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The Financial Macro-econometric Model (FMM, 2022 Version)

Financial System and Bank Examination Department, Bank of Japan
ABE Nobuhiro
CHIKAMATSU Kyosuke
KANAI Kenji
KAWASUMI Yusuke
MUNAKATA Ko
NAKAYAMA Koki
OKUDA Tatsushi
TAKANO Yutaro

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Financial System and Bank Examination Department, Bank of Japan
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Financial System and Bank Examination Department, Bank of Japan
ABE Nobuhiro[1] CHIKAMATSU Kyosuke[2] KANAI Kenji[3] KAWASUMI Yusuke[4]
MUNAKATA Ko[5] NAKAYAMA Koki[6] OKUDA Tatsushi[7] TAKANO Yutaro[8]

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Abstract

The Financial Macro-econometric Model (FMM) is the model that the Bank of Japan (BOJ) employs in its macro stress testing to examine the risk resilience of Japan's financial system in a comprehensive and quantitative manner. The BOJ semiannually publishes the results of its analyses based on this model in the *Financial System Report*. The FMM is also used in the simultaneous stress testing based on common scenarios conducted periodically with the Financial Services Agency of Japan. Key characteristics of the FMM are that it (1) explicitly captures feedback loops between the domestic banking sector and the real economy, and (2) makes it possible to calculate the variables of interest (e.g. amount of loans and capital adequacy ratios of Japanese banks), not only at the sector level but also at the individual bank level. Since its development in 2011, the FMM has been continuously improved to reflect new developments in economic and financial conditions and to better incorporate the transmission mechanisms of financial shocks into the macro stress testing. This paper provides an outline of the basic macro stress testing framework and the FMM, and then describes the structure of the model as of September 2022 in detail.

[1] E-mail: nobuhiro.abe@boj.or.jp
[2] Currently at Research and Statistics Department; E-mail: kyousuke.chikamatsu@boj.or.jp
[3] Currently at Personnel and Corporate Affairs Department; E-mail: kenji.kanai@boj.or.jp
[4] E-mail: yuusuke.kawasumi@boj.or.jp
[5] E-mail: kou.munakata@boj.or.jp
[6] E-mail: kouki.nakayama@boj.or.jp
[7] Currently at International Monetary Fund; E-mail: TOkuda@imf.org
[8] E-mail: yuutarou.takano@boj.or.jp
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Outline

1. Introduction

The Bank of Japan (BOJ) regularly conducts macro stress testing to examine the stability of Japan's financial system and releases the results of its analysis twice a year in the *Financial System Report* (FSR). Macro stress testing is one analytical approach used to quantitatively examine the risk resilience of the financial system and is conducted based on stress scenarios assuming "severe but plausible" macroeconomic shocks to examine how the financial system would be affected. Specifically, the stress testing assumes the materialization of tail risks regarding the economic and financial environment (tail events) that, while not very likely, would cause extremely large stress in the financial system if they did occur, and forecasts banks' losses, capital adequacy ratios, etc., through simulations. Based on the results of these simulations, the FSR identifies the nature of risks faced by Japanese banks and assesses the risk resilience of the financial system as a whole. The results are also used to deepen the BOJ's dialogue with relevant parties in the world of finance at home and abroad.

Stress testing, which examines the resilience of financial institutions and the financial system overall based on a scenario assuming the materialization of the tail risks, has developed since the 1990s. Originally it was mainly used for risk management at individual financial institutions.[1] However, since the Federal Reserve Board (FRB) implemented the Supervisory Capital Assessment Program (SCAP) for 19 large U.S. financial institutions immediately after the global financial crisis in the late 2000s, stress testing has been widely used by national authorities and international organizations from the perspective of both microprudential and macroprudential policy.[2]

Stress testing is utilized by national authorities for many purposes. The FRB, the Bank of England (BOE), and the European Banking Authority (EBA)/European Central Bank (ECB) formulate stress scenarios and then conduct supervisory simultaneous stress tests of financial institutions in their jurisdiction based on a common stress scenario. They then use the results in supervisory policies for financial institutions, such as the approval

[1] Stress testing conducted by individual financial institutions aims to help financial institutions understand the risk characteristics of their own portfolios and is used by the board of directors and senior management to discuss those risks. As such, the stress testing conducted by financial institutions differs from that conducted by supervisors and central banks, which takes macroeconomic feedback effects into account. An overview of the risk management framework and tools used by financial institutions in the 1990s, such as the contents of stress tests, is provided by Fender, Gibson, and Mosser (2001) based on a survey by the Committee on the Global Financial System.

[2] Microprudential policy focuses on ensuring the soundness of individual financial institutions, while macroprudential policy focuses on ensuring the stability of the financial system by analyzing and assessing risks to the system and designing rules and policies based on these analyses and assessments. For more details on the BOJ's views on macroprudential policy, see, for example, Bank of Japan (2011).

process for financial institutions' capital planning.[3] Moreover, from a macroprudential perspective to monitor the financial system in the euro area, the ECB regularly conducts top-down stress testing.[4] The top-down stress testing incorporates feedback loops between the financial sector and the real economy, and the results of the tests are published in its Financial Stability Review (ECB 2021a). As mentioned above, the BOJ also regularly publishes the results of its top-down stress testing in the FSR. In addition, with the aim of establishing comprehensive evaluation targets regarding the financial soundness of banks and promoting the development of risk management arrangements through dialogue with banks, the BOJ, jointly with the Financial Services Agency (FSA), has been conducting "simultaneous stress testing based on common scenarios" focusing on major banks since 2020 (Bank of Japan and Financial Services Agency 2020).

Reflecting the expanding scope of the use of stress testing, authorities in major economies have been developing and improving models used for stress testing.[5] In 2011, the BOJ developed the Financial Macro-econometric Model (FMM), a macroeconomic model that explicitly models feedback loops between the banking sector and the real economy, including the effects of the real economy on banks' capital adequacy ratios and the effects of financial intermediation activities on the real economy (Ishikawa et al. 2012). Since then, various improvements have been made in accordance with changes in the economic and financial environment and advances in academic research on both the theoretical and the empirical front. For example, from the perspective of refining the measurement of the transmission effects of tail risk, in 2012, the model was refined so that it could take into account the heterogeneity in the risk characteristics of individual banks' loan portfolios using granular financial data for individual banks and firms. Further, the model was improved to capture nonlinearities in the link between banks' capital adequacy ratios, profits, and the amount of loans as well as the impact of higher foreign currency funding

[3] The FRB and the BOE use stress tests once a year and the EBA/ECB use them every other year for large financial institutions in their jurisdictions as part of the approval process for capital planning. For example, the FRB, through its Dodd-Frank Act Stress Tests and Comprehensive Capital Analysis and Reviews quantitatively examines financial institutions' capital adequacy and uses the results to determine the adequacy of their capital planning, including their dividends and stock buybacks. The BOE uses the results of its stress testing to set capital buffers for individual banks, to determine the appropriateness of dividends and stock buybacks, and to set countercyclical capital buffers to make provisions for macroprudential risks. The EBA/ECB use the stress test results to set supervisory capital buffer levels based on Pillar 2 and to determine the appropriateness of dividends and stock buybacks.

[4] Baudino et al. (2018) classify stress testing conducted by financial institutions as bottom-up stress testing and stress testing using models developed by authorities as top-down stress testing.

[5] For a list of top-down stress testing models developed by central banks, see Appendix 6. For an international comparison of stress testing models, see Dent et al. (2016), Baudino et al. (2018), and Anderson et al. (2018).

costs when banks' own creditworthiness (capital adequacy ratio) declines. In addition, while initially only net interest income and domestic credit costs were modeled in banking sector, in 2014, realized and valuation gains/losses on securities holdings, credit costs on foreign lending, net non-interest income, and risk-weighted assets were also modeled in order to capture the wide variety of transmission channels through which tail risks affect banks. These changes are published in the form of research papers, which form the basis for discussions with related parties in the world of finance and researchers at universities and research institutions.[6]

Against the background, this paper explains the structure of the FMM as of September 2022. While previous papers explaining the FMM and macro stress testing, such as Kitamura et al. (2014), have focused on feedback loops between the banking sector and the real economy as well as specific topics such as interest rate risk and credit risk, this paper provides a comprehensive and detailed explanation of the structure of the model of the domestic banking sector, given that stresses in the real economy and financial markets can have a wide range of effects on the banking sector. The paper is organized as follows. Section 2 provides an outline of the FMM and the macro stress testing framework, while Section 3 explains the structure of the model of the domestic banking sector in the FMM. Section 4 describes the behavior of the FMM assuming a tail event in the form of a financial crisis, taking the "financial stress scenario" used in the macro stress testing in the April 2022 issue FSR as an example. Section 5 discusses future issues. Meanwhile, the appendix materials at the end of the paper provide the modeling of GDP demand items in the domestic economy of the FMM (Appendix 1), the modeling of the domestic and foreign corporate sectors (Appendix 2), a list of scenario variables for the domestic and foreign financial markets (Appendix 3), the results of simulation under a scenario in which the stress is half the size of that in the "financial stress scenario" (Appendix 4), the framework for the analysis of the stress imposed on the real economy by the outbreak of the Covid-19 pandemic, a tail event that did not take the form of a financial crisis (Appendix 5), and an overview of stress testing models used by central banks in America and Europe (Appendix 6).

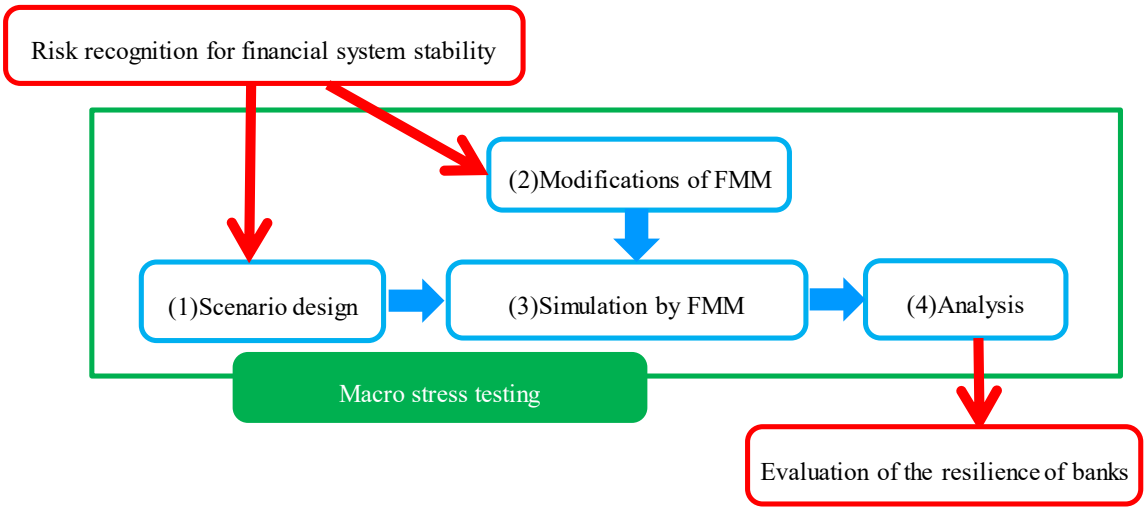
[6] For details on past improvements since the release of the first model in Ishikawa et al. (2012), see Kitamura et al. (2014) and Financial System Report - Annex, "The Financial Macro-econometric Model (FMM, March-2020 Version): Overview and Recent Developments" (published in August 2020). For analyses using the FMM, see Kamada and Kurachi (2012), Kawata et al. (2012), and Kawata et al. (2013).

2. Overview of Stress Testing

2.1. The macro stress testing framework

The BOJ's macro stress testing framework based on the FMM is as shown in Chart 1.

Chart 1. Macro stress testing framework



To start with, tail risk scenarios expressing the stress on the real economy and financial markets in the form of a deterioration in economic variables such as GDP and financial market variables such as stock prices are formulated (shown as (1) in the chart).[7] In order to accurately identify the nature of risks to the financial system through macro stress testing, the scenarios need to reflect the financial and economic conditions at the time and the BOJ's perception of risks.[8,9] Moreover, in certain scenarios, the BOJ may modify the

[7] Looking at examples of macro stress tests conducted in various countries, in addition to stress scenarios, a baseline scenario in line with the forecasts of financial market participants and economists is often developed. This is thought to facilitate the identification of the nature of risks to the financial system by analyzing the differences between the stress scenarios and the baseline scenario. Hence, the BOJ's macro stress tests also include a baseline scenario in addition to stress scenarios. See Basel Committee on Banking Supervision (2009), Dees, Henry, and Martin (2017), and Liang (2018) for international discussions on the setting of stress test scenarios.

[8] It should be noted that the stress scenarios in the BOJ's macro stress testing are designed to assess the stability of the financial system and the capital adequacy of individual banks under stress conditions; they are not the events that are assumed to be the most likely to occur. In other words, the stress scenarios are based on the conditions of the financial system, the risk profiles of individual banks, and other economic and financial conditions at the time, and are designed to effectively examine changes in economic and financial conditions that could pose a threat to the stability of Japan's financial system and the soundness of individual banks. Therefore, they are completely different in nature from economic forecasts that present scenarios with a high likelihood of coming to pass. They represent neither the BOJ's outlook for the future economic and financial environment, asset prices, policy conduct, nor the likelihood of the outcome.

[9] In the United States, the approach for constructing stress scenarios and the degree of stress in the

FMM in order to accurately capture scenario-specific risks (represented by (2) in the chart).[10] The economic and financial variables in the scenarios are then inserted into the FMM as input variables, and simulations are conducted for the future developments of the variables of individual banks such as their amount of loans and of macroeconomic variables such as GDP, taking into account the feedback effects ((3) in the chart).[11] Finally, the resilience of the financial system as a whole to tail risk events is assessed by examining the predicted profitability and capital adequacy ratios of all banks generated in the simulation ((4) in the chart).[12]

The primary interest in macro stress testing is the level of capital adequacy ratios during the simulation period, especially at the end of the simulation period. This level depends on three factors: the size and composition of banks' assets and liabilities and capital adequacy ratios at the end of the pre-simulation period, the severity of the stress in the scenario, and the structure of the FMM. The lower capital adequacy ratios at the end of the pre-simulation period are, the greater the severity of stress is, and the more sensitive

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FRB's Dodd-Frank Act Stress Tests are set out in the "Policy Statement on the Scenario Design Framework for Stress Testing" (12 CFR 252, Appendix A), and scenarios are formulated in line with this (Board of Governors of the Federal Reserve System 2019). In Europe, the European Systemic Risk Board (ESRB), which is in charge of macroprudential issues, sets scenarios for the EBA/ECB's EU-wide stress tests in collaboration with the EBA/ECB (European Systemic Risk Board 2020). Moreover, in the IMF's Financial Sector Assessment Program stress tests, the degree of economic deterioration in case of a tail event assuming current financial conditions is calculated separately using Growth at Risk analysis (Adrian, Boyarchenko, and Giannone 2019, Adrian et al. 2022), and the scenario is set by calibrating financial and economic variables to reflect this deterioration (Adrian et al. 2020).

[10] For example, in the macro stress testing in the October 2020 FSR, changes were made, among other things, to the credit cost model in order to incorporate the severe impact of the Covid-19 pandemic on economic activity in certain industries, such as face-to-face services, and the effect of policy measures to support corporate financing.

[11] In the scenario assuming a global financial crisis, in which there is a negative shock to foreign economies and financial markets that propagates to the domestic economy, the scenario for GDP uses endogenous values in the model. On the other hand, in scenarios where there is a direct negative shock to the domestic economy, such as the pandemic, exogenous values are used for the scenarios for GDP.

[12] In terms of assessment criterion for simulated capital adequacy ratios, the capital adequacy requirements of Basel III, which were introduced in 2010 (in particular, the minimum required Common Equity Tier 1 ratio of at least 4.5 percent) are used for internationally active banks. On the other hand, for banks that conduct business only in Japan and are not internationally active, the domestic capital adequacy requirements (of at least 4 percent) are used. In addition, among internationally active banks, the following levels of capital adequacy ratios are determined as loss absorbency requirements as of the writing of this paper; for global systemically important banks (G-SIBs), 8.5 percent for Mitsubishi UFJ Financial Group (consisting of a minimum CET1 ratio of 4.5 percent plus a capital conservation buffer of 2.5 percent and an additional buffer of 1.5 percent) and 8.0 percent for Mizuho Financial Group and Sumitomo Mitsui Financial Group (additional buffer: 1 percent); for domestic systemically important banks (D-SIBs), 7.5 percent for Sumitomo Mitsui Trust Holdings (additional buffer: 0.5 percent); and 7.0 percent for all others (no additional buffer).

the model is to stress, the lower capital adequacy ratios are during the simulation period. Meanwhile, it should be noted that while, in the FMM, banks' financial variables in the pre-simulation period are updated semiannually for banks excluding *shinkin* banks and annually for *shinkin* banks, during the simulation period, changes in financial variables are projected on a quarterly basis based on the quarterly scenario for economic and financial variables.

2.2. Overview of the FMM

As a stress testing model, the purpose of the FMM, as mentioned, is to quantitatively assess the risk resilience of Japan's financial system by simulating the amount of losses and capital adequacy ratios of Japanese banks in the event that tail risks to economic and financial conditions materialize.

The FMM is a macroeconomic model that broadly consists of two sectors: the banking sector and the real economy. For the banking sector, financial and other variables are modeled for each bank, yielding not only macroeconomic aggregate variables such as total loans, but also variables for individual banks. The model focuses on banks (major banks, regional banks, and *shinkin* banks) that hold current accounts at the BOJ.[13] As a result of modeling the detailed account items for each of these banks to calculate their capital adequacy ratios in line with regulations, the number of variables included in the model is approximately 140,000 (of which 70,000 are endogenous variables and 70,000 are exogenous variables). The quantitative relationships among the variables, including the behavioral equations for banks, such as the effect of changes in GDP on the amount of lending, are estimated using panel estimation and other approaches to take heterogeneity across banks to some extent into account. In terms of the nature of the model, it can be regarded as a macroeconomic model belonging to the family of semi-structural models, which impose some theoretical constraints on individual equations based on economic theory while selecting explanatory variables that fit the actual data well.[14] In principle, the explanatory variables in the model are those for which the

[13] Major banks comprise the following 10 banks: Mizuho Bank, MUFG 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 62 member banks of the Regional Banks Association of Japan (Regional banks I) and the 37 member banks of the Second Association of Regional Banks (Regional banks II). *Shinkin* banks are the 247 *shinkin* banks (as of the end of March 2022) that hold current accounts at the BOJ. Taken together, these banks account for about 80–90 percent of lending by private-sector financial institutions.

[14] On the other hand, models built strictly based on relationships derived from economic theory, such as dynamic stochastic general equilibrium models, are called structural models.

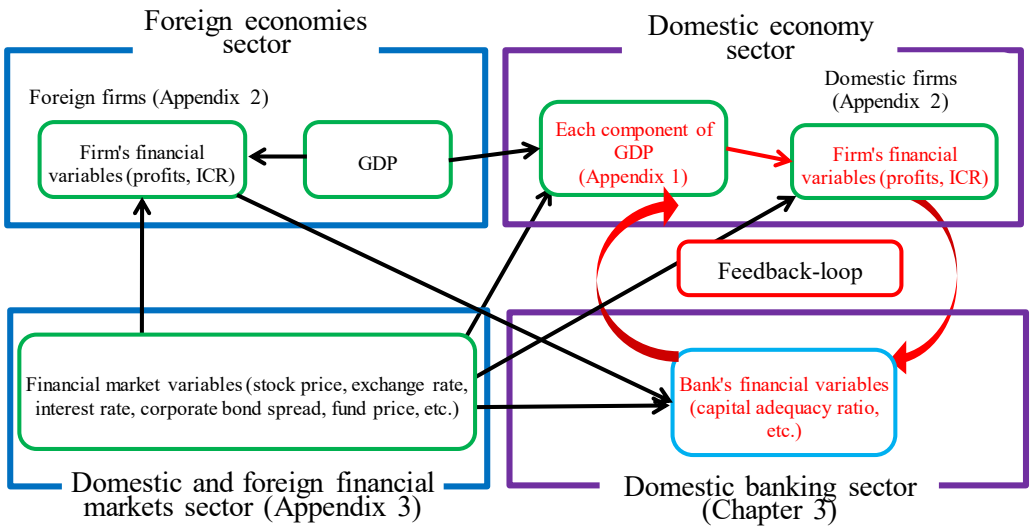
estimated coefficients have the expected sign suggested by economic theory and are statistically significantly different from zero.

Relatedly, the BOJ maintains another semi-structural model for macroeconomic forecasting, the Quarterly-Japanese Economic Model (Q-JEM).[15] In contrast to the Q-JEM, the FMM, which aims to calculate the capital adequacy ratios of individual banks as well as financial system as a whole, does not model real economic variables in detail, while balance sheet and income statement items of individual banks are modeled in detail, reflecting the purpose of the model.

To provide an overview of the structure of the FMM, it is useful to regard the model as consisting of four sectors: the financial sector, which is divided into (1) domestic and foreign financial markets sector and (2) the domestic banking sector,[16] and the real economy, which is divided into (3) foreign economies sector and (4) the domestic economy sector (Chart 2).

The following subsections provide an overview of each sector and its relationship to the other sectors, starting with foreign economies, followed by domestic and foreign financial markets, the domestic economy, and the domestic banking sector.

Chart 2. The four sectors constituting the FMM



[15] For an outline of Q-JEM, see Ichiue et al. (2009), Fukunaga et al. (2011), and Hirakata et al. (2019).

[16] The foreign banking sector (such as U.S. and European financial institutions) is not modeled.

Foreign economies sector

Variables for foreign economies include real GDP, industry-level GDP, and financial variables of the corporate sector (the growth rate of sales and the interest coverage ratio, ICR[17]) for the United States, Europe (the euro area), and Asia and Pacific.[18] Changes in the real GDP of the different regions affect Japan's domestic economy through changes in the demand for Japanese exports,[19] while changes in the financial variables of the corporate sector in these regions change the foreign credit costs of banks in the domestic banking sector in proportion to their exposure. Including these variables means that spillover effects from abroad are incorporated into the model.

Domestic and foreign financial markets sector

To reflect the impact of developments in domestic and foreign financial markets, the model includes about 50 financial market variables covering stock markets, foreign exchange markets, bond markets, credit markets, and investment fund and alternative investment markets (see Appendix 3 for details). These variables capture the impact of changes in the prices of securities held by domestic banks on banks' realized and valuation gains/losses on securities as well as the direct impact of changes in Japanese stock prices on domestic households' consumption behavior through the wealth effect. In addition, an increase in domestic and foreign (U.S. and European) interest rates, for example, leads to a deterioration in the ICR of the corporate sector in domestic and foreign economies and hence increases domestic banks' credit costs in line with their exposure.

Domestic economy sector

Variables for the domestic economy primarily consist of macroeconomic variables such as nominal and real GDP and GDP demand components. For the corporate sector, in addition to business fixed investment as a GDP demand component, a range of financial variables are modeled (see Appendix 1 for details on the modeling of GDP demand components). Conversely, the government sector, including the central bank, is not explicitly modeled, and interest rates and government spending are exogenous variables. Inflation is in principle also treated as exogenous. As discussed below, these macroeconomic variables have an impact on the financial variables of domestic banks, such as their lending and credit costs.

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[17] The ICR is defined as (Operating profits + Interest and dividends received) / Interest payments.

[18] Asia and Pacific consists of China, the NIES, the ASEAN countries, and Oceania.

[19] For details, see the specification of the nominal and real export functions in Appendix 1.

Domestic banking sector

As outlined in Section 3, the domestic banking sector is modeled in detail, consisting mainly of variables for banks' assets and liabilities, such as investment and funding, periodic profits and losses, risk-weighted assets, and capital adequacy ratios. The model also incorporates various channels that affect the capital adequacy ratios of individual banks. Specifically, changes in financial variables relating to the corporate sector in the domestic and foreign economies, changes in banks' lending and funding rates, and changes in yields on, and market values of, securities holdings all affect the capital adequacy ratios through changes in their investment holdings and funding, periodic profits and losses, valuation gains/losses on securities holdings, risk-weighted assets, etc.

Importantly, linkages between the domestic economy and the domestic banking sector are explicitly incorporated.[20] In other words, a downturn in the domestic economy pushes down the amount of lending from the demand side by reducing the demand for funds in the lending market, and a deterioration in the financial conditions of the corporate sector leads to a reduction in lending from the supply side by lowering banks' capital adequacy ratios through higher credit costs. The reduction in lending due to supply-side factors further depresses the domestic economy by hampering investment and consumption.

It should be noted that with regard to the domestic banking sector, a distinction is made between banks excluding *shinkin* banks and *shinkin* banks, and that banks are further divided into internationally active and domestic banks,[21] which are subject to different definitions and calculation methods with respect to their regulatory capital adequacy requirements, so that there are three types of banks in total. Similar to domestic banks,

[20] Although there were some studies highlighting the existence of linkages between the real economy and the financial sector (e.g., Bernanke, Gertler and Gilchrist 1996; Kiyotaki and Moore 1997), a widely accepted view among macroeconomists before the global financial crisis was that the financial sector was merely a mirror of the real economy. However, since the global financial crisis, the importance of frictions and shocks in the financial sector, including financial imbalances, for the real economy has been recognized, and there is a growing body of both theoretical and empirical research on the linkages. Recent studies confirming such linkages between the real economy and the financial sector include Lopez-Salido, Stein, and Zakrajsek (2017) for the United States and Amiti and Weinstein (2018) for Japan. For more details, including on the quantitative impact of such linkages in the FMM, see Appendix 1, "Quantification of the Negative Feedback-Loop Effect from the Financial Sector to the Real Economy," in Financial System Report - Annex, "The Financial Macro-econometric Model (FMM, March-2020 Version): Overview and Recent Developments" (published in August 2020).

[21] Specifically, 17 banks (Mizuho Bank, MUFG Bank, Sumitomo Mitsui Banking Corporation, Mitsubishi UFJ Trust and Banking Corporation, Mizuho Trust and Banking Company, Sumitomo Mitsui Trust Bank, Gunma Bank, Chiba Bank, Bank of Yokohama, Hachijuni Bank, Hokkoku Bank, Shizuoka Bank, Shiga Bank, Chugoku Bank, Yamaguchi Bank, Iyo Bank, and Bank of Nagoya) are internationally active banks, while all others are domestic banks.

shinkin banks are subject to domestic capital adequacy requirements.

2.3. Estimation method

The FMM is estimated on an equation-by-equation basis, and many of the estimations are conducted using linear regression. This is a common approach for the estimation of large macro models.[22] The data used in the estimation include official statistics such as SNA statistics, data provided by external vendors[23] such as granular data for the corporate sector, as well as the results of various surveys conducted by the BOJ and tabulations reported by individual banks. In principle, the estimates are based on data from as far back as possible in the past to as recent as possible, and the estimates are updated in time to the stress testing for the FSR. However, in cases where it is clear that the relationship between variables in the model deviates from the past due to temporary and special factors, separate measures are taken. For instance, for the estimation of the credit cost model, the end of the estimation period is set to fiscal 2019 because of the policy measures to support corporate financing in response to the Covid-19 pandemic from fiscal 2020.[24] Moreover, all data used in the FMM are in yen, and when taking the impact of exchange rates on items related to business in foreign currencies into account, the U.S. dollar/yen exchange rate sensitivity of items is estimated on a yen basis.

[22] For instance, in the FRB's macroeconomic forecasting model, the FRB/US model, most of the model is estimated using equation-by-equation estimation, since it would be "infeasible" to estimate a very large number of equations simultaneously (Brayton, Laubach, and Reifschneider 2014). The same applies to the BOJ's macroeconomic forecasting model, the Q-JEM.

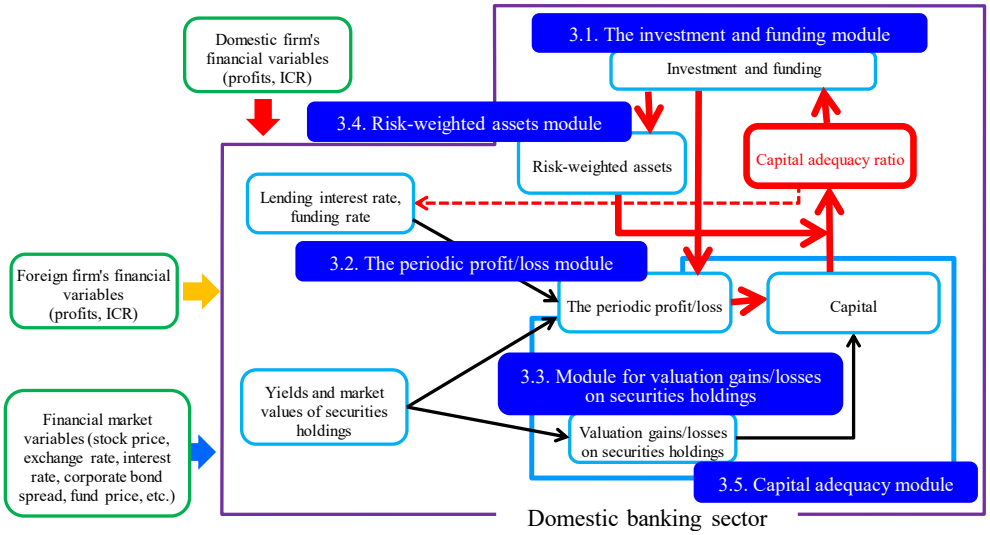
[23] For example, to calculate the ICR of each bank's borrower firms, financial information on individual firms and information on the banks with which they do business provided by Teikoku Databank is used.

[24] While the identification of structural changes requires a sufficiently large number of observations before and after such changes, in general, observations tend to be scarce especially after a structural change, so that in practice changes are identified by looking at the time-series behavior of the data and taking into account whether there have been financial or economic events that may have had a major impact on the data, meaning that to some extent the identification of structural changes is based on a subjective assessment. It is therefore necessary to systematically examine ex post whether such assessments were correct, using statistical methods. Relatedly, Japanese data suggest that there was a structural break in the relationship between certain variables around the year 2000, when there were a large number of mergers of financial institutions, and models employing those variables are estimated using data after the potential structural change.

3. Structure of the Model of the Domestic Banking Sector

As mentioned earlier, one of the most important variables in the FMM is the capital adequacy ratio of banks. In the domestic banking sector, the ratio is calculated by combining five different types of modules. The following explains the framework of the calculation and then provides details of each module.

Chart 3. Framework of the calculation of capital adequacy ratios



The investment and funding module (3.1 in Chart 3 above, described in detail in Section 3.1 below) is used to calculate developments in loans (in asset side) and funding (in liability side) in each scenario. For example, in a scenario in which domestic and foreign economic and financial conditions are firm, banks increase their lending and funding; conversely, in a scenario in which economic and financial conditions deteriorate, banks' lending -- and at the same time their funding -- decreases due to weak corporate demand in loan markets and tightening of banks' lending stance.

The periodic profit/loss module (3.2 in Chart 3, described in detail in Section 3.2) is used to calculate estimates for the items comprising net income, based on changes in investment and funding amounts, and the economic and financial environment assumed in the scenarios. Specifically, we estimate (i) pre-provision net revenue (PPNR) excluding trading income (=operating profits from core business), which refers to income from lending and securities investment-related businesses and fees and commissions, (ii) realized gains/losses on securities holdings, which refers to the amount of capital gains or losses realized from the securities investment business, and (iii) credit costs due to changes in the creditworthiness of borrower firms.[25] For example, in a scenario in which

[25] Credit costs are defined as Loan-loss provisions + Write-offs + Losses on nonperforming credit

the domestic and foreign economic and financial environment deteriorates, in many cases, the margins on loans and on investments in securities are squeezed, leading to the decline of PPNR, and the prices of risk assets fall, putting downward pressure on realized gains/losses on securities holdings through impairment losses and other factors. In addition, credit costs increase due to defaults and a deterioration in the creditworthiness of borrower firms. As a result of these factors, net income declines.

Valuation gains/losses on securities holdings, which are the capital gains/losses generated from the securities investment business that have not been realized, are calculated using the module for valuation gains/losses on securities holdings (3.3 in Chart 3, described in detail in Section 3.3 below). Specifically, valuation gains/losses on securities for each period are calculated by subtracting gains/losses on securities realized through sales, redemptions, and devaluation from the change in the market value of securities in each period.

Risk-weighted assets are calculated in the risk-weighted assets module (3.4 in Chart 3, details are provided in Section 3.4), which incorporates changes in risk-weighted assets due to changes in the creditworthiness of borrower firms, etc., as well as changes in the amount of lending and the market value of stockholdings.[26] Banks' capital adequacy ratios for the current period is calculated in the capital adequacy module (3.5 in Chart 3, see Section 3.5 for details) by adding the net income (after tax) obtained in the periodic profit/loss module and changes in valuation gains/losses on securities holdings to the amount of capital in the previous period, and then subtracting dividends. Finally, capital adequacy ratios are calculated by dividing the amount of capital by risk-weighted assets.[27]

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sales – Recoveries of write-offs.

[26] In this context, it should be noted that, in line with current regulations, the model for the risk-weighted assets of banks that have adopted the standardized approach is different from the model for those that have adopted the internal ratings approach.

[27] The capital adequacy ratio is calculated in accordance with Basel III (Basel Committee on Banking Supervision 2021) and the public notices issued by the Financial Services Agency in line with the Basel III regulations. Meanwhile, even when the simulation period includes a period in which the application of the finalized version of the Basel III regulations (Basel Committee on Banking Supervision 2017b) begins, the capital adequacy ratios are calculated based on the current regulations. Individual banks in the banking sector are modeled on a consolidated basis, including consolidated subsidiaries of the relevant bank. Because for consolidated subsidiaries the data necessary to identify risk factors is often limited, and it is difficult to model them in a manner that is linked to economic and financial conditions, asset and liability items are assumed to remain unchanged during the simulation period, and periodic profits/losses are assumed to be zero, so that they do not contribute to changes in the capital adequacy ratio in the simulation. However, in light of the losses incurred by subsidiaries in the bankruptcy of Sanyo Securities in 1997 and the bailout of American International Group (AIG) in 2008, modeling consolidated subsidiaries is an important future issue from the perspective of expanding the coverage of risks that financial institutions may face.

3.1. The investment and funding module

In the investment and funding module, changes in important investment and funding account items, such as items accounting for large amounts, are modeled separately, while the other balance sheet items are modeled together (Charts 4 and 5).[28] Moreover, domestic and foreign account items are modeled separately.[29] The reason is that it is assumed that the determinants of changes in domestic and foreign account items differ, even if the account items are the identical.

Starting with the asset side, asset items are classified into three categories: loans,[30] securities (on a book value basis), and other assets.

Chart 4. Investment and funding accounts

Investment	Funding
A-1. Loans	B-1. Deposits
A-2. Securities	B-2. Payables under repurchase agreements
A-3. Trading securities	B-3. Negotiable certificates of deposit
A-4. Money held in trust	B-4. Bonds
A-5. Call loans	B-5. Call money
A-6. Receivables under resale agreements	B-6. Payables under securities lending transactions
A-7. Receivables under securities borrowing transactions	B-7. Bills sold
A-8. Bills bought	B-8. Commercial papers
A-9. Monetary claims bought	B-9. Borrowings
A-10. Due from banks	B-9-1. Borrowings from BOJ
A-11. Negotiable due from banks	B-9-2. Borrowings from other banks
A-12. Foreign exchanges	B-10. Foreign exchanges
A-13. The others	B-11. Bonds payable and bonds with share acquisition rights
	B-12. The others

Chart 5. Investment and funding module

Investment	Funding
Loans [A-1]	Domestic [(B-1)+…+(B-12)]
Domestic	Deposits [B-1]
Corporate loans (★)	Borrowings from BOJ [B-9-1]
Retail loans (★)	Market fundings[(B-2)+…+(B-12) <excl. B-9-1>]
Loans for local governments	Foreign [(B-1)+…+(B-12)]
Foreign (★)	Deposits [B-1]
Securities [A-2]	Repo [(B-2)+(B-6)]
The others [(A-3)+…+(A-13)]	Market fundings [(B-3)+…+(B-12)]

Note: The ★ denotes items that are modeled as endogenous variables. The letters and numbers in square brackets show the correspondence to the investment and funding account items in Chart 4.

[28] Assets and liabilities other than those in the investment and funding accounts, such as fixed assets, are assumed to remain unchanged from the end of the pre-simulation period.

[29] "Domestic" refers to the accounts of the domestic business sector, while "foreign" refers to the accounts of the international business sector (the same applies below).

[30] When we refer to loans in this paper, we are referring to the amount of loans outstanding (the same applies below).

Of these, only loans are assumed to fluctuate in response to changes in macroeconomic variables in the scenarios, while securities and other assets are assumed to remain unchanged in book value terms from the actual values at the end of the pre-simulation period throughout the simulation period, regardless of the scenario. Therefore, the value of total assets during the simulation period is the value at the end of the pre-simulation period plus the change in loans during the simulation period.[31] In addition, it is assumed that the composition of borrowers of loans remains unchanged from the actual values at the end of the pre-simulation period. Proceeds from securities are also assumed to be reinvested in the same type of securities when they reach maturity, so that both the total amount and the composition of securities holdings are assumed to remain unchanged during the simulation period.[32]

Loans are composed of domestic loans to corporations, individuals, and local governments, and foreign loans. With the exception of loans to local governments, which are assumed to remain unchanged from the pre-simulation period values in all scenarios, each of these are specified such that they are influenced by the economic and financial conditions to differing degrees. Moreover, the FMM is specified such that loans decline in line with the deterioration in the real economy,[33] and that this decline in loans spills over to the domestic economy, with the decline in banks' corporate loans negatively affecting firms' investment in the economy and the decline in loans to individuals negatively affecting private consumption.

On the liabilities side, funding is divided into domestic and foreign funding and is specified such that domestic funding fluctuates in line with changes in domestic loans and foreign funding fluctuates in lines with changes in foreign loans.[34] In this case, it is

[31] From the perspective of taking the detailed linkages between the real economy and the banking sector into account, it would be desirable to model securities holdings in a manner such that their value depends on financial conditions, etc. This is an issue to be addressed in the future.

[32] The assumption that the total amount and composition of financial institutions' balance sheet items remain unchanged during the simulation period is called the "static balance sheet assumption" and is widely used in macro stress testing as a regulatory tool by supervisors. Key reasons are that the assumption facilitates interpretation and comparison of results and eliminates the possibility of an upward bias in capital adequacy ratio estimates due to arbitrary and subjective assumptions on balance sheet dynamics (Basel Committee on Banking Supervision 2017a, Board of Governors of the Federal Reserve System 2021, European Banking Authority 2021).

[33] In the early stages of major recessions, such as during the global financial crisis of 2008 and the outbreak of the Covid-19 pandemic in 2020, lending by financial institutions relative to GDP temporarily increased in some cases due to firms' use of credit lines (Berrospide, Meisenzahl, and Sullivan 2012, Acharya, Engle, and Steffen 2021, and Aoki et al. 2021). However, since these loans were subsequently repaid relatively quickly, we use time dummies in our loan model estimates to control for fluctuations in lending in the immediate post-crisis period.

[34] The specification that the amount of liabilities is passively determined after the amount of assets is

assumed that the composition in terms of deposits, loans from the BOJ, and market-based funding among the domestic funding and the composition in terms of deposits, repos, and market-based funding among the foreign funding remain unchanged from the current compositions. The following subsections describe the specifications of the functions for domestic corporate loans, domestic loans to individuals, and foreign loans.

Model for domestic corporate loans

Domestic corporate loans are specified such that they are explained by macroeconomic and bank-specific factors that are thought to affect lending.[35] Specifically, the output gap,[36] the expected growth rate (over the next three years),[37] the population growth rate,[38] and the rate of change of land prices[39] are used as variables to capture changes in macroeconomic demand for loans by corporations. This specification is to capture changes in the volume of lending due to changes in firms' cash flows on hand, expected returns on investment, and the value of collateral held by firms. The lower these explanatory variables are, the lower is firms' demand in the loan market and the lower is the amount of loans.

The variables used to capture the lending stance of banks – the suppliers of loans – are

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determined first implies that banks can always raise, both domestically and abroad, funds equal to the amount of assets; in other words, it does not assume extremely severe liquidity stress that would force banks to make large changes in the amount of assets in a short period of time as the amount of liabilities changes. This is due to the fact that the FMM focuses on examining the adequacy of banks' capital and not on liquidity risks, while the importance of liquidity risk was highlighted by Basel Committee on Banking Supervision (2013). The models used by the FRB and the ECB for stress testing (see Appendix 6) also exclude liquidity risk, while the IMF uses separate models for capital adequacy and liquidity stress testing (Adrian, Morsink, and Schumacher 2020). The FMM does not completely abstract from liquidity-related stresses but rather incorporates a mechanism whereby stresses in banks' financing can reduce capital adequacy ratios by increasing funding costs and squeezing periodic profits.

[35] Since standard economics assume that loans and interest rates are determined endogenously and simultaneously, it cannot be ruled out that in this specification the parameter estimates in the equation may be subject to simultaneous equation bias. For this reason, the simulation results based on this model should be interpreted with a degree of caution.

[36] The historical values of the output gap are estimated by the BOJ, and the forecast values for the simulation period are prepared using potential GDP estimated by applying a Hodrick-Prescott (HP) filter to the GDP scenario. Level adjustments are made when connecting the forecast values to the historical values.

[37] Actual figures for the pre-simulation period are based on the average for all industries of responses to the Cabinet Office's "Annual Survey of Corporate Behavior."

[38] The National Institute of Population and Social Security Research's estimates and projections of the working-age population (those aged 15 years and older) are used.

[39] For land prices, the Japan Real Estate Institute's urban land price index is used. The simulation period is specified in such a way that the ratio of land prices to nominal GDP converges to the historical average.

their capital adequacy ratios and net income return on assets (ROA).[40] The specification is such that the lower the capital adequacy ratio and the lower the net income ROA, the more loans decrease.[41] Moreover, the amount of loans falls in a nonlinear fashion[42] once the capital adequacy ratio falls below a certain threshold[43] and net income ROA turns red.

Another explanatory variable for loans used in the model is lending interest rates. A priori, the impact of lending interest rates on loans is ambiguous. For example, on the demand side, an increase in lending interest rates is expected to reduce firms' demand for borrowing, while on the supply side, banks are expected to take a more aggressive lending stance due to the higher lending interest rates. In practice, the estimation results suggest that an increase in lending interest rates reduces lending on a net basis.

Specification of the model for domestic corporate loans

$$
\begin{aligned}
&\text{Domestic corporate loans}_i \text{ [y/y chg.]} \\
&= \alpha_1 \times \text{Output gap} + \alpha_2 \times \text{Expected economic growth rate} \\
&+\alpha_3 \times \text{Population growth rate} + \alpha_4 \times \text{Growth rate of land prices} \\
&+\alpha_5 \times (\text{Capital adequacy ratio}_i - \text{Threshold}_i) \times \left(1 + \gamma_1 \times \text{Dummy}_{\text{CAR}_i<\text{threshold}_i}\right) \\
&+\alpha_6 \times ROA_i \times \left(1 + \gamma_2 \times \text{Dummy}_{\text{Net income ROA}_i<0}\right) \\
&+\alpha_7 \times \text{Domestic lending interest rate}_i \text{ [1-quarter lag, chg. from previous year]} \\
&+\text{Fixed effect}_i + \text{Constant}
\end{aligned}
$$

—— i denotes individual banks, hereafter.

Model for domestic loans to individuals

While the explanatory variables in the model for domestic loans to individuals are the same as those in the model for domestic loans to corporations, they are estimated in separate models since the sensitivities are not necessarily the same. In fact, the estimated coefficients do differ; for example, the sensitivity of loans to individuals to the output gap

[40] Ratio of net income to total assets = (After-tax) net income/Total assets.

[41] This follows preceding empirical studies showing that lower capital adequacy ratios reduce loans. See Peek and Rosengren (1997, 2000) and Amiti and Weinstein (2018) for studies on Japanese banks and Berrospide and Edge (2010) for a study on U.S. banks.

[42] Such nonlinear relationships for both the net income ROA and capital adequacy ratios are found in panel estimations for banks presented in the October 2015 FSR and the October 2016 Annex, "Macro Stress Testing in the *Financial System Report* (October 2016)" (released in October 2016).

[43] The threshold for internationally active banks is a total capital adequacy ratio of 8 percent, while the threshold for domestic banks and *shinkin* banks is a capital ratio of 4 percent (the same applies to the function for domestic loans to individuals and the function for international loans).

is smaller than that of loans to corporations.

Specification of the model for domestic loans to individuals

$$\begin{aligned}&\text{Domestic household loans}_i \ [\text{y/y chg.}]\\&= \alpha_1 \times \text{Output gap} + \alpha_2 \times \text{Expected economic growth rate}\\&+\alpha_3 \times \text{Population growth rate} + \alpha_4 \times \text{Growth rate of land prices}\\&+\alpha_5 \times (\text{Capital adequacy ratio}_i - \text{Threshold}_i) \times \left(1 + \gamma_1 \times \text{Dummy}_{\text{CAR}_i<\text{threshold}_i}\right)\\&+\alpha_6 \times ROA_i \times \left(1 + \gamma_2 \times \text{Dummy}_{\text{Net income ROA}_i<0}\right)\\&+\alpha_7 \times \text{Domestic lending interest rate}_i \ [\text{1-quarter lag, chg. from previous year}]\\&+\text{Fixed effect}_i + \text{Constant}\end{aligned}$$

Model for foreign loans

The model for foreign loans uses as explanatory variables the growth trend in loans specific to each bank and macroeconomic factors that are regarded to be determinants of fluctuations in loans. In this regard, the output gap for foreign economies[44] is used as a variable to capture changes in the demand for loans by foreign firms, and the more negative the gap, the lower the demand in the loan market and the less loans are extended. Moreover, as with loans to domestic borrowers, the capital adequacy ratios of banks is used as a variable to capture their lending stance, and the dollar/yen exchange rate is included as an explanatory variable to account for changes in the yen value of loans due to exchange rate fluctuations.

Specification of the model for foreign loans

$$\begin{aligned}&\text{Foreign loans}_i \ [\text{y/y chg.}]\\&= \alpha_1 \times \text{Foreign output gap} \ [\text{chg. from previous year}]\\&+\alpha_2 \times (\text{Capital adequacy ratio}_i - \text{Threshold}_i)\\&+\alpha_3 \times \text{Exchange rates} \ [\text{USD/JPY, y/y chg.}] + \text{Fixed effect}_i + \text{Constant}\end{aligned}$$

3.2. The periodic profit/loss module

For periodic profits/losses, of the various items in banks' income statements (Chart 6), those that make a substantial contribution to overall changes in periodic profits/losses, such as items related to their lending and securities investment business, are modeled. In this regard, commission business-related items are modeled only for major banks, and the other items are assumed to remain constant in all scenarios, in line with historical averages,

[44] Actual values for the pre-simulation period are based on the IMF's World Economic Outlook. Forecasts for the simulation period are prepared using potential GDP estimated by applying HP filters to the GDP scenarios for foreign economies.

etc.[45] For the FMM, these items related to net periodic profits/losses are classified into three top-level account items (Chart 7).

Chart 6. Income statement items

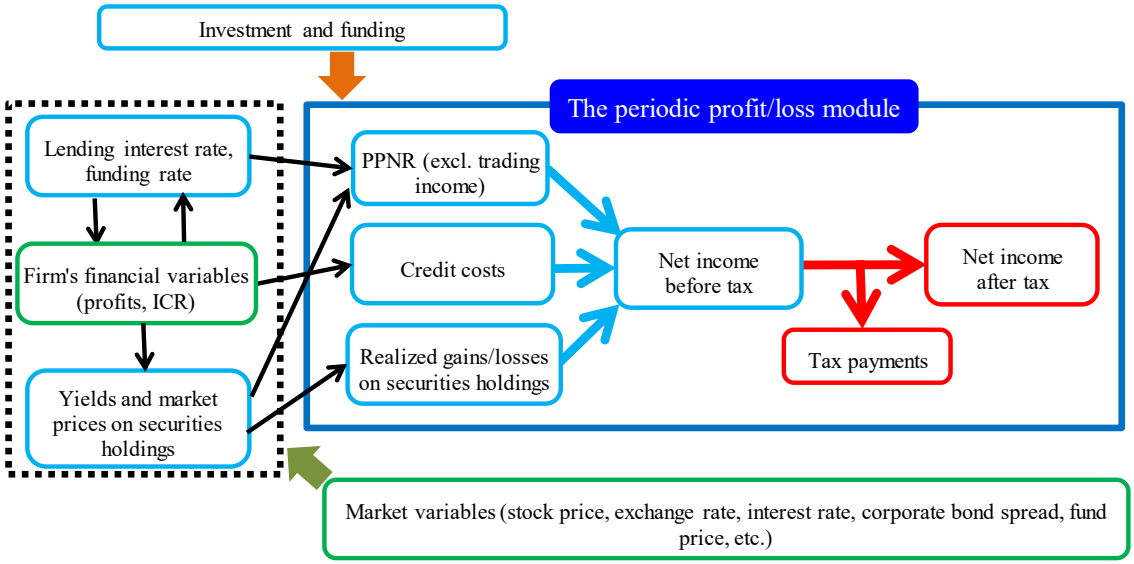
Revenues	Expenses
A. Ordinary income (A-1)+…+(A-5)	B. Ordinary expenses (B-1) +…+(B-6)
A-1. Interest income	B-1. Interest expenses
A-1-1. Interest on loans	B-1-1. Domestic business
A-1-2. Interest and dividends on securities	B-1-2. International business
A-1-3. The others	
A-2. Fees and commissions	B-2. Fees and commissions payments
A-3. Trading income	B-3. Trading expenses
A-4. Other ordinary income	B-4. Other ordinary expenses
A-4-1. Gain on sales or redemption of bonds	B-4-1. Loss on sales, redