediation function smoothly.[2]

While financial institutions have been using stress testing for their own risk management since the 1990s, supervisors have taken up stress testing more widely since the global financial crisis in the late 2000s. For example, in the United States (the Federal Reserve), the United Kingdom (the Bank of England), and the European Union (the European Banking Authority and the Single Supervisory Mechanism), the supervisory authorities formulate stress scenarios, conduct simultaneous stress tests on large financial institutions under common stress scenarios, and use the results for both the micro- and macroprudential supervision of financial institutions.[3] Others, including the Bank of Japan, the European Central Bank (ECB), the Swiss National Bank, and the International Monetary Fund (IMF) have developed and used models for macro stress testing and have conducted analyses examining the stress resilience of the financial system overall. The main aim in developing such models is to take a macroprudential perspective. For example, some models have expanded coverage from large-scale financial institutions subject to supervisory stress tests by adding data on regional financial institutions, and some models have incorporated mechanisms that amplify shocks, such as interactions between the real economy and the financial sector and/or asset fire sales during a financial crisis.[4]

The Bank of Japan developed the Financial Macro-econometric Model (FMM), a two-sector model consisting of the real economy and the financial sector, in 2011 and uses it for regular macro stress testing (Ishikawa et al. 2012). A key feature of the FMM is that it explicitly incorporates a feedback-loop mechanism between the real economy and the financial sector in which a decline in credit

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[1] This paper is an English translation of the original Japanese released on March 25, 2020 and was prepared mainly by Ko Miura, Yojiro Ito, Kosuke Takatomi and Mitsuhiro Osada of the Financial System and Bank Examination Department. A large number of staff members of the Bank of Japan were involved in developing and improving the FMM, with Shuichiro Ikeda, Haruhiko Inatsugu, Mitsuru Katagiri, Satoko Kojima, Koji Takahashi, Yoichiro Tamanyu, Saori Naganuma, Wataru Hirata, Taichi Matsuda, Hiroki Yamamoto and others contributing to the revisions in recent years.

[2] For the Bank's basic macroprudential principles, see, for example, Bank of Japan (2011).

[3] Baudino et al. (2018) classify stress tests of the entire financial system (system-wide stress tests) into those for supervisory purposes (either micro- or macroprudential); and those conducted by entities themselves (bottom-up stress tests implemented by financial institutions or top-down stress tests using models developed by supervisory authorities). In this paper, 'macro stress test' refers to all stress tests whose main purpose is to assess the stability of the financial system overall rather than that of individual financial institutions.

[4] The Banking Euro Area Stress Test (BEAST) model recently developed by the ECB is quite similar to the Bank of Japan's FMM described later in that it focuses on nearly 100 financial institutions within the euro area and takes into account the interactions between the real economy and the financial sector (Budnik et al. 2019). Moreover, the IMF is also developing a new stress test model (the Macro-Financial System Simulator, MASS) for its Financial Sector Assessment Program (FSAP), which incorporates interactions between the real economy and the financial sector (Adrian et al. 2020).

supply at the macro level can have second-round effects on the real economy as financial institutions that have sustained damage to their capital adequacy ratio in the event of a negative shock curb their lending.[5] The FMM is being continuously revised to ensure it captures issues important for the assessment of financial system stability by appropriately incorporating the transmission mechanisms of shocks to the financial system (Chart I). As a result of the revisions, the potential uses of the FMM have greatly expanded. For example, the use of balance sheet and profit-and-loss (P&L) data of individual financial institutions enable their different risk characteristics to be taken into account (Kitamura et al. 2014). Also we will show how medium- to long-term simulations and stress testing assuming a stress event in the medium- to long-term future enable us to assess the potential impact should the decline of financial institutions' core profitability continue in the future.[6]

Chart I: Development history of FMM

	Model developments
2011	- FMM developed that incorporates a feedback-loop mechanism between the real economy and the financial sector
2012-2013	- Balance sheet and P&L data of individual financial institutions incorporated to enable their different risk characteristics to be taken into account
2014	- Credit cost model improved to include borrowers' interest payment capacity - Risk-weighted asset model introduced to include changes in risk weights
2015-2017	- Loan function improved by taking nonlinearity into account - Credit cost models for overseas loan introduced - Model of net non-interest income for major banks introduced by taking into account the income's procyclicality to business cycle fluctuations
2018-2019	- Effects of increased foreign-currency funding costs in times of stress incorporated - Credit cost model improved using firm-level granular data - Model for securities investment improved by taking into account the room to lock in gains - New framework developed of medium- to long-term simulation of financial institutions' profits and stress testing assuming a stress event in the medium- to long-term future • Several subsequent revisions: e.g. lending rate model revised to account for structural changes in supply-demand balance in domestic lending market - Interest rate model improved to more accurately reflect recent bond market developments

In recent years, the Bank of Japan has also used the results obtained for individual financial institutions from macro stress testing in its dialogue with those individual financial institutions as part of its on-site examinations and off-site monitoring. Furthermore, from 2020, the FMM is being used as one of the supervisory models employed in the simultaneous stress testing based on common stress scenarios conducted jointly between the Bank of Japan and the Financial Services Agency of Japan in their comparative examination of the stress testing results reported by major financial institutions. It is, therefore, important to increase the transparency of the FMM and the stress testing methodology to boost our ability to identify risks and maximize the effectiveness of

[5] For international comparisons of stress test models, see Dent et al. (2016), Baudino et al. (2018), and Anderson et al. (2018). These surveys highlight the key characteristic of the FMM as one of important features of the models for macroprudential stress testing.

[6] Other studies conducting analyses based on the FMM include Kamada and Kurachi (2012), Kawata et al. (2012), and Kawata et al. (2013).

the supervisory dialogue with financial institutions.[7] At the same time, with the expansion of the range of uses of the FMM, it is vital that up-to-date information on its approaches, caveats, and issues should be widely available – in which effort this paper plays its part.

This paper, taking the previous paper explaining the FMM and macro stress testing as of 2014 (Kitamura et al. 2014) as its point of departure, explains the subsequent further development of the FMM. Section II introduces the basic framework of the FMM and presents some stress testing results. Section III then explains major revisions of the model in recent years. Next, Section IV provides some caveats on the use of the FMM and interpretation of the stress testing results, as well as highlighting issues for the future and some possible uses. The full equations of the FMM can be found in the Supplement.

II. The FMM and Macro Stress Testing: The Basic Framework

The three basic factors that influence the results of macro stress testing are: first, the nature and severity of the stress scenarios; second, the risk characteristics and financial bases of financial institutions; and third, the transmission mechanisms through which the stress scenarios affect financial institutions' profits and financial soundness. For example, if financial institutions are assumed to have increased their risk taking before a stress event for some reason, such as compensating for a decline in their core profitability, then financial institutions' credit costs and losses on securities will be larger even when the severity of the stress scenario does not differ between the scenarios. This shows the reason why the model used for stress testing needs to reflect the risk characteristics of financial institutions and to incorporate the main transmission channels of any shock.

A. Overview of the FMM: key mechanisms

Outline of the FMM and macro stress testing framework

The FMM used by the Bank for macro stress testing, as mentioned, is a macro-econometric model consisting of two sectors, the real economy and the financial sector, and incorporates interactions between the two sectors. For the financial sector, it uses balance sheet and P&L data of individual financial institutions, so that it is possible to obtain not only aggregate results but also results for individual financial institutions. The model focuses on financial institutions (major banks, regional banks, and *shinkin* banks[8]) that hold current accounts at the Bank of Japan. Constructed and

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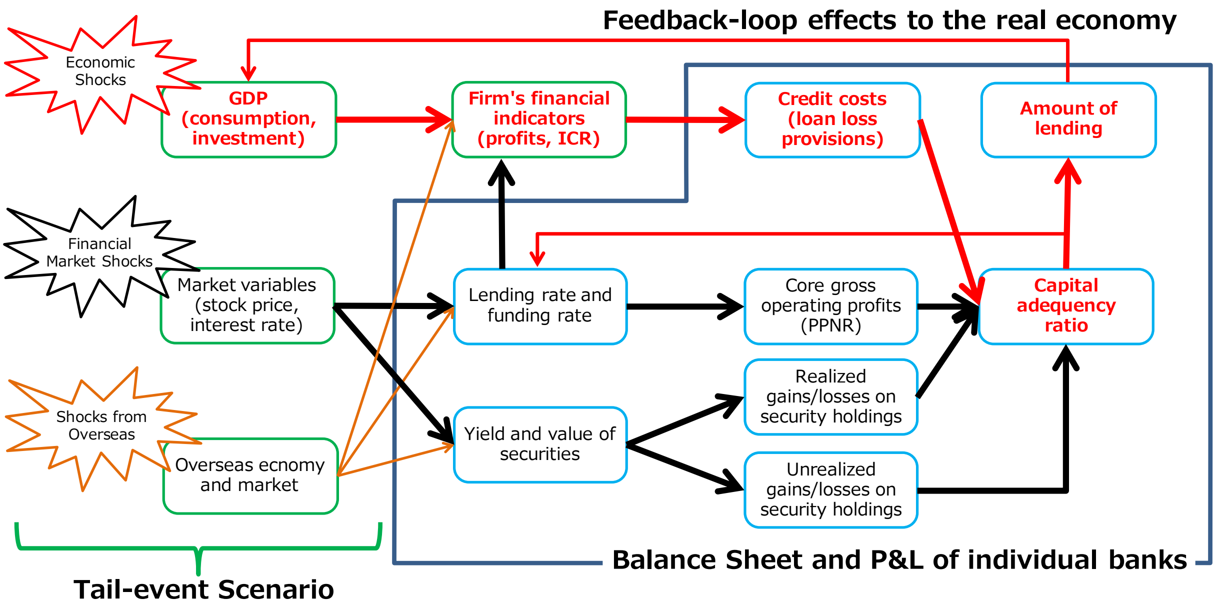
[7] On this point, see de Guindos (2019) and Board of Governors of the Federal Reserve System (2019a). On the other hand, attention also needs to be paid to the possibility that financial institutions' risk management methods could become too standardized as a result of the release of supervisory models, leading to vulnerabilities to risks not anticipated in the models. On the risks of a "model monoculture," see, e.g., Bernanke (2013).

[8] Major banks comprise the following 10 banks: Mizuho Bank, MUFJ Bank, Sumitomo Mitsui Banking Corporation, Resona Bank, Saitama Resona Bank, Mitsubishi UFJ Trust and Banking Corporation, Mizuho Trust and Banking Company, Sumitomo Mitsui Trust Bank, Shinsei Bank, and Aozora Bank. Regional banks comprise the 64 member banks of the Regional Banks Association of Japan (Regional banks I) and the 39 member banks of the Second Association of Regional Banks (Regional banks II). *Shinkin* banks are the 249 *shinkin* banks that hold current accounts at the Bank of Japan. Taken together, these banks account for about 80–90 percent of lending by private-sector financial institutions.

estimated from a large amount of data obtained from individual financial institutions, the model consists of a large-scale system of simultaneous equations comprising about 40,000 endogenous variables. The relationships between the variables (i.e., individual behavioral equations) are described mainly by a panel-data model constructed with an emphasis on their empirical fit.[9] This means that the FMM basically incorporates the average behaviors of financial institutions observed in the past.

Chart II-1 provides a schematic overview of the macro stress testing framework, showing the complex interdependent relationships in simplified form.

Chart II-1: Overview of BOJ's macro stress testing based on FMM



(1) First, for macroeconomic and financial market variables (GDP, stock prices, market interest rates, etc.), a stress scenario assuming that tail risk such as a financial crisis materializes is formulated.

(2) Next, based on the FMM, which includes the balance sheet and P&L data of individual financial institutions, the profits and capital adequacy ratios of individual financial institutions under the stress scenario are estimated.

(3) Lastly, the final results are calculated based on mechanisms included in the FMM in which the impact of a negative shock on financial institutions (calculated in (2)) is fed back to the real economy through financial intermediation activities.

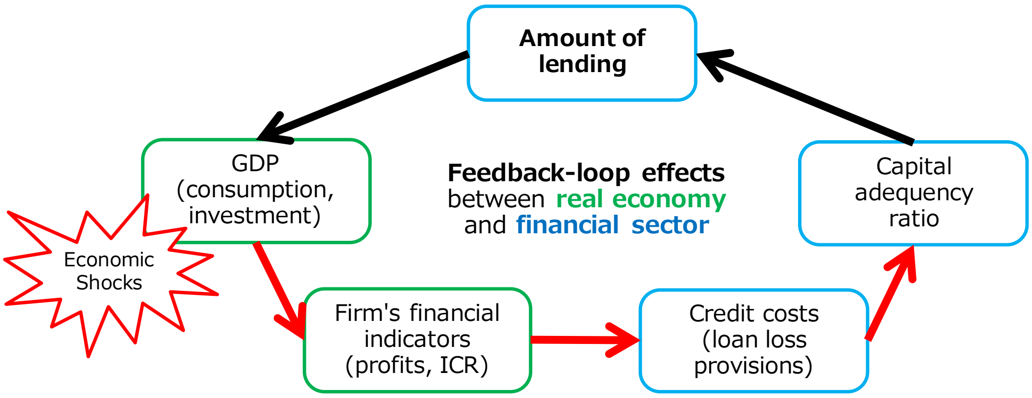
In practice, the impact of (2) and (3) is calculated simultaneously and consistently by solving the system of simultaneous equations.

[9] The FMM is not a structural model with micro-foundations incorporating, for example, optimization behavior by economic agents. It is a hybrid model (semi-structural model) that takes empirical fit into account as well as making certain assumptions about financial institutions' behavior.

Interactions between the real economy and the financial sector

Chart II-2 provides a further simplified diagram of the interactions between the real economy and the financial sector, focusing only on the main channels.

Chart II-2: Feedback loop between the real economy and the financial sector



The feedback loop incorporated into the FMM works as follows. In the event of a negative shock to the real economy (GDP, etc.), financial institutions will incur credit costs due to the deterioration in firms' financial conditions and their net income will decline; if they register net losses, their capital adequacy ratios will decline. This decline in capital adequacy ratios and profits (in terms of their net income ROA) will then lead to a decline in lending by financial institutions, which will in turn lead to a decline in household consumption and business fixed investment in the real economy. This is an illustration of the feedback loop through which a decline in financial institutions' lending capacity would have a negative impact on the real economy.[10] The FMM can quantitatively show the magnitude of such a negative feedback-loop effect from the financial sector to the real economy in times of stress (see Appendix 1 for details).

B. Overview of the macro stress testing results

Taking the simulations in the October 2019 issue of the FSR as an example, this section provides a basic overview of the regular stress testing results.

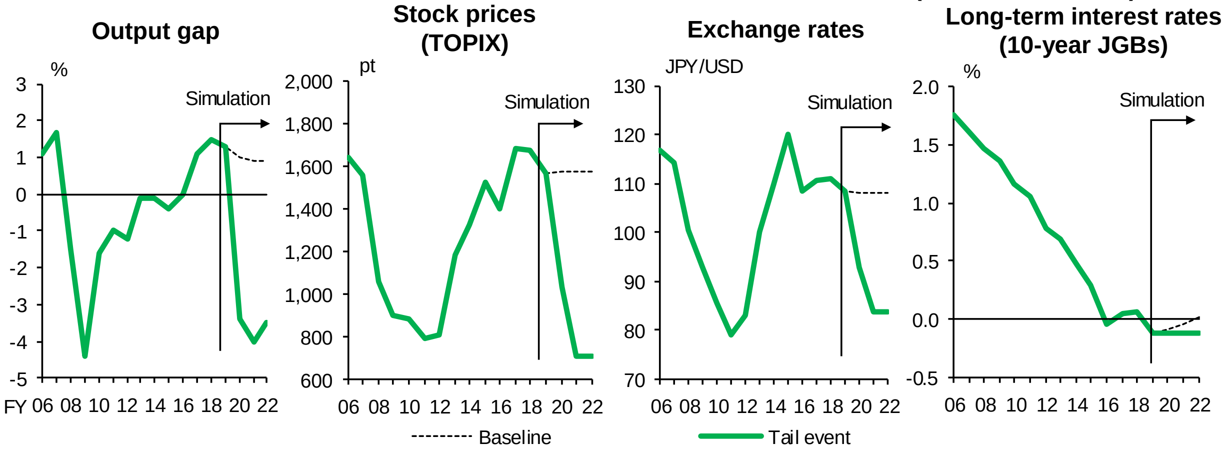
The simulation considers two scenarios, a "baseline scenario" assuming that there is no stress and a "tail event scenario" assuming a stress event, and compares the simulation results to quantitatively assess the impact of a stress event on the financial system. The simulation period is three years.

The baseline scenario, serving as reference to assess the results of the tail event scenario, is based on the average forecasts of various research institutions and market participants. The baseline scenario in the October 2019 FSR assumes that "with overseas economies continuing to grow moderately on the whole, Japan's economy will continue on an expanding trend" (Chart II-3). For domestic economic growth, the private sector forecasts in the *ESP Forecast: Monthly Survey of Professional Forecasters in Japan* are used. It is assumed that government bond yields evolve in

[10] In addition, the FMM incorporates mechanisms where a negative shock is amplified through an increase in funding rates due to the decline in capital adequacy ratios in times of stress and through an increase in lending rates due to a rise in non-performing loan ratios.

line with the forward rates implied by the most recent yield curve (in the October 2019 FSR, the yield curve as of late July 2019), and that stock prices (TOPIX) and foreign exchange rates remain unchanged from their most recent levels (in the October 2019 FSR, the levels as of late July 2019). For overseas economies, the growth forecasts from the IMF's *World Economic Outlook* are used.

Chart II-3: Macroeconomic variables in baseline and tail-event scenarios (October 2019 FSR)



Source: BOJ; Tokyo Stock Exchange; Ministry of Finance.

On the other hand, the tail event scenario assumes a "deterioration in economic and financial conditions at home and abroad to levels comparable to those following the collapse of Lehman Brothers (i.e., during the global financial crisis)," in which financial markets experience a decline in stock prices, the yen appreciates against the U.S. dollar, and domestic and foreign interest rates decline, all to the same extent as during the global financial crisis.[11] At the same time, a significant economic slowdown abroad as well as a deterioration in Japan's output gap -- again to the same extent as during the global financial crisis -- are assumed (Chart II-3).[12] It should be noted that these scenarios are purely hypothetical and adopted to examine the stress resilience of financial institutions and in no way represent the Bank of Japan's outlook for future economic and financial conditions or asset prices, nor do they represent the likelihood of the outcomes (also see Appendix 2 for details on how the tail event scenario is designed).

The main results of the macro stress testing are summarized in Chart II-4. The developments in profits and capital adequacy ratios in the baseline scenario and the tail event scenario are shown for three types of bank: internationally active banks, domestic regional banks, and domestic *shinkin* banks. To assess profits, the size of losses in the event of stress is examined using the "net income ROA," which represents net income adjusted for asset size. To assess capital adequacy ratios relative to the minimum level required by regulations (referred to as the "minimum (capital) requirements"), since internationally active banks and domestic banks are under different regulatory regimes in Japan,[13] the Common Equity Tier 1 (CET1) ratio is used for internationally

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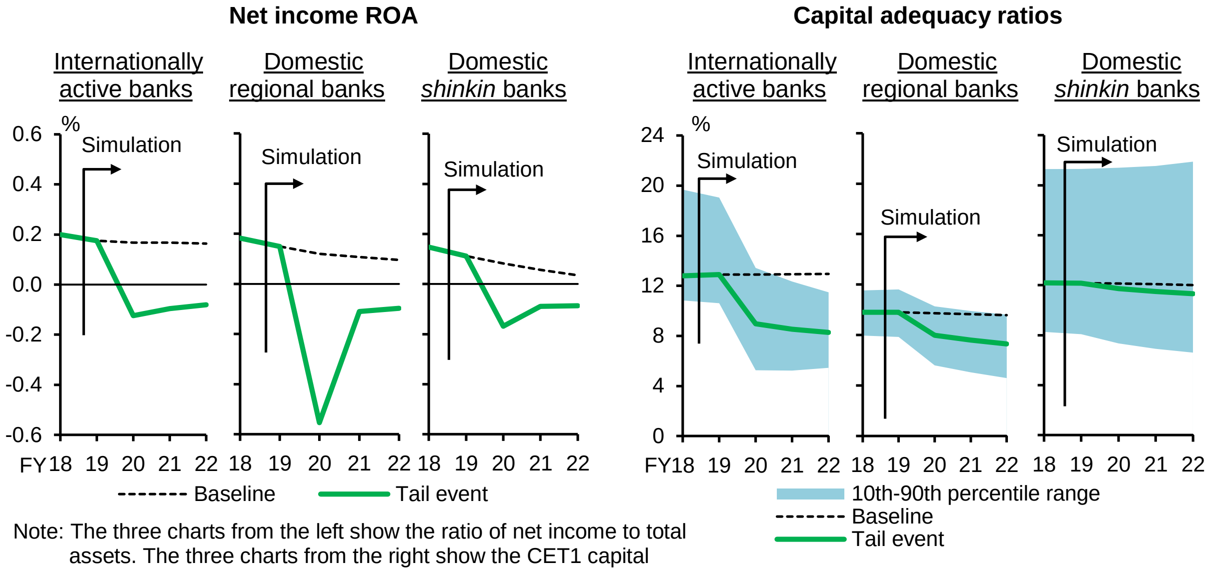
[11] However, since the lower limit for government bond yields is set at the lowest level ever historically, the decline in yields both at home and abroad in the tail event scenario in the October 2019 FSR is smaller than in the period during the global financial crisis.

[12] Japan's output gap is expected to deteriorate for four quarters from the stress event. The values in Chart II-3 include the impact of the decline in lending by financial institutions pushing down the output gap (i.e., the negative feedback-loop effect from the financial sector to the real economy).

[13] The minimum requirement of the CET1 ratio for "internationally active banks" is set to 4.5% in line with the Basel III agreements, while the minimum requirement of the regulatory core capital ratio for "domestic banks" is set to 4%.

active banks while the core capital ratio is used for domestic banks.

Chart II-4: Results of macro stress testing (October 2019 FSR)



Note: The three charts from the left show the ratio of net income to total assets. The three charts from the right show the CET1 capital ratios for internationally active banks and the core capital ratios for domestic banks.

The stress test results for the tail event scenario show that for banks of all three types net income falls substantially in the first year following the stress event as credit costs and losses on securities are incurred and lending margins decline. Subsequently, reflecting the economic downturn, net income remains negative from the second year onward due to sluggish lending, increasing credit costs, etc. As a result, the capital adequacy ratios of all three types of bank decrease correspondingly. However, since the average capital adequacy ratios of banks, again of all three types, remain above minimum requirements, Japan's financial system can be judged to be fairly resilient even in a tail event comparable to the global financial crisis.

Next, Chart II-5 provides a decomposition of the decrease in capital adequacy ratios in the event of stress. While the capital adequacy ratios of all three types of bank fall substantially in the event of stress, the decomposition shows that the patterns differ across types of bank. First, the decline in capital adequacy ratios is largest for internationally active banks. The reason is that regulatory capital adequacy ratios for these banks reflect unrealized losses on securities; moreover, their pre-provision net revenue (PPNR) falls substantially as the yen-denominated value of interest income on overseas loans decreases considerably due to the appreciation of the yen. Further, looking at domestic banks, the decline in regional banks' capital adequacy ratio is larger than that of *shinkin* banks, mainly due to credit costs and the deterioration in realized gains/losses on securities holdings.[14,15]

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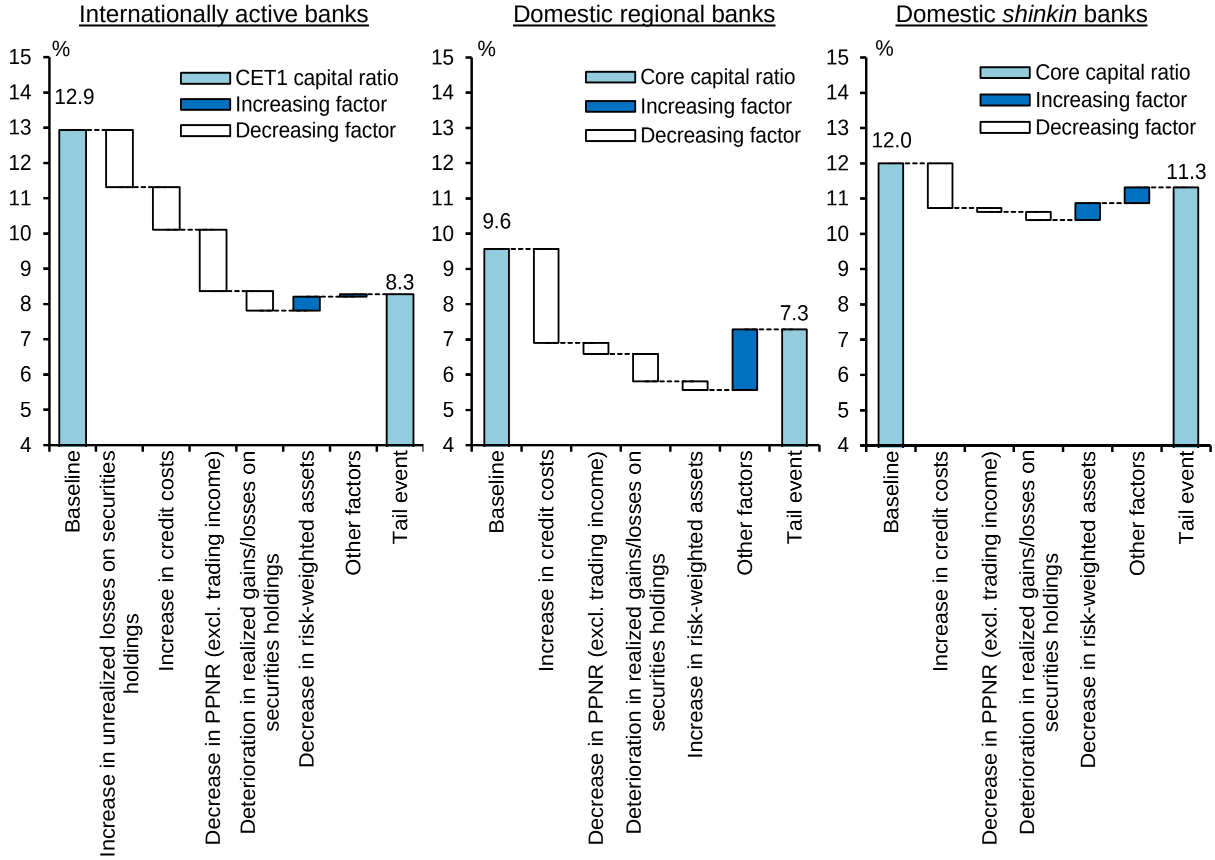
[14] The credit cost ratio of domestic banks is significantly higher than that of *shinkin* banks, partly because at regional banks the share of loans to low-return borrowers is higher (see Subsection III.B below) and partly because differences in credit costs during the global financial crisis reflect differences in the sensitivity to business conditions estimated by bank type in the credit cost model of the FMM.

[15] Changes in risk assets also contribute to the larger decline in regional banks' capital adequacy ratio. Basically, risk assets -- the denominator of the capital adequacy ratio -- decrease as in times of stress lending falls relative to the baseline; on the other hand, for major and regional banks that have adopted an internal ratings-based approach, the FMM also models how an increase in default rates leads to an increase in risk assets through an increase in

Chart II-5: Decomposition of the decrease in capital adequacy ratios in the event of stress (October 2019 FSR)



Note: 1. The charts indicate the contribution of each factor to the difference between the capital adequacy ratios at the end of the simulation period (as at end-March 2023) under the baseline and tail event scenarios. "Increase in unrealized losses on securities holdings" takes tax effects into account.
2. The charts show the CET1 capital ratio for internationally active banks and the core capital ratio for domestic banks.
3. "Other factors" includes taxes, dividends, and CET1 regulatory adjustments.

III. Revisions of the FMM in Recent Years

As mentioned in the introduction, the FMM is being continuously revised to ensure that it takes into account issues important for the assessment of financial system stability and adequately captures the transmission mechanisms of shocks to the financial system (Chart I). Since Kitamura et al. (2014) explained the model, it has undergone the following major revisions and enhancements:

A. The loan function has been enhanced by taking nonlinearity into account.

B. The credit cost model has been refined by using granular data.

C. The new framework of medium- to long-term simulation of financial institutions' profits and stress testing assuming a stress event in the medium- to long-term future has been developed.

D. The securities investment model has been refined by taking into account the room for locking in gains.

E. The effect of increases in foreign-currency funding costs in times of stress has been incorporated into the model.

credit risk weights. For domestic regional banks, the latter effect outweighs the former, contributing to the decline in their capital adequacy ratio.

This section outlines these revisions, including the background to and motivations for them.

A. Enhancement of the loan function to reflect nonlinearity

The reduction of lending by financial institutions in times of stress, as seen in the previous section, is an essential channel in the feedback loop between the real economy and the financial sector, and one that amplifies the negative impact of a shock. However, the extent to which financial institutions reduce their lending is not simply proportional to their capital adequacy ratio. For example, those whose capital adequacy ratio is well above minimum requirements may not reduce lending substantially when their capital adequacy ratio falls slightly. On the other hand, those whose capital adequacy ratio is close to the minimum requirement, or close to the capital adequacy ratio that they have set as their target for business stability, will be more conscious of capital constraints and will tend to reduce their lending considerably with even a slight fall in their capital adequacy ratio.

The FMM incorporates this nonlinearity in lending behavior. The 2014 revision incorporated the capital gap (= capital adequacy ratio – minimum requirement) as an explanatory variable in financial institutions' loan function to reflect that the closer a financial institution's capital adequacy ratio falls to the minimum requirement, the more reluctant the financial institution is to provide loans. In the subsequent revision, a nonlinear relationship was additionally incorporated into the model where financial institutions, even if their capital adequacy ratio does not approach the minimum requirement, curtail their lending more severely if their capital adequacy ratio falls below a certain threshold[16] or net income falls into the red (Chart III-1-1).[17]

Chart III-1-1: Nonlinear effects of ROA and capital on loan growth

<table>
<tr><th rowspan="2"></th><th colspan="2">Domestic regional banks</th><th colspan="2">Domestic shinkin banks</th></tr>
<tr><th>Positive net income ROA</th><th>Negative net income ROA</th><th>Positive net income ROA</th><th>Negative net income ROA</th></tr>
<tr><td>High capital adequacy ratio</td><td rowspan="2">0.91</td><td>1.42</td><td>—</td><td>2.52</td></tr>
<tr><td>Low capital adequacy ratio</td><td>2.27</td><td>0.90</td><td>3.42</td></tr>
</table>

Note: The figures show estimates of elasticities of net income ROA to domestic corporate loan growth by using panel data. The estimated equations include dummy variables depending on levels of ROA and capital adequacy ratio. For details of the estimation methodology, see BOX 2 in the FSR Annex, October 2016.

Loan function in FMM

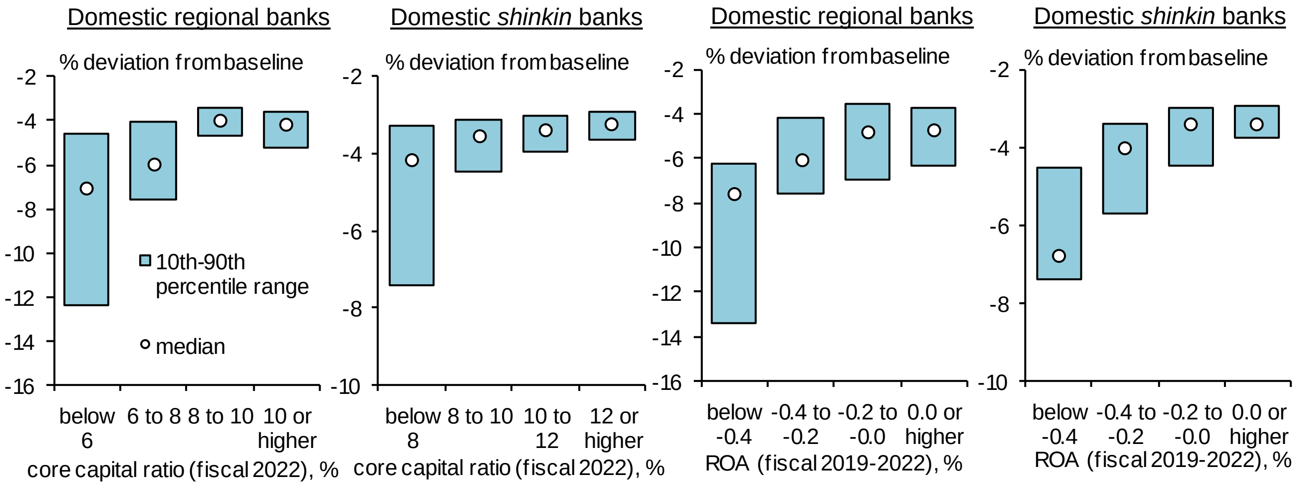
$$\begin{aligned}\text{Loan growth}_i \text{ (for bank i)} = {} & \alpha_1 \cdot \text{Output gap} + \alpha_2 \cdot \text{Expected economic growth (over the next 3 years)} \\ & + \alpha_3 \cdot \text{Lending rate (y/y chg.)}_i + \alpha_4 \cdot \text{Population growth} + \alpha_5 \cdot \text{Land prices (y/y \% chg.)} \\ & + \alpha_6 \cdot (\text{Capital adequacy ratio}_i - \text{Minimum requirement}_i) \cdot (1 + \gamma_1 \cdot \text{Dummy}_{CAR_i < \text{threshold}_i}) \\ & + \alpha_7 \cdot \text{Net income ROA}_i \cdot (1 + \gamma_2 \cdot \text{Dummy}_{\text{Net income ROA}_i < 0}) \\ & + \text{Fixed effect}_i + \text{constant.}\end{aligned}$$

16 For instance, domestic banks tend to set a capital adequacy ratio of 8 percent as their target for business stability. However, the capital adequacy ratio that individual financial institutions set as their target for business stability is not a specific threshold value but likely differs depending on their risk profile, profitability, and business environment such as regional economic developments (see Box 3 in the October 2019 FSR).

17 The Annexes for the October 2016 and October 2015 issues of the FSR use panel estimation of data for financial institutions to examine whether such nonlinearity can be observed in practice.

The revision makes it possible to measure in stress testing based on the FMM the extent to which the decline in lending is larger for those financial institutions whose capital adequacy ratio and profits fall substantially in the event of stress (Chart III-1-2).

Chart III-1-2: Impacts of decrease in capital adequacy ratio and ROA on lending in the event of stress



Note: 1. The figures show the deviations of domestic corporate loan outstanding at the end of the simulation period (as at end-March 2023) under the tail event scenario from the baseline.
2. Calculated using the results of macro stress testing in the October 2019 FSR.

B. Refinements of the credit cost model using granular data

The October 2018 and April 2019 issues of the FSR focused on the vulnerabilities inherent in regional financial institutions' lending to medium-risk firms, which has been increasing in recent years. This trend prompted refinements of the credit cost model of the FMM to take into account the heterogeneity in firms' (borrowers') interest payment capacity. The following first provides an outline of the credit cost model in the FMM and then explains details of the revision.

Outline of the credit cost model in the FMM

The FMM measures credit costs[18] by combining data on loan amounts by the standardized borrower classification among banks and the transition between the borrower classifications with data on loan-loss provision ratios by the borrower classification (Chart III-2-1). All data are obtained from financial institutions so that bank-level results are calculated. In other words, financial institutions incur credit costs when the borrower of a loan is downgraded (for example, if the borrower transitions from being a "normal" borrower to one that "needs attention"), and the loss is calculated by multiplying the loan amount by the applicable loan-loss provision ratio (in the case of loans other than those where the borrower becomes bankrupt or de facto bankrupt and then losses arise directly). Since this methodology of calculating credit costs is consistent with financial institutions' own accounting practices, the model has the advantage that the stress testing results conform with actual practice and are easy to understand.

[18] Credit costs = Loan-loss provisions + Write-offs + Losses on credit sales – Recoveries of write-offs.

Chart III-2-1: Credit cost calculation in FMM

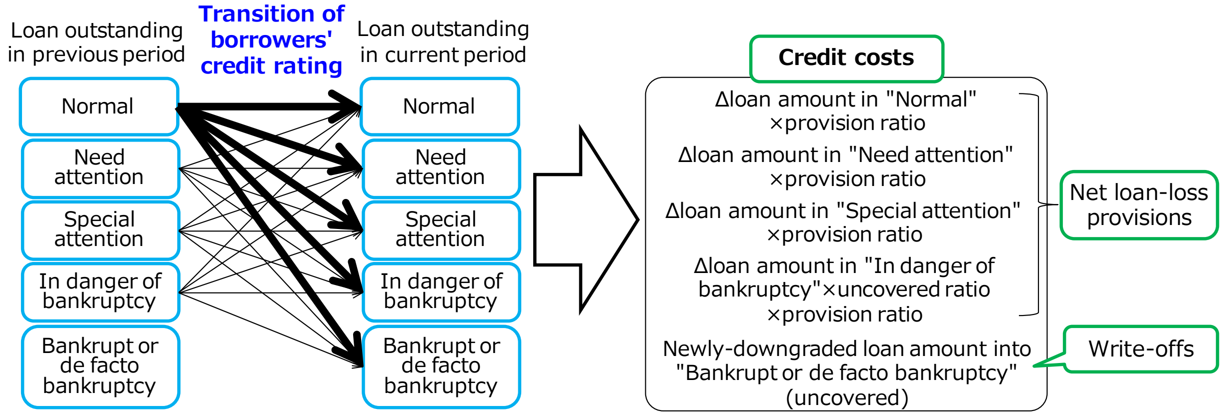
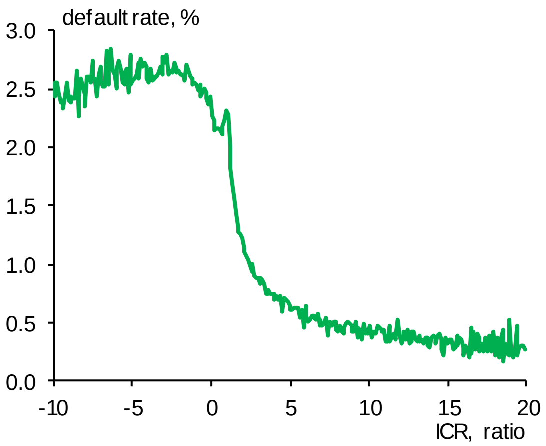


Chart III-2-2: Borrowers' ICR and default rates



Note: Covers financial statements data of small firms from January 1999 to March 2018. Defaults are defined as (1) being overdue by more than 3 months, (2) having one's borrower classification downgraded to "in danger of bankruptcy" or below, or (3) being subrogated by Credit Guarantee Corporations. Firms are sorted by their ICRs, and the default rate is calculated for each group.
Source: CRD; October 2018 FSR.

Transition probability function in FMM

Probability of transition from borrower classification m to n for bank i ($PT_i^{m\to n}$) :

$$Ln\left(\frac{PT_i^{m\to n}}{1-PT_i^{m\to n}}\right) = \alpha_1^{m\to n}\cdot \text{GDP growth} + \alpha_2^{m\to n}\cdot \text{ICR} + \alpha_3^{m\to n}\cdot \text{Quick ratio} + \text{Fixed effect}_i + \text{constant},$$

$$\text{where ICR} \equiv \frac{\text{Operating profits}+\text{Interest and dividends received}}{\text{Interst payments}} = \frac{\text{Operating ROA}}{\text{Borrowing rate}\cdot\text{Leverage ratio}}$$

The model assumes that the probability of a change of the borrower classification, the transition probability, is affected by both the macroeconomic environment and by the financial conditions of the borrower firm (the latter represented by the interest coverage ratio (ICR), which captures their interest payment capacity, and the quick ratio[19]). In general, a deterioration in the macroeconomic environment and/or a firm's financial position is seen to have a nonlinear effect on the probability of downgrades and the default rate (Chart III-2-2).[20] For this reason, in the panel estimation of

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[19] The ICR is defined as (Operating profits + Interest and dividends received) / Interest payments. The quick ratio is defined as Current assets (such as Cash and deposits and Trade accounts receivable) / Liquid liabilities.

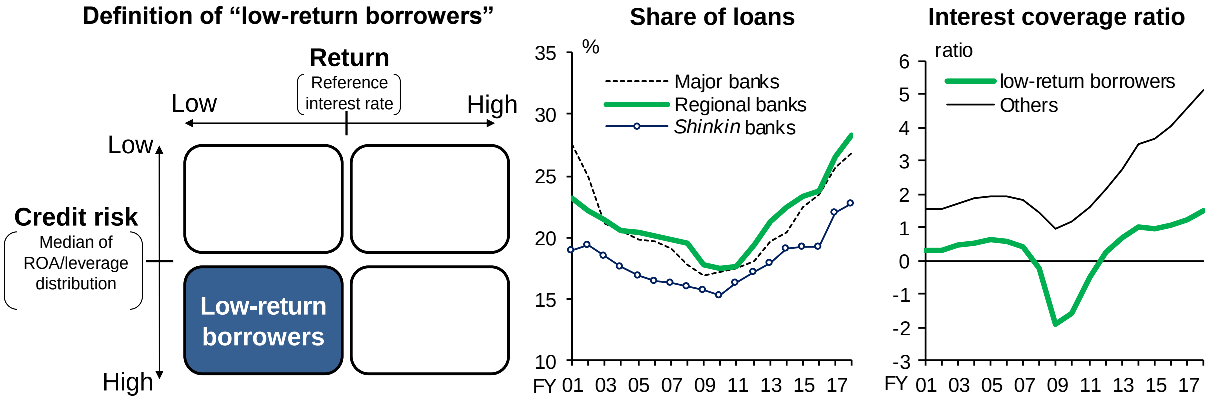
[20] Another model for forecasting the probability of default based on granular firm-level financial data shows the following: (1) firms' probability of default tends to increase nonlinearly as their interest payment capacity decreases; and (2) such an increase in the probability of default is much larger for more leveraged firms. For details, see FSR

transition probability, a logistic model taking such nonlinearity into account is used. The ICR, which is one of the key determinants of the transition probability in this specification, is assumed to be determined by the output gap, lending interest rates, etc. (For details, see the supplement on the "FMM System of Equations.")

Model refinements in response to the increase in loans to medium-risk borrowers

Thus, the FMM provides a credit cost model that makes it possible to capture the impact of stress by reflecting individual financial institutions' composition of loans by the borrower classification. However, in recent years, lending, particularly by regional financial institutions, has been increasing, to borrowers that, although classified as "normal" borrowers, are in fact in a relatively poor financial condition (so-called medium-risk firms). Amid the prolonged low interest rate environment and declining loan demand, financial institutions appear to have been active in such lending in search of higher returns and new demand; however, the number of loans to borrowers where the returns do not match the risk ("low-return borrowers") has been increasing. The FSR defines "low-return borrowers" as "firms with a relatively weak financial position whose borrowing interest rates are low relative to their credit risk through the business cycle" (left panel of Chart III-2-3) and provides estimates of the share of loans to such borrowers among all loans to small and medium-size enterprises (which is referred to as the "share of loans to low-return borrowers").[21] And the share of loans to these low-return borrowers has been increasing in recent years for banks of all types (middle panel of Chart III-2-3).

Chart III-2-3: Share of loans to low-return borrowers and their interest payment capacity



Note: The middle chart shows the share of loans to low-return borrowers among the total amount of loans to small firms.
Source: Teikoku Databank.

These low-return borrowers are relatively likely to default in times of stress, so that the higher a financial institution's share of loans to low-return borrowers, the larger is the increase in credit costs

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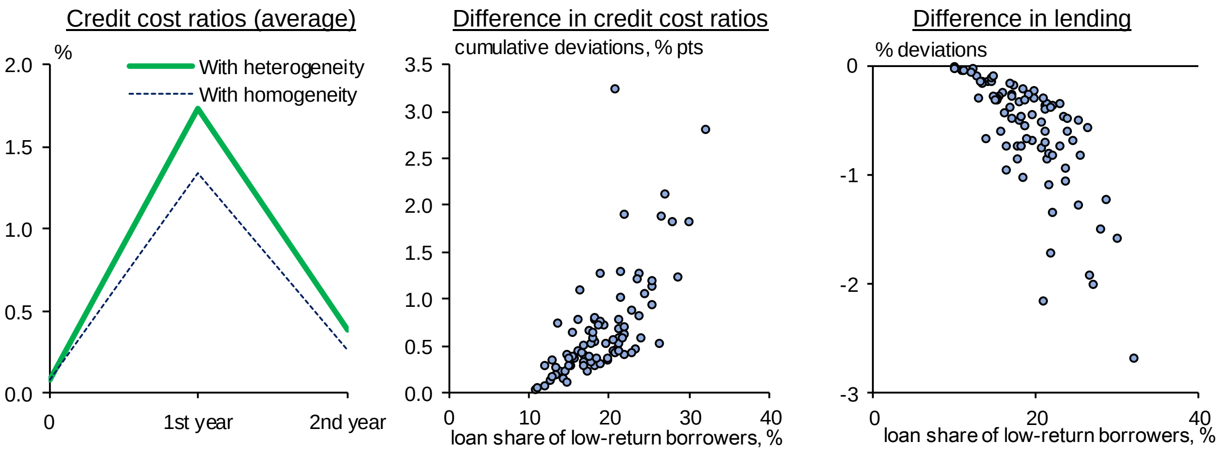
Annex, "A Forecast Model for the Probability of Default Based on Granular Firm-Level Data and Its Application to Stress Testing" (May 2019).

[21] Specifically, "low-return borrowers" are defined as small and medium-sized enterprises (SMEs) that meet one of the following two criteria in 2 consecutive years: (1) the firm's operating ROA is below the median of the distribution of all firms, but its borrowing interest rate is lower than that for the most creditworthy firms in the ROA distribution (i.e., firms in the top 10 percent in the distribution); and/or (2) the firm's financial leverage is above the median of the distribution of all firms, but its borrowing interest rate is lower than that for the most creditworthy firms in the financial leverage distribution (i.e., firms in the bottom 50 percent in the distribution). They are identified using granular firm-level data including information on the financial institutions they transact with. On the other hand, SMEs other than "low-return borrowers" are referred to as "other borrowers". For details, see the April 2018 FSR (Chapter VI) and Kawamoto et al. (2020).

in the event of stress likely to be. This is because the ICR of low-return borrowers -- given the close nonlinear relationship observed between firms' ICR and the default rate (Chart III-2-2) -- is lower than that of other borrowers and tends to fall by more when economic conditions deteriorate (right panel of Chart III-2-3). The model was, therefore, revised to incorporate the heterogeneity in loans due to differences in borrower characteristics that are not reflected in the borrower classification.

Specifically, first, because the sensitivity of the ICR to macroeconomic fluctuations differs between low-return borrowers and other borrowers, we estimated the ICR for the two groups of borrowers separately. Second, we incorporated differences in the concentration of loans to medium-risk borrowers into the model by using the weighted average of the ICR of individual financial institutions' borrowers, where the ICRs of low-return borrowers and other borrowers are weighted by the share of loans to low-return borrowers. Such firm-level granular data were used in the macro stress testing for the October 2018 FSR. The results showed that the higher a financial institutions' share of loans to low-return borrowers,[22] the larger the increase in the credit cost ratio in the event of stress, which in turn resulted in a larger decline in the capital adequacy ratio and a correspondingly larger decline in lending (Chart III-2-4). To estimate the change in lending volume, we used the revised model that takes the nonlinearity described in Section III.A into account. The results also suggest that if the share of loans to low-return borrowers continues to increase, the increase in credit costs in the case of a stress event in the medium- to long-term future would be larger than in the case of an immediate stress event (see Section III.C).

Chart III-2-4: Results of Stress test taking into account heterogeneity in firms' interest payment capacity (October 2018 FSR)



Note: 1. The figures show the results of macro stress testing assuming heterogeneity/homogeneity in firms' interest payment capacity. Covers domestic regional banks whose loan shares of low-return borrowers can be estimated.
2. The right-hand chart shows the deviations of domestic corporate loan outstanding at the end of the simulation period.

[22] The simulation in the October 2018 FSR accounted for the differences in the share of loans to low-return borrowers in regional banks only. From the April 2019 FSR, low-return borrower coverage has been expanded to all bank types, although due to data limitations, we have used the average value for the bank type to which a particular financial institution belongs (major bank, regional bank, or *shinkin* bank) for the share of loans to low-return borrowers.

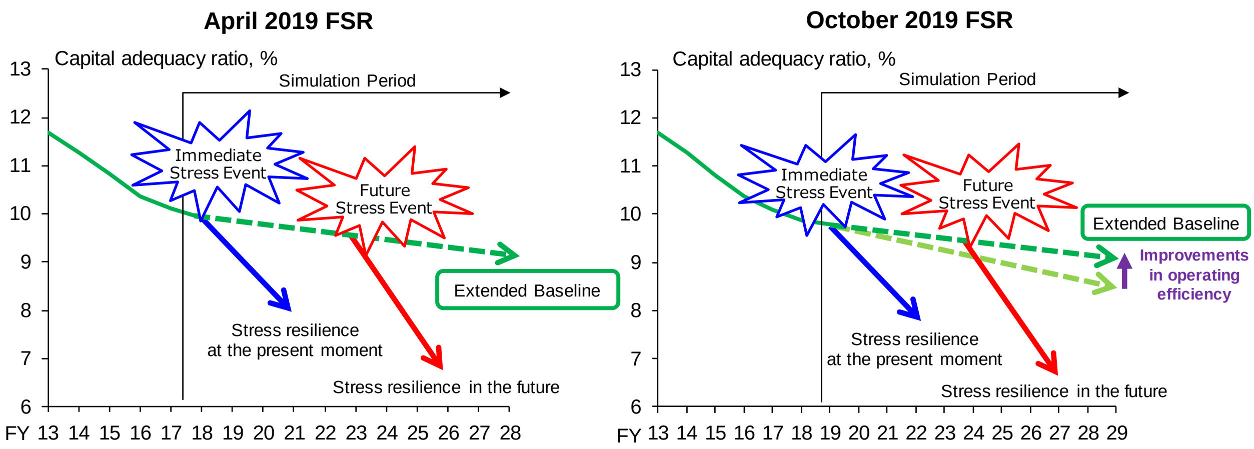
C. Medium- to long-term simulation of financial institutions' profits and stress testing assuming a stress event in the medium- to long-term future

In the April 2019 issue of the FSR, the framework of the FMM was significantly expanded. In addition to the regular macro stress testing, stress testing assuming a stress event in the medium- to long-term future was newly conducted, based on a medium- to long-term simulation of financial institutions' profits.

In recent years, the profitability of domestic deposit-taking and lending activities, which are the core of financial intermediation activities, has been declining, especially for regional financial institutions. This decline is mainly due to structural factors, such as declining loan demand and lower potential economic growth caused by the declining population, together with the prolonged low interest rate environment. Any vulnerability of financial institutions to this continued downward pressure warrants vigilance.[23] The expansion and improvement of the FMM here provides a framework to examine stress resilience, not only to an immediate stress event but also to one in the future based on the assumption that this decline in the core profitability will continue in the future. Examining future stress resilience is also gaining attention overseas, where a prolonged low interest rate environment similar to that experienced by Japan is becoming a major issue with regard to financial stability.

Specifically, in the April 2019 FSR, the simulation period, normally 3 years in the baseline scenario, is extended to 10 years. Also, in addition to the regular stress test, where it is assumed that a tail event similar to the global financial crisis occurs immediately, it is assumed that such a tail event occurs in 5 years' time, with the results of the two scenarios compared in order to quantitatively examine the loss-absorbing capacity of financial institutions in the future (Chart III-3-1). In a further expansion, in the October 2019 FSR*,* simulations and stress tests were conducted that incorporated the effect of efforts by regional financial institutions to boost their operating efficiency in mitigation of future declines in profitability and/or financial soundness.

Chart III-3-1: Framework of medium- to long-term simulation and stress test assuming stress in the future

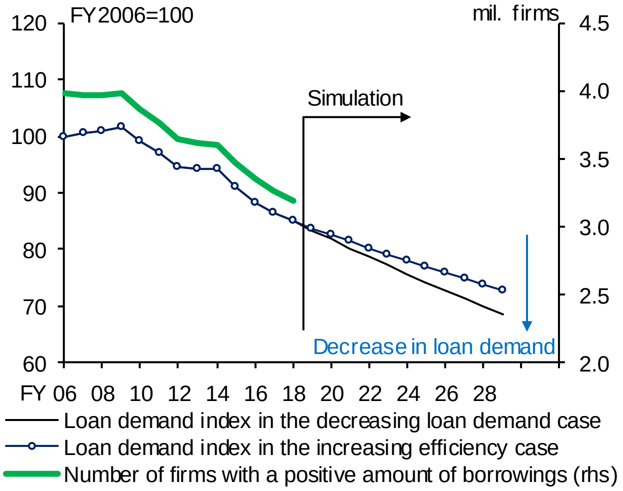


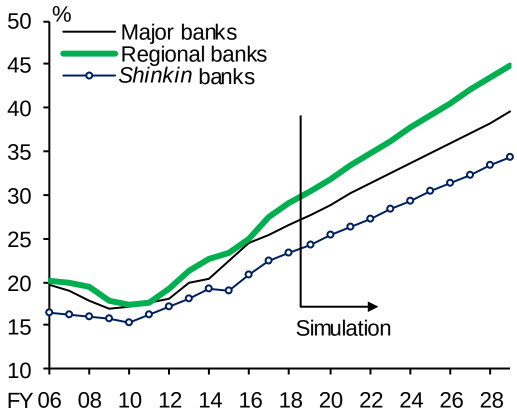
[23] For this reason, the Financial Services Agency of Japan revised its early warning system in 2019 and added regional financial institutions' medium- to long-term profitability as one of the criteria in the early warning system.

Assumptions and results of the medium- to long-term profit simulation

When we extend the baseline scenario in the medium- to long-term simulation, we need to make certain assumptions about medium- to long-term changes in the economic and financial structure that might significantly affect the test results, necessitating various revisions of the model. First, regarding macroeconomic and financial conditions, for example, we assume that the output gap, which represents the level of real economic activity, follows the regular baseline scenario for the first 3 years but over the next 7 years gradually converges to its long-term equilibrium, that is zero, where the economy neither overheats nor is in recession. Government bond yields, similar to the regular baseline scenario, are assumed to evolve in line with the forward rates implied by the yield curve. For simplicity, stock prices (TOPIX) and exchange rates are assumed to remain unchanged over the entire simulation period.

Chart III-3-2: Medium- to long-term baseline scenario (October 2019 FSR)





Note: 1. "Loan demand index" is calculated by dividing the number of borrowing firms by the number of effective bank branches (which takes into account the effects of “branch-in-branch” consolidation). "Loan demand index in the increasing efficiency case" additionally supposes that overhead cost saving efforts induce streamlining of branches, etc.
2. The right-hand chart shows the share of loans to low-return borrowers among the total amount of loans to small firms.

Source: Ministry of Internal Affairs and Communications; Teikoku Databank; The Japan Financial News; October 2019 FSR.

Domestic lending rate function in FMM

$$\text{Domestic lending rate}_i \text{ (for bank i)} = \alpha_1 \cdot \text{Domestic funding rate}_i + \alpha_2 \cdot \text{Term spread (5-year minus 3-month)}$$
$$+ \alpha_3 \cdot \text{Loan demand Index}_i + \alpha_4 \cdot \text{Non-performing loan ratio}_i$$
$$+ \text{Fixed effect}_i + \text{constant.}$$

Regarding the underlying supply-demand conditions in the domestic loan market, one of the structural factors causing the secular decline in the profitability of lending activities, the firms’ loan demand is assumed to continue decreasing at the same pace as seen so far, a "decreasing loan demand case" (left panel of Chart III-3-2).[24] Specifically, the "loan demand index," calculated as

[24] The April 2019 FSR also considers a "constant loan demand case," in which firms’ loan demand stops declining and, by comparing the two cases, quantifies the impact that structural factors will have on financial stability in the future.

the number of borrowing firms per bank branch, is used as a proxy variable for the underlying supply-demand conditions in the loan market, and it is assumed that this index continues to decline during the simulation period in line with the trend observed since 2010. In the specification of the domestic lending interest rate function, as shown above, the loan demand index is used as one of the explanatory variables, thus incorporating into the model a mechanism whereby long-term structural factors, such as the decrease in the population and the number of firms, exert downward pressure on loan interest rates through the secular decline in loan demand.

In tandem with the decline in the loan demand index, the share of loans to low-return borrowers, loans for which the loan interest rate is not commensurate with the credit risk involved (see Section III.B), is assumed to continue to rise (right panel of Chart III-3-2).[25] This assumption would induce the results in which credit costs in the case of a future stress event will be higher. Meanwhile, with regard to securities-related gains, financial institutions are assumed to continue realizing gains on securities holdings at the same pace as seen in the past 3 years up until they have exhausted all unrealized gains (on the treatment of securities investment in the FMM, see Section III.D).

Chart III-3-3: Combination of overhead cost savings and increases in net non-interest income

Top value: bil. yen; middle and bottom values: %

	Actual values of FY2018		Upper value: assumed amount of increase in net non-interest income Middle value: assumed rate of increase in net non-interest income Bottom value: assumed net non-interest income ratio		
	Core gross operating profits	Net non-interest income	Three cases of overhead cost savings over the next 10 years		
			-5%	-10%	-15%
Regional banks	4,141.0	510.3 <12.3>	+151.8 [+29.7] <15.4>	+45.5 [+8.9] <13.3>	+7.0 [+1.4] <12.5>
Shinkin banks	1,594.7	57.2 <3.6>	+89.7 [+156.7] <8.7>	+34.2 [+59.7] <5.6>	+10.2 [+17.8] <4.2>

Note: 1. Figures in angle brackets indicate net non-interest income ratio (= net non-interest income / core gross operating profits).
2. The increasing efficiency case in the October 2019 FSR assumes that individual regional financial institutions can save overhead costs at most by -10% over the next 10 years.

The October 2019 FSR additionally considers an "increasing efficiency case." In the simulation for this case, we assume that financial institutions manage to improve their operating efficiency such that the average adjusted overhead ratio (OHR; overhead costs divided by core gross operating profits) of each bank type declines by around 5 percentage points from the current level.[26] Regional banks, for example, are assumed: (1) to continue reducing their overhead costs at about the same pace as in recent years (about 1 percent per year); and (2) to increase their net non-interest income by about 10 percent in total over the next 10 years (Chart III-3-3).[27] These assumptions are only an example, and there are a variety of options that financial institutions can pursue in order to

[25] As for determinants of the share of loans to low-return borrowers, see the April 2018 FSR (Chapter VI, Box 4).

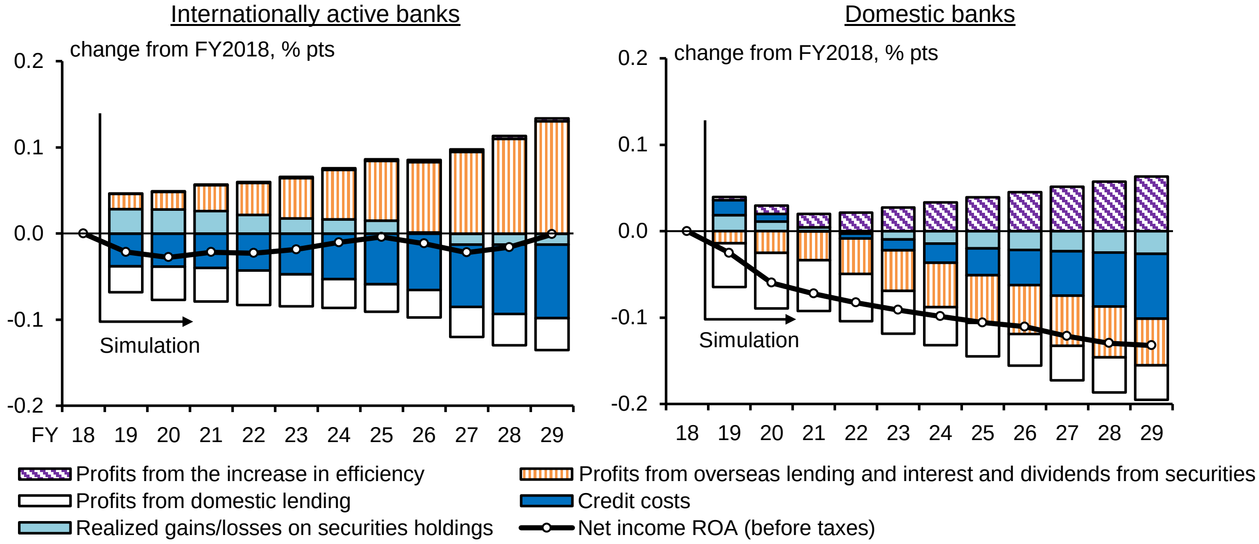
[26] Because there is substantial heterogeneity in individual financial institutions' adjusted OHRs, the degree of improvement in efficiency is not assumed to be uniform. See the October 2019 FSR (Chapter VI, Box 4) for details.

[27] The FMM simulations usually assume that future overhead costs and net non-interest income (net fees and commissions) of regional financial institutions will remain unchanged from recent actual figures (note, though, that the net non-interest income of major banks is a function of stock prices, exchange rates, and the output gap). Here, the simulation of improvements in operating efficiency is performed by taking the assumed future path of these variables as exogenously given.

improve their operating efficiency. To show possible options, Chart III-3-3 provides the increase in net non-interest income required when overhead cost reductions are larger or smaller than in the example. Moreover, since improvements in operating efficiency tend to include the streamlining of branch networks, the resulting eased decline in the loan demand index (the degree to which loan demand slackens) is also taken into account (left panel of Chart III-3-2).

The results of the baseline scenario show that the net income of financial institutions can be expected to continue to decline, particular at domestic banks, including many regional financial institutions. Moreover, although improvements in operating efficiency do not fully compensate for this downward pressure, they do make a considerable contribution to propping up profits (Chart III-3-4).

Chart III-3-4: Net income ROA in the medium- to long-term simulation (October 2019 FSR)



Note: "Profits from the increase in efficiency" is the sum of the overhead cost savings and the increase in the net non-interest income assumed in the increasing efficiency case.
"Profits from domestic lending" indicates the net interest income from domestic lending (domestic loans outstanding × lending margins in the domestic business sector).
"Profits from overseas lending and interest and dividends from securities" is defined as the PPNR (excluding trading income) minus the net interest income from domestic lending and the profits from the increase in efficiency.

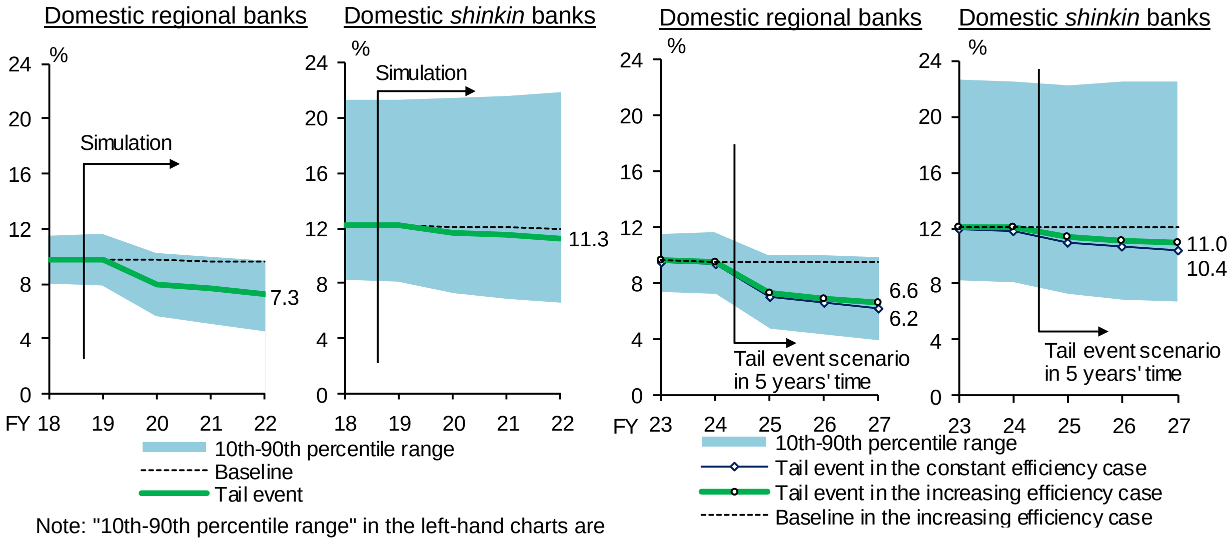
Stress test assuming stress in the medium- to long-term future: the results

In the October 2019 FSR, the results of our stress testing assuming a stress event in 5 years' time suggest that domestic banks' capital adequacy ratios will be significantly lower than in the case of an immediate stress event (Chart III-3-5). This reflects three factors: (1) the lower capital adequacy ratios in the extended baseline scenario due to the cumulative effect of the ongoing decline in financial institutions' profitability; (2) a larger deterioration in credit costs in the event of stress due to the increased share of loans to low-return borrowers associated with the secular decline in loan demand; and (3) larger impairment losses on securities holdings in the event of stress due to the shrinking buffer of unrealized gains that inevitably results from successive rounds of actually realizing gains.

However, the capital adequacy ratios in the "increasing efficiency case" are about half a percentage point higher than in the case where there are no improvements in efficiency (i.e., "constant efficiency case"). This indicates that efforts by financial institutions to improve their operating efficiency have a significant positive effect on their future stress resilience.

Chart III-3-5: Results of stress test assuming stress in the future (October 2019 FSR)

Immediate tail-event scenario **Tail-event scenario in 5 years' time**



Note: "10th-90th percentile range" in the left-hand charts are for the tail event, and those in the right-hand charts are for the tail event in the increasing efficiency case.

While results from the medium- to long-term simulation and stress testing for a stress event in the medium- to long-term future are subject to a larger margin of error and therefore need to be interpreted with greater care than the regular stress testing results, they do nevertheless provide a useful basis for objective and quantitative discussions on the severity of the profit environment that financial institutions will face in the future and on the importance of making efforts to respond to this profit environment.

D. Refinements to reflect the room held by securities investment to lock in gains

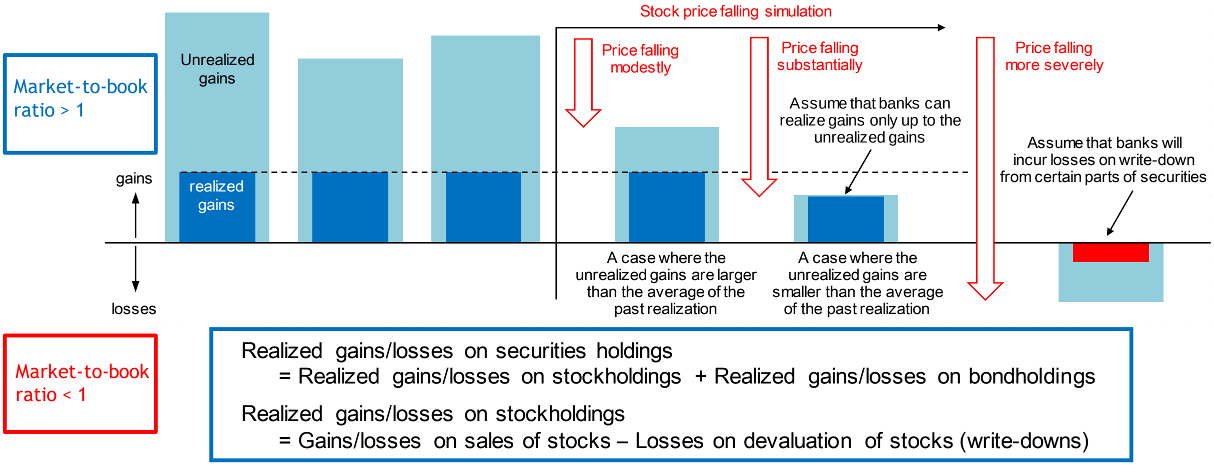
In recent years, Japanese financial institutions, faced with a decline in their core profitability, have actively realized gains from the sale of securities. With this realization, however, the book values of their securities holdings have been increasing, so that the room to lock in gains on securities has become smaller. For financial institutions that have exhausted their room to lock in gains, a deterioration in pre-provision net revenue (PPNR) and increase in credit costs will directly lower their net income and capital base.[28]

Prior to the October 2018 FSR, the FMM assumed that individual financial institutions would realize gains on securities at the same pace as that of their most recent actual sales. However, in recent years, an increasing number of banks have reached a point where they are unable to continue realizing gains at the same rate as before. And therefore, since the October 2018 FSR, although the FMM still assumes that financial institutions will realize gains at the average pace of the past 3

[28] It should be noted that the treatment of unrealized gains/losses on securities holdings in capital adequacy ratio regulations differs for internationally active and domestic banks. While for internationally active banks, unrealized gains/losses are directly reflected in their capital adequacy ratio (CET1 ratio), for domestic banks unrealized gains/losses are not reflected in their capital adequacy ratio (core capital ratio).

years[29], an upper limit for the realization of gains has now been set (Chart III-4).

Chart III-4: Concept chart for setting the upper limit of realizing gains on securities



In addition to the upper limit for the sale of securities, we also set an upper limit for the sale of stocks, and we assume that if a financial institution has exhausted its unrealized gains on stocks, it can instead realize gains on bonds in order to achieve gains that cannot be realized through stocks due to its upper limit. This revision enables the medium- to long-term simulation (Section III.C) to capture one of the reasons why the impact of a stress event in the medium- to long-term future is greater than that of an immediate stress event; namely that because of successive rounds of realizing gains, the number of financial institutions that have exhausted their room to realize gains will increase over time.

Moreover, the larger the unrealized losses on stocks in times of stress, the more likely are financial institutions to suffer realized stock losses through impairment procedures. For this reason, at the same time as we made the revision above, we also modeled the relationship between the market-to-book ratio of securities holdings and the write-down ratio (write-down losses/book value before write-downs) based on past data. This allowed us to incorporate a mechanism where financial institutions that realize a large amount of gains and whose book value of securities has been increasing will suffer larger securities-related losses at a time of stress due to larger unrealized losses.

In order to accurately grasp the unrealized securities-related gains/losses of individual financial institutions, we also calculate in detail the impact of interest rate changes on the market value of bond-holdings based on estimates of their outstanding amount of bond-holdings by remaining and original maturity. The actual calculation is performed using an interest rate model that serves as a satellite model of the FMM, with the calculation results inserted into the FMM as exogenous variables (for details of the interest rate model, see Appendix 3). Moreover, for stocks, investment trusts, etc., changes in market value are calculated by making assumptions on the sensitivity to changes in financial market variables such as stock prices.

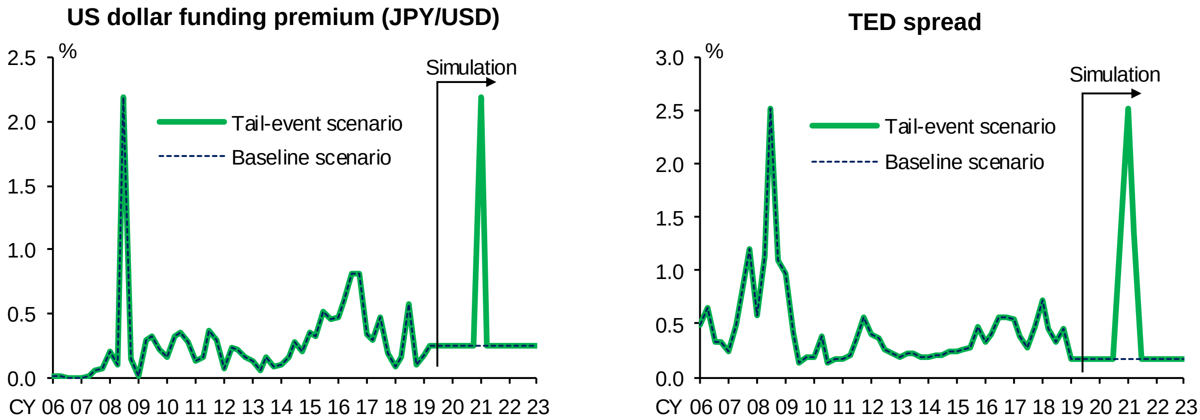
[29] Regarding strategic stockholdings of financial institutions, it is assumed that they can realize gains on the strategic stockholdings even though it may be actually difficult to continue to sell them due to the strategic relationship with the firms. Moreover, regarding bonds, for simplicity, an upper limit for the realization of gains from the sale of bonds is set on a net basis of foreign and domestic bonds.

E. Incorporating the effect of increases in foreign-currency funding costs in times of stress

Foreign currency funding costs have become increasingly important for many Japanese financial institutions. Following the global financial crisis in the late 2000s, Japan's major banks partly took over the credit creation functions of those U.S. and European financial institutions whose financial soundness had declined, and, to compensate for the decline in profitability of domestic lending, many of Japan's financial institutions have substantially increased their overseas exposure. Hence the significance of managing foreign currency liquidity risk has further increased, especially as Japanese financial institutions have limited means of raising foreign currency funding. Macro stress testing, therefore, needs to incorporate the transmission channels of potential stress in the foreign currency funding environment.

Thus, in the April 2018 FSR, we introduced a mechanism in the FMM whereby an increase in Japanese banks' dollar funding costs in times of stress pushes down their profits through a deterioration in the profitability of their overseas business. To do so, two types of premiums were introduced into the model: a U.S. dollar funding premium, defined as the difference between U.S. dollar funding costs using foreign exchange swaps and U.S. dollar LIBOR (3-month); and TED spreads, defined as the difference between U.S. dollar LIBOR and U.S. Treasury yields. Specifically, in the tail event scenario, we assume that these premiums rise to the same level as during the global financial crisis, and measure the impact of this increase in premiums (Chart III-5).

Chart III-5: Assumptions on foreign-currency funding costs under baseline and tail-event scenarios



Note: Assumptions are for macro stress testing in October 2019 FSR.
Source: Bloomberg.

IV. Use of the FMM - Caveats and Issues for the Future

The Bank of Japan has continuously enhanced and updated the FMM to ensure that it continues to capture the considerations necessary in order to assess the stability of the financial system and to incorporate the transmission mechanisms of shocks to the financial system. As we have seen, the model is also being used in a wider range of roles, making it incumbent on us to ensure that in addition to the model's advantages, the caveats and limitations of its use are sufficiently understood by its users.

First, there are caveats regarding the assumed scenario. While in the FSR's regular macro stress testing a tail event scenario assumes the same degree of stress as during the global financial crisis, any future financial crisis is unlikely to take the exact same form as the global financial crisis.[30] Moreover, as noted repeatedly, the various assumptions for the baseline and tail event scenarios are hypothetical and are made solely in order to examine the stress resilience of the financial system. Nor do they in any way represent the Bank's forecasts of future economic and financial conditions, asset prices, etc. The assumptions about future developments of a number of variables are simplifications, where it was assumed that some of the variables remain unchanged from current levels. In particular, the quantitative results of the medium- to long-term simulations as well as the stress testing for a tail event in the medium- to long-term future in Section III.C are subject to a greater margin of error than the regular stress tests. These, therefore, need to be interpreted with care. Furthermore, the FMM does not take into account the possibility that the patterns of behavior shown by financial institutions could change in the future, except where concrete additional assumptions are made, such as in the "increasing efficiency case" (Section III.C).

The second caveat concerns limitations of the quantitative model. Like many quantitative models, the FMM uses data observed in the past to model the relationships between various variables and the transmission channels of shock. Model specification and estimated parameters have uncertainties, and data limitations render some areas difficult to incorporate. In addition, to obtain robust estimation results, we use time-series data for a relatively long period of time, which means that the model may not capture recent structural changes. While large macro-econometric models with large systems of equations, including the FMM, have the great advantage of capturing the relationships between a wide range of economic and financial variables simultaneously, dealing with all these issues flexibly tends to be difficult. Furthermore, while a strength of the FMM is that it is built by incorporating balance sheet and P&L information for individual financial institutions, it also has parts where various parameters are assumed to be identical for banks of the same type. And therefore when using the macro stress testing results of the FMM for individual financial institutions, the quantitative results need to be interpreted with care as they are subject to a significant margin of error.

To tackle these issues, we are considering further refinements and expansions of the model, for example, by obtaining new data. However, the more the model is revised, the larger and more complex it becomes, inevitably making it less flexible and more difficult to interpret. A balance needs to be struck between greater detail and more complexity on one hand, and greater flexibility but loss of detail on the other.[31] Moreover, depending on the aim and purpose, sometimes it is better to use an approach other than a large-scale model.

Looking at future uses of the FMM, one task is to refine the scenarios and the mechanisms incorporated in the FMM for the simultaneous stress testing based on a common scenario, which is currently being conducted (see Section I). Frameworks to use simultaneous stress testing as a core tool for regulation and supervision have been established in the United States and in European countries.[32] In Japan, too, it is very likely that simultaneous stress testing will be very useful in

[30] Alfaro and Drehmann (2009) and Borio et al. (2014) argue that it is difficult to identify unknown vulnerabilities and, given this, to build credible stress scenarios before a financial crisis actually occurs, and therefore they warn against an over-reliance on stress testing during normal times.

[31] In the case of the FMM, the number of endogenous variables is about twice that in 2014. While incorporating more data and making model improvements to more appropriately describe reality, it is also essential to minimize "model risk," that is, modelling errors that may affect policy judgments. For measures to manage model risk taken by overseas authorities, see Board of Governors of the Federal Reserve System (2019b), Bank of England Prudential Regulation Authority (2018), and Basel Committee on Banking Supervision (2018).

[32] For example, in the United States, the Federal Reserve conducts Dodd-Frank Act Stress Tests (DFAST) to quantitatively and simultaneously examine the sufficiency of large banks' capital levels based on a common

identifying the risk characteristics, issues in risk management and financial soundness of large financial institutions, all of which will help us better understand and assess the stability of the financial system overall. Given this, the Bank is currently working on ways to capture in greater detail the credit costs and losses on securities that may arise from overseas exposure in times of stress.[33] Moreover, as it is likely that the decline in regional financial institutions' profitability will continue in the future, there remains considerable scope for continuing to use the medium- to long-term simulations and stress tests for a stress event in the medium- to long-term future.

Other potential uses for further examination include: an assessment of the impact on financial systems' soundness and capital adequacy ratios of a fire sale of foreign currency-denominated assets resulting from illiquidity in foreign currency funding markets; model simulations on the effects of hypothetical changes in macroprudential policies; stress tests incorporating climate-related risks, which some central banks especially in Europe have been starting to conduct; and stress tests incorporating vulnerabilities in the non-bank sector. However, attempts to incorporate such issues, which fall outside the current specification, would require drastic revisions of the model, and at this point, constraints in terms of the necessary data (i.e., data gaps) are fairly substantial, so that the first step would be to learn from preceding research and experiences overseas. Always, when considering enhancements to and the future development of the FMM, as explained above, the Bank will constantly review the FMM to ensure that it continues to respond appropriately to new issues arising from changes in the environment surrounding Japan's financial system.

scenario set by the Federal Reserve and the Comprehensive Capital Analysis and Review (CCAR) examining the appropriateness of large banks' capital planning as key supervisory tools. In the United Kingdom, financial institutions are required to hold sufficient capital to cover losses in times of stress, and the Bank of England employs stress test results as key inputs in setting the capital buffer (Prudential Regulatory Authority (PRA) buffer) for each financial institution and in setting macroprudential countercyclical capital buffer (CCyB) rates (Bank of England 2015, 2016). Moreover, in Europe, the European Banking Authority introduced the Pillar 2 capital guidance (P2G), which is mainly based on the results of the simultaneous stress tests, and utilizes the tests in its supervision based on Pillar 2 (European Banking Authority 2018).

[33] For example, for the estimation of the credit cost model for overseas lending, we are currently examining whether (1) to divide loans outstanding to "normal" borrowers, which have hitherto been grouped together, into several groups based on their creditworthiness, and (2) to newly add foreign firms' interest coverage ratios (ICRs, aggregated by region) as explanatory variables of default rates similar to the way ICRs are used in the domestic credit cost models. Such revisions should enable us to capture in greater detail the impact that the increase in lending to borrowers that are relatively risky (such as borrowers of leveraged loans) but classified as "normal borrowers" would have on credit costs in times of stress.

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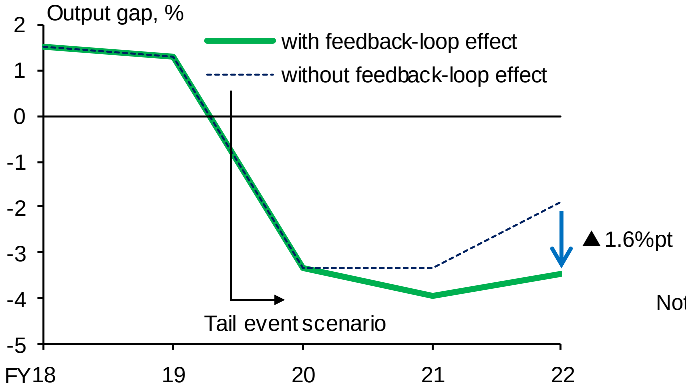
Appendix 1. Quantification of the Negative Feedback-Loop Effect from the Financial Sector to the Real Economy

Using the FMM, this Appendix quantitatively examines to what extent a reduction in lending by financial institutions facing a decline in profits and capital adequacy ratios in times of stress exerts downward pressure on the real economy and, moreover, the extent to which this downturn in the real economy additionally affects the financial soundness of those financial institutions.

First, estimating the negative feedback-loop effect from the financial sector to the real economy based on the FMM shows that the output gap at the end of the stress period is about 1.5 percentage points lower, suggesting that the impact is quite substantial (see Chart A1-1). Specifically, we quantified the negative feedback-loop effect on the real economy by conducting a simulation for the case in which financial institutions' lending does not change from the baseline scenario (depicted by the line labelled "without feedback-loop effect" in Chart A1-1) and comparing the output gap with that obtained in the tail event scenario in the October 2019 issue of the FSR (depicted by the line labelled "with feedback-loop effect" in the chart).[34] The ECB also conducts a similar exercise using a recently developed stress test model (BEAST, see footnote 4) and finds that in a severe stress scenario in which euro area GDP over the course of 3 years contracts by 7.8 percent relative to the baseline due to turmoil in global financial markets the resulting decline in lending by financial institutions leads to an additional cumulative drop in GDP of 1.6 percentage points over 3 years (Budnik et al. 2019).

Chart A1-1: Feedback-loop effect on the real economy in the event of stress



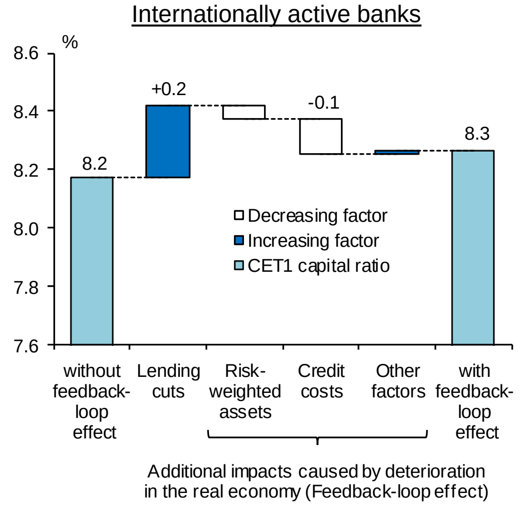
Note: Calculated using the results of macro stress testing in the October 2019 FSR. (i.e., the results of "with feedback-loop effect" are identical to the results under the tail event scenario in the FSR.)

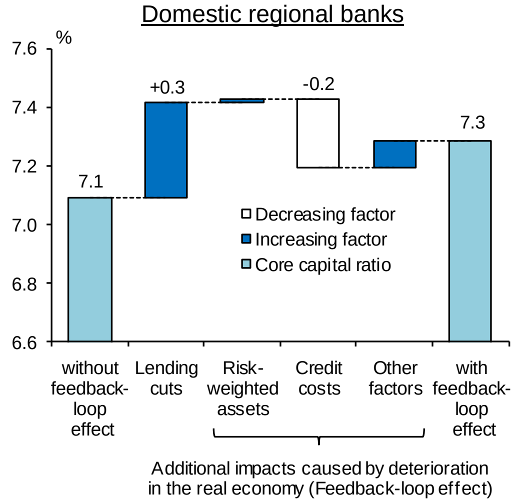
Next, Chart A1-2 shows the additional impact that the downturn in the real economy exerts on the capital adequacy ratios of financial institutions through the negative feedback loop. Looking at the change in financial institutions' capital adequacy ratios after the initial drop due to the occurrence of stress shows that while the decrease in risk-weighted assets due to the reduction in lending pushes capital adequacy ratios up (depicted by the bar labelled "Lending cuts" in the chart), the downturn in the real economy exerts downward pressure on capital adequacy ratios mainly through the second-round increase in credit costs and the increase in risk weights on credit, so that the two factors ultimately cancel each other out and the additional impact on capital adequacy ratios is

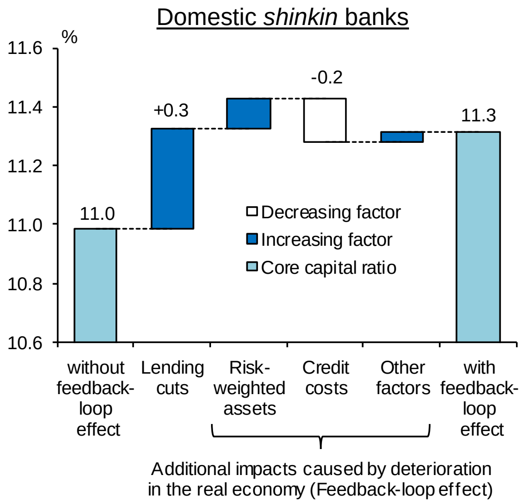
[34] The fact that in Chart A1-1 the (endogenous) feedback-loop effect arises from FY 2021, i.e., the year after the stress event, is due to the technical reason that the output gap during the year from the stress event is treated as an exogenous variable in order to control for the severity of the tail event scenario (for details of the design of the tail event scenario see Appendix 2).

negligible.

Chart A1-2: Feedback-loop effect on capital adequacy ratios in the event of stress



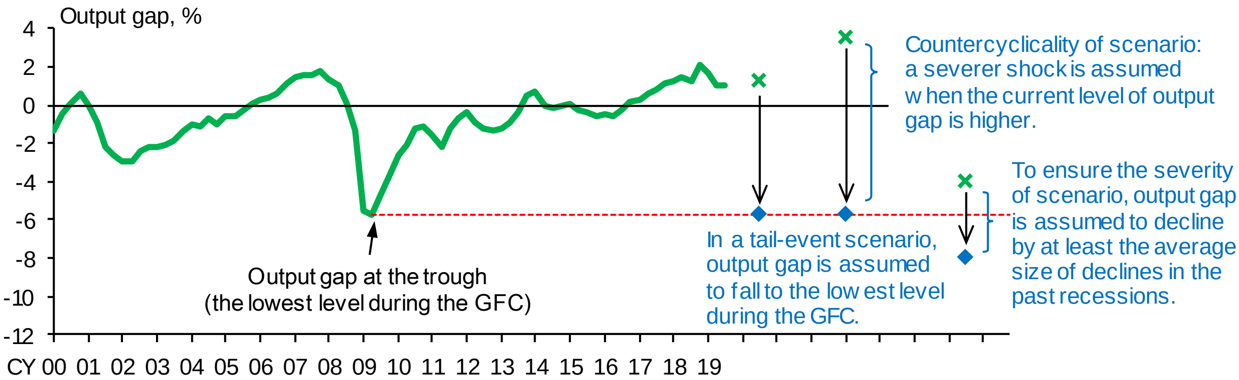




Appendix 2. Setting of the Tail Event Scenario (Scenario Design)

In order for macro stress testing to be effective, the tail event scenario must be (1) sufficiently severe (but also plausible), (2) countercyclical (that is, the larger the financial imbalances that have built up, the more severe the stress), and (3) forward-looking (i.e., it focuses not on past stress events but on possible future stress events) (see, e.g., Liang 2018). The tail event scenario in the macro stress testing in the FSR discussed in this paper meets these conditions in that it is based on (1) the assumption of a severe stress event similar to the global financial crisis, and (2) the assumption that, in the event of stress, the output gap will deteriorate to the same level as during the global financial crisis, so that the higher the current level of the output gap, the more severe the stress will be (in terms of the size of the change) (Chart A2). The design of the scenarios in stress tests in the United States and European countries also takes these conditions into account, so that scenarios are prepared assuming stress events based on current risk perceptions and using the most severe recessions in the past as a benchmark.[35]

Chart A2: Concept of scenario design (severity of a tail-event scenario)



Meanwhile, particular risks that are not sufficiently covered in the regular macro stress testing can be examined by flexibly designing scenarios that reflect the economic and financial environment and financial institutions' risk characteristics at the time. In fact, in past issues of the FSR, we designed a scenario assuming a rise in interest rates (such as in the April 2015 issue) as well as stress scenarios focusing on the Asian economy and the real estate market ("tailored event scenarios" in the October 2015 and April 2017 issues) and published stress testing results based on these scenarios.

[35] For example, in Europe, the European Banking Authority (EBA) and ECB prepare forward-looking narratives based on perceived risks highlighted by the European Systemic Risk Board (ESRB) and design scenarios consistent with these narratives using macroeconomic models (ESRB 2020). In the United States, the Federal Reserve designs stress scenarios such that the unemployment rate rises to at least 10 percent (the average of the worst three recessions in the post-war period) (Board of Governors of the Federal Reserve System 2019c). Meanwhile, in its stress tests in the Financial Sector Assessment Program (FSAP), the IMF measures the severity of the economic downturn in a tail event conditional on the current financial environment by employing the "growth at risk" approach and designs scenarios in which economic and financial variables are calibrated so that they become consistent with the estimated severity (Adrian et al. 2020).

Appendix 3. Overview of the Interest Rate Model and Recent Revisions

The interest rate model is a satellite model of the FMM to calculate the interest on bonds and unrealized gains/losses on bondholdings, which in the FMM itself are treated as exogenous variables. In order to simulate financial institutions' future interest income and unrealized gains/losses on bondholdings, information on the future market interest rate and on the yield at the time of acquisition of each bond is required.[36] We set the future market interest rate for every bond by remaining maturity based on current yield curve information (see Section II.B). On the other hand, we set the yield at the time of acquisition by classifying bondholdings by remaining maturity and by original maturity (1 year, 10 years, etc.). Strictly speaking, we should obtain information on yields separately for each point in time that bonds were acquired; however, since data disaggregated to this extent are not available, the interest rate model for the FMM uses the market interest rate (coupon rate) at the time a bond was issued instead. This is equivalent to assuming that financial institutions acquired all bonds at the time they were issued and have kept holding them (in practice, financial institutions often acquire bonds in the secondary market). Moreover, to conduct such calculations, we use data available from financial institutions and, based on certain assumptions, estimate the composition of bondholdings by remaining and original maturity.[37]

The interest rate model was revised in two ways in the October 2019 issue of the FSR to more accurately reflect recent bond market developments. The first revision aims to reflect changes in the composition of the outstanding amount of bonds issued by original maturity in the market and financial institutions' outstanding amount of bonds held by original maturity. Previously, we calculated the composition of bondholdings by original maturity by imposing the assumption that financial institutions hold the same amount of bonds of every remaining maturity for each bond with the same original maturity. However, in recent years, the increasing issuance of long-term bonds and the impact of the Bank of Japan's large-scale purchases of Japanese government bonds have led to noticeable discrepancies between the above simple assumptions and reality. Therefore, we introduced a new approach in which we calculate matrixes of the composition of outstanding bonds by remaining and original maturity by multiplying (1) financial institutions' composition of bondholdings by remaining maturity with (2) the share of bondholdings by original maturity for each remaining maturity, which is assumed to be equivalent to the share calculated using data on outstanding bond issuances in the market overall (excluding the holdings of the Bank of Japan).

Second, we changed the assumptions about how the proceeds from bonds that have matured are reinvested in the simulation period. Previously, it was assumed that proceeds from bonds that have matured during the simulation period would be reinvested in bonds with the same term, which resulted in a constant term composition across periods. Following the revision, we assume that financial institutions reinvest the proceeds in line with the investment shares in the most recent quarter, so that financial institutions' current investment stance is now reflected in the term composition of their bondholdings going forward.

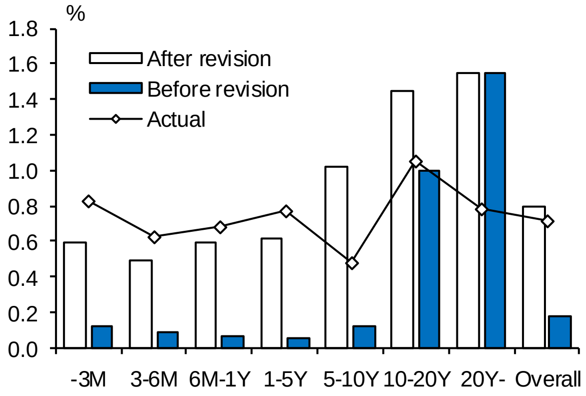
Looking at yields by remaining maturity calculated after the revision shows that they are closer to

[36] Unrealized gains/losses on bonds can be calculated by comparing the book value (at amortized cost) calculated from the yield at the time of acquisition of the bonds and the market value calculated from the current market interest rate.

[37] Interest income on bonds is calculated using the outstanding amount of bonds held by remaining and original maturity and the estimated yield at the time of acquisition. Dividend income from stocks, investment trusts, etc., is calculated based by imposing certain assumptions regarding the real dividend yield on a market value basis (in the baseline scenario, it is assumed to remain unchanged from current values, while in the tail event scenario, it is assumed to fall to a similar extent as during the global financial crisis).

the actual values than the previous estimates (Chart A3).

Chart A3: Interest rate on bank-held bonds by remaining maturity (regional banks)



Note: As at the end-March 2018.
Source: BOJ.

Supplement: FMM System of Equations

This supplement provides every specification of the simultaneous equations in the FMM.

Definition of subscripts

c: Overseas countries and regions

i: Individual banks (financial institutions)

j: Types of banks (1: major banks, 2: regional banks, 3: *shinkin* banks)

k: Types of banks (1: internationally active banks, 2: domestic banks)

l: Borrower characteristics (see equation (60)-(62))

m, n: Borrower classification (1: Normal, 2: Need attention, 3: Special attention, 4: In danger of bankruptcy, 5: Bankrupt or de facto bankruptcy)

A. Profit and loss accounts of individual financial institutions

A.1. Net income

$$\text{Net income (after tax)}_i = \text{Net income (before tax)}_i \cdot \left(1 - \text{Effective tax rate}_j\right) \quad (1)$$

$$\begin{aligned}\text{Net income (before tax)}_i &\\ &= \text{Operating profits from core business}_i - \text{Credit costs}_i \\ &+ \text{Realized gains/losses on securities holdings}_i + \text{Others}_i\end{aligned} \quad (2)$$

where operating profits from core business indicates pre-provision net revenue (PPNR) excluding trading income (see equation (3)).

A.2. Operating profits from core business (PPNR excluding trading income)

$$\begin{aligned}\text{Operating profits from core business}_i &\\ &= \text{Net interest income}_i + \text{Net non-interest income}_i \\ &- \text{General and administrative expense}_i\end{aligned} \quad (3)$$

A.3. Net interest income

$$\begin{aligned}\text{Net interest income}_i &\\ &= \text{Loan outstanding}_i \cdot \text{Lending rate}_i - \text{Funding amount}_i \cdot \text{Funding rate}_i \\ &+ \text{Interest and dividends on securities}_i + \text{Other interest income}_i\end{aligned} \quad (4)$$

Lending rate (loan interest rate)

$$\begin{aligned}\text{Domestic lending rate}_i &\\ &= \alpha_1 \cdot \text{Domestic funding rate}_i + \alpha_2 \cdot \text{Term spread [5-year} - \text{3-month]} \\ &+ \alpha_3 \cdot \text{Loan demand Index}_i + \alpha_4 \cdot \text{Non-performing loan ratio}_i \\ &+ \text{Fixed effect}_i + \text{constant}\end{aligned} \quad (5)$$

where the loan demand index is defined as a ratio of the number of borrowing firms to the number of effective bank branches (which takes into account the effects of "branch-in-branch" consolidation) in the prefecture where a bank i is located.

Estimation period: from 1999/Q1

$$\begin{aligned}&\text{Foreign lending rate}_i \\ &\quad = \alpha_1 \cdot \text{Foreign funding rate}_i + \alpha_2 \cdot \text{US corporate credit spread} \\ &\quad + \alpha_3 \cdot \text{Overseas economic growth} + \text{Fixed effect}_i + \text{constant}\end{aligned} \tag{6}$$

Estimation period: from 1999/Q1

Funding rate

$$\begin{aligned}\text{Domestic funding rate}_i &= \alpha_1 \cdot \text{Short-term interest rate [3-month T-Bills]} \\ &+ \alpha_2 \cdot (\text{Capital adequacy ratio}_i - \text{Mimimum requirement}_i) \\ &+ \text{Fixed effect}_i + \text{constant}\end{aligned} \tag{7}$$

Estimation period: from 1990/Q2

$$\begin{aligned}\text{Foreign funding rate}_i &= \alpha_1 \cdot \text{US dollar LIBOR [US 3-month T-Bills} + \text{TED spread]} \\ &+ \alpha_2 \cdot (\text{Capital adequacy ratio}_i - \text{Mimimum requirement}_i) \\ &+ \alpha_3 \cdot \text{US dollar funding premium} \\ &+ \text{Fixed effect}_i + \text{constant}\end{aligned} \tag{8}$$

Estimation period: from 1999/Q1

Interest and dividends on securities and other interest income

$$\begin{aligned}&\text{Interest and dividends on securities}_i \\ &\quad = \text{Interest on bonds}_i + \text{Interest and dividends on non-bond securities}_i\end{aligned} \tag{9}$$

$$\text{Interest on bonds}_i = \text{Interest rate on bonds}_i \cdot \text{Amount of bondholdings}_i \tag{10}$$

$$\begin{aligned}&\text{Interest and dividends on non-bond securities}_i \\ &\quad = \text{Return on non-bond securities}_i \cdot \text{Amount of non-bond securities holdings}_i\end{aligned} \tag{11}$$

$$\text{Other interest income}_i = \text{Return on other assets}_i \cdot \text{Amount of other assets}_i. \tag{12}$$

$$\text{Return on other assets [q/q chg.]}_i = \text{Funding rate [q/q chg.]}_i \tag{13}$$

A.4. Net non-interest income

$$\begin{aligned}&\text{Net non-interest income}_i \\ &\quad = \text{Net fees and commissions}_i + \text{Other net non-interest income}_i\end{aligned} \tag{14}$$

$$\begin{aligned}&\text{Net fees and commissions (for major banks)}_i \\ &\quad = \alpha_1 \cdot \text{Output gap} + \alpha_2 \cdot \text{Stock prices [y/y \% chg.]} \\ &\quad + \alpha_3 \cdot \text{Exchange rates [USD/JPY]} + \alpha_4 \cdot \text{Deregulation trend} \\ &\quad + \text{Fixed effect}_i + \text{constant}\end{aligned} \tag{15}$$

Estimation period: from 1993/Q2

A.5. Credit costs

$$\text{Credit costs}_i = \text{Credit costs (domestic business sector)}_i + \text{Credit costs (international business sector)}_i + \text{Other credit costs}_i \quad (16)$$

Domestic business sector

$$\begin{aligned}\text{Credit costs (domestic business sector)}_i &= \text{Net loan-loss provisions}_i + \text{Write-offs}_i \\ &= \Delta \sum_{n=1}^{5} [\text{Loan amount (to borrowers in } n)_i \cdot \text{Provision rate (of } n)_i \\ &\qquad \cdot \text{Uncovered ratio (only of } n{=}4,5)_i]\end{aligned} \quad (17)$$

$$\begin{aligned}\text{Loan amount (to borrowers in } n)_i &= \sum_{m=1}^{4} [\text{Loan amount (to borrowers in } m, \text{previous period})_i \\ &\qquad \cdot \text{Probability of transition}_i^{m\to n}] \cdot \text{Domestic loan growth}_i\end{aligned} \quad (18)$$

Probability of transition from borrower classification m to n for bank i ($PT_i^{m\to n}$) :

$$Ln\left(\frac{PT_i^{m\to n}}{1 - PT_i^{m\to n}}\right) = \alpha_1^{m\to n} \cdot \text{GDP growth} + \alpha_2^{m\to n} \cdot \text{ICR}_j + \alpha_3^{m\to n} \cdot \text{Quick ratio} + \text{Fixed effect}_i + \text{constant} \quad (19)$$

where ICR differs among types of bank (see equation (59)) and parameters in times of stress are separately estimated by using quantile regression method.

Estimation period: from 2005/Q2

International business sector

$$\begin{aligned}\text{Credit costs (international business sector)}_i &= \sum_{c=1}^{4} \left(\text{Net loan-loss provisions}_{c,i} + \text{Write-offs}_{c,i}\right) \\ &= \sum_{c=1}^{4} \Big[\Delta \sum_{n=1}^{5} [\text{Loan amount (to borrowers in } n)_{c,i} \\ &\qquad \cdot \text{Provision rate (of } n)_{c,i} \cdot \text{Uncovered ratio (only of } n{=}4,5)_{c,i}]\Big]\end{aligned} \quad (20)$$

$$\begin{aligned}\text{Loan amount (to borrowers in } n)_{c,i} &= \sum_{m=1}^{4} [\text{Loan amount (to borrowers in } m, \text{previous period})_{c,i} \\ &\qquad \cdot \text{Probability of transition}_{c,i}^{m\to n}] \cdot \text{Overseas loan growth}_{c,i}\end{aligned} \quad (21)$$

Credit costs and credit cost ratios of the international business sector are estimated using the equations above for the internationally active banks for which relevant data are available. Using the average of their credit cost ratios, credit costs for the other internationally active banks are estimated by multiplying this average by their overseas loans outstanding.

A.6. Realized gains/losses on securities holdings

$$\begin{aligned}&\text{Realized gains/losses on securities holdings}_i \\ &= \text{Realized gains/losses on stockholdings}_i + \text{Realized gains/losses on bondholdings}_i \\ &= min[\text{Average realized gains on securities holdings in past 3 years}_i, \\ &\qquad \text{Unrealized gains on bondholdings}_i + \text{Realized gains/losses on stockholdings}_i]\end{aligned} \tag{22}$$

When room for realizing gains on stockholdings exists (positive unrealized gains): (23)

$$\begin{aligned}&\text{Realized gains on stockholdings}_i \\ &= min[\text{Average realized gains on stockholdings in past 3 years}_i, \\ &\qquad\qquad \text{Unrealized gains on stockholdings}_i]\end{aligned}$$

When room for realizing gains on stockholdings doesn't exist (negative unrealized gains):

$$\text{Realized losses on stockholdings}_i = -\text{Losses on write-down of stockholdings}_i$$

$$\begin{aligned}&\text{Losses on write-down of stockholdings}_i \\ &\qquad = \text{Write-down ratio}_i \cdot \text{Amount of stockholdings}_i\end{aligned} \tag{24}$$

$$\text{Write-down ratio}_i = \frac{\alpha_1}{\text{Market-to-book ratio (before write-down)}_i + \alpha_2} \tag{25}$$

where the market-to-book ratio in each quarter is estimated using the market-to-book ratio at the beginning of the fiscal year and the percent changes in stock prices during the period, and parameters are estimated by using non-linear OLS regression.

Estimation period: from 2006/Q2

B. Balance sheet accounts of individual financial institutions

B.1. Total assets

$$\begin{aligned}\text{Total assets}_i &= \text{Total liabilities}_i + \text{Net assets}_i \\ &= \text{Loan outstanding}_i + \text{Amount of securities holdings}_i + \text{Amount of other assets}_i\end{aligned} \tag{26}$$

B.2. Loan outstanding

$$\begin{aligned}&\text{Loan outstanding}_i \\ &\quad = \text{Corporate loan outstanding}_i + \text{Household loan outstanding}_i \\ &\quad + \text{Government loan outstanding}_i + \text{Overseas loan outstanding}_i\end{aligned} \tag{27}$$

$$\begin{aligned}&\text{Corporate loan growth [y/y]}_i \\ &= \alpha_1 \cdot \text{Output gap} + \alpha_2 \cdot \text{Expected economic growth [over the next 3 years]} \\ &+ \alpha_3 \cdot \text{Domestic lending rate [y/y chg.]}_i \\ &+ \alpha_4 \cdot \text{Poplation growth} + \alpha_5 \cdot \text{Land prices [y/y \% chg.]} \\ &+ \alpha_6 \cdot (\text{Capital adequacy ratio}_i - \text{Minimum requirement}_i) \cdot \left(1 + \gamma_1 \cdot \mathrm{D}_{\mathrm{CAR}_i < \mathrm{threshold}_i}\right) \\ &+ \alpha_7 \cdot \text{Net income ROA}_i \cdot \left(1 + \gamma_2 \cdot \mathrm{D}_{\text{Net income ROA}_i < 0}\right) + \text{Fixed effect}_i + \text{constant}\end{aligned} \tag{28}$$

Estimation period: from 1990/Q2

$$\begin{aligned}&\text{Household loan growth [y/y]}_i \\ &= \alpha_1 \cdot \text{Output gap} + \alpha_2 \cdot \text{Expected economic growth [over the next 3 years]} \\ &+ \alpha_3 \cdot \text{Domestic lending rate [y/y chg.]}_i \\ &+ \alpha_4 \cdot \text{Poplation growth} + \alpha_5 \cdot \text{Land prices [y/y \% chg.]} \\ &+ \alpha_6 \cdot (\text{Capital adequacy ratio}_i - \text{Minimum requirement}_i) \cdot \left(1 + \gamma_1 \cdot \mathrm{D}_{\mathrm{CAR}_i < \mathrm{threshold}_i}\right) \\ &+ \alpha_7 \cdot \text{Net income ROA}_i \cdot \left(1 + \gamma_2 \cdot \mathrm{D}_{\text{Net income ROA}_i < 0}\right) + \text{Fixed effect}_i + \text{constant}\end{aligned} \tag{29}$$

Estimation period: from 1991/Q1

$$\begin{aligned}&\text{Overseas loan growth [y/y]}_i \\ &= \alpha_1 \cdot \text{Exchange rates [USD/JPY, y/y \% chg.]} + \alpha_2 \cdot \text{Overseas GDP gap} \\ &+ \alpha_3 \cdot (\text{Capital adequacy ratio}_i - \text{Minimum requirement}_i) \\ &+ \alpha_4 \cdot \text{Japanese banks' share of foreign claims} + \text{Fixed effect}_i + \text{constant}\end{aligned} \tag{30}$$

Estimation period: from 1989/Q1

B.3. Total liabilities

$$\text{Total liabilities}_i = \text{Funding amount}_i + \text{Amount of other liabilities}_i \tag{31}$$

Funding amount

$$\text{Funding amount}_i = \text{Domestic funding amount}_i + \text{Overseas funding amount}_i \tag{32}$$

$$\text{Domestic funding amount [y/y chg.]}_i = \text{Domestic loan outstanding [y/y chg.]}_i \tag{33}$$

$$\text{Overseas funding amount [y/y chg.]}_i = \text{Overseas loan outstanding [y/y chg.]}_i \tag{34}$$

C. Capital adequacy ratios of individual financial institutions

C.1. CET1 capital (Common Equity Tier 1 capital) [for internationally active banks]

$$\text{CET1 capital}_i = \text{CET1 components}_i - \text{CET1 regulatory adjustments}_i \tag{35}$$

$$\begin{aligned}\text{CET1 components}_i = {} & \text{Common share and retained earnings}_i \\ & + \text{Accumulated other comprehensive income}_i\end{aligned} \tag{36}$$

$$\begin{aligned}\text{CET1 regulatory adjustments}_i = {} & \text{Items for all deductions}_i \\ & + \text{Certain items for limited recognition (10\%/15\% thresholds)}_i\end{aligned} \tag{37}$$

where the examples of the deductions are goodwill and other intangible assets, deferred tax assets and deferred gains/losses on hedges. Deferred tax assets from temporary differences, one of the certain items that have thresholds for limited recognition are considered as in equation (43).

$$\begin{aligned}&\text{Common share and retained earnings [y/y chg.]}_i = \text{Net income (after tax)}_i \\ &- max[\text{Net income (after tax)}_i \cdot min[\gamma, \text{Average payout ratio in past 3 years}_i], 0]\end{aligned} \tag{38}$$

where γ is set to 0.3 in order to treat an extraordinary large payout ratio as an outlier.

$$\begin{aligned}&\text{Accumulated other comprehensive income}_i \\ &\quad = \text{Valuation difference on available-for-sale securities}_i \\ &\quad + \text{Foreign currency translation adjustment}_i + \text{Other components}_i\end{aligned} \tag{39}$$

$$\begin{aligned}&\text{Valuation difference on available-for-sale securities}_i \\ &\quad = \text{Valuation difference on available-for-sale stocks}_i \\ &\quad + \text{Valuation difference on available-for-sale bonds}_i\end{aligned} \tag{40}$$

$$\begin{aligned}&\text{Valuation difference on available-for-sale stocks [q/q chg.]}_i \\ &\quad = (\text{Changes in the fair value of stocks [q/q]}_i \\ &\quad + \text{Realized gains/losses on stockholdings}_i) \cdot (1 - \text{Effective tax rate}_j)\end{aligned} \tag{41}$$

$$\begin{aligned}&\text{Valuation difference on available-for-sale bonds [q/q chg.]}_i \\ &\quad = (\text{Changes in the fair value of bonds [q/q]}_i \\ &\quad + \text{Realized gains/losses on bondholdings}_i) \cdot (1 - \text{Effective tax rate}_j)\end{aligned} \tag{42}$$

$$\begin{aligned}&\text{Deferred tax assets from temporary differences}_i \\ &\quad = -\text{Valuation difference on available-for-sale securities}_i \cdot \frac{\text{Effective tax rate}_j}{1 - \text{Effective tax rate}_j} \\ &\quad + \text{Other deferred tax assets from temporary differences}_i\end{aligned} \tag{43}$$

C.2. Core capital [for domestic banks]

$$\text{Core capital}_i = \text{Core capital components}_i - \text{Core capital regulatory adjustments}_i \quad (44)$$

$$\begin{aligned}\text{Core capital components}_i = &\ \text{Common share and retained earnings}_i \\ &+ \text{Part of accumulated other comprehensive income}_i \\ &+ \text{Transitional adjustments for core capital}_i\end{aligned} \quad (45)$$

where the common share and retained earnings are modeled using the same equation as the internationally active banks (see equation (38)) and the part of accumulated other comprehensive income does not include valuation difference on available-for-sale securities.

C.3. Risk-weighted assets

$$\begin{aligned}&\text{Risk-weighted assets}_i \\ &\quad = \text{Credit risk assets}_i + \text{Market risk assets}_i + \text{Operational risk assets}_i\end{aligned} \quad (46)$$

For banks adopting standardized approach (SA) to credit risk:

$$\begin{aligned}&\text{Credit risk assets}_i \\ &\quad = 1 \cdot \text{Equities}_i + \alpha_2 \cdot \text{Corporate exposures}_i + \alpha_3 \cdot \text{Retail exposures}_i \\ &\quad + \text{Fixed effect}_i + \text{constant}\end{aligned} \quad (47)$$

For banks adopting internal rating based approach (IRB) to credit risk:

$$\begin{aligned}&\text{Credit risk assets}_i \\ &\quad = \beta_1^k \cdot \text{Equities}_i + \beta_2^k \cdot \text{Credit-risk-weight parameter}_i \cdot \text{Exposures to corporates}_i \\ &\quad + \beta_3 \cdot \text{Retail exposures}_i + \text{Fixed effect}_i + \text{constant}\end{aligned}$$

where β_1^k and β_2^k are assumed to be different between internationally active banks and domestic banks and the credit-risk-weight parameters are derived by the following risk-weight functions.

$$\begin{aligned}&\text{Credit-risk-weight parameter}_i \\ &\equiv \Phi\left(\sqrt{\frac{1}{1-\rho_i}} \times \Phi^{-1}(\mathrm{PD}_i) + \sqrt{\frac{\rho_i}{1-\rho_i}} \times \Phi^{-1}(0.999)\right) - \mathrm{PD}_i\end{aligned}$$

where Φ denotes the cumulative distribution function of the standard normal distribution, PD_i denotes probability of default for bank i, and ρ_i denotes correlation depending on bank i's probability of default.

Estimation period: from 1989/Q1

$$\begin{aligned}&\text{Operational risk assets}_i \\ &\quad = \alpha_1 \cdot \text{Gross operating profits from core business}_i + \text{Fixed effect}_i + \text{constant}\end{aligned} \quad (48)$$

where the gross operating profits from core business consist of net interest income and net non-interest income.

Estimation period: from 2007/Q1

C.4. Capital adequacy ratios (CET1 ratios and Core capital ratios)

$$\text{Capital adequacy ratios}_i = \frac{\text{CET1 capital}_i \ or \ \text{Core capital}_i}{\text{Risk-weighted assets}_i} \quad (49)$$

D. Macroeconomic variables

D.1. Gross Domestic Product

$$\text{Nominal GDP} = \text{Household Expenditure} + \text{Private Investment} + \text{Private Inventory} + \text{Government Expenditure} + \text{Exports} - \text{Imports} \quad (50)$$

$$\text{Real GDP} = \frac{\text{Nominal GDP}}{\text{GDP deflator}} \cdot 100 \quad (51)$$

$$\begin{aligned} &\text{Household Expenditure [y/y \% chg.]} \\ &\quad = \alpha_1 \cdot \text{Nominal employee compensation [y/y \% chg.]} \\ &\quad + \alpha_2 \cdot \text{Stock prices [y/y \% chg.]} \\ &\quad + \alpha_3 \cdot \text{Household loan growth [y/y]} \\ &\quad + \alpha_4 \cdot \text{Domestic lending rate [y/y chg.]} \end{aligned} \quad (52)$$

Estimation period: from 1984/Q3

$$\begin{aligned} &\text{Private Investment [y/y \% chg.]} \\ &\quad = \alpha_1 \cdot \text{Corporate profit ROA [y/y chg.]} \\ &\quad + \alpha_2 \cdot \text{Expected economic growth [over the next 3 years]} \\ &\quad + \alpha_3 \cdot \text{Corporate loan growth [y/y]} \\ &\quad + \alpha_4 \cdot \text{Domestic lending rate [y/y chg.]} \end{aligned} \quad (53)$$

Estimation period: from 1984/Q3

$$\begin{aligned} &\text{Exports [y/y \% chg.]} \\ &\quad = \alpha_1 \cdot \text{Overseas economic growth [y/y]} \\ &\quad + \alpha_2 \cdot \text{Real effective exchange rate [y/y \% chg.]} \\ &\quad + \alpha_3 \cdot \text{Exports [y/y \% chg., previous quarter]} \end{aligned} \quad (54)$$

Estimation period: from 1982/Q1

$$\begin{aligned} &\text{Imports [y/y \% chg.]} \\ &\quad = \alpha_1 \cdot \text{Import price index [y/y \% chg.]} \\ &\quad + \alpha_2 \cdot \text{Real effective exchange rate [y/y \% chg.]} \\ &\quad + \alpha_3 \cdot \text{Exports [y/y \% chg.]} + \alpha_4 \cdot \text{Imports [y/y \% chg., previous quarter]} \end{aligned} \quad (55)$$

Estimation period: from 1981/Q2

$$\begin{aligned} &\text{Expected economic growth [over the next 3 years]} \\ &\quad = \alpha_1 \cdot \text{Potential GDP growth} + \alpha_2 \cdot \text{GDP growth [y/y]} \end{aligned} \quad (56)$$

Estimation period: from 1983/Q4

$$\text{Nominal employee compensation [y/y \% chg.]} = \alpha_1 \cdot \text{GDP growth [y/y]} + \alpha_2 \cdot \text{Labor share [y/y chg.]} + \alpha_3 \cdot \text{Consumer price index [y/y \% chg.]} \tag{57}$$

Estimation period: from 1981/Q2

$$\text{Corporate profit ROA [y/y chg.]} = \alpha_1 \cdot \text{Output gap [y/y chg.]} + \alpha_2 \cdot \text{Domestic lending rate [y/y chg.]} + \alpha_3 \cdot \text{Labor share [y/y chg.]} \tag{58}$$

Estimation period: from 1984/Q1

D.2. Interest Coverage Ratio

$$\text{ICR}_j = \frac{\text{Operating profits}_j + \text{Interest and dividends received}_j}{\text{Interest payment}_j} = \frac{\text{Operating ROA}_j}{\text{Borrowing rate}_j \cdot \text{Leverage ratios}_j} \tag{59}$$

$$\text{Operating ROA}_j = \sum_{l=1}^{3} w_j^l \cdot \text{Operating ROA}^l \tag{60}$$

$$\text{Leverage ratios}_j = \sum_{l=1}^{3} w_j^l \cdot \text{Leverage ratios}^l \tag{61}$$

$$\text{Borrowing rate}_j = \sum_{l=1}^{3} w_j^l \cdot \text{Borrowing rate}^l \tag{62}$$

where l denotes borrower characteristics (1: not small firms, 2: small but not low-return borrowers, 3: low-return borrowers) and w^l denotes share of loan to certain borrowers ($w_j^1 = 1 - \text{Loan share of small firms}_j$, $w_j^2 = \text{Loan share of small firms}_j \cdot \left(1 - \text{Loan share of low-return borrowers}_j\right)$, $w_j^3 = 1 - w_j^1 - w_j^2$).

$$\text{Operating ROA}^l = \alpha_1^l \cdot \text{Output gap} + \alpha_2^l \cdot \text{Import price index} + \alpha_3^l \cdot \text{Exchange rates [USD/JPY]} + \text{constant}^l \tag{63}$$

Estimation period: from 1999/Q2

$$\text{Leverage ratios [y/y chg.]}^l = \alpha_1^l \cdot \text{Output gap [y/y chg.]} + \text{constant}^l \tag{64}$$

Estimation period: from 2001/Q2

$$\text{Borrowing rate [q/q chg.]}^l = \text{Domestic lending rate [q/q chg.]} \tag{65}$$

$$\text{Quick ratio} = \alpha_1 \cdot \text{Output gap} + \alpha_2 \cdot \text{Corporate profit ROA} + \text{constant} \tag{66}$$

Estimation period: from 1985/Q1

D.3. Other macroeconomic variables

$$\begin{aligned}&\text{Import price index [q/q \% chg.]}\\ &\qquad = \alpha_1 \cdot \text{Exchange rates [USD/JPY, q/q \% chg.]} + \text{constant}\end{aligned} \tag{67}$$

Estimation period: from 1990/Q2

$$\begin{aligned}\text{Land prices [y/y \% chg.]} &= \alpha_1 \cdot \text{Domestic loan growth [y/y]}\\ &\quad + \alpha_2 \cdot \text{Consumer price index [y/y \% chg.]} + \text{constant}\end{aligned} \tag{68}$$

Estimation period: from 1985/Q3

$$\begin{aligned}&\text{US lending rate} - \text{US government bond yield [1-year]}\\ &\qquad = \alpha_1 \cdot \text{US economic growth [y/y]} + \text{constant}\end{aligned} \tag{69}$$

Estimation period: from 1999/Q1

$$\begin{aligned}&\text{EU lending rate} - \text{Germany government bond yield [1-year]}\\ &\qquad = \alpha_1 \cdot \text{EU economic growth [y/y]} + \text{constant}\end{aligned} \tag{70}$$

Estimation period: from 2003/Q1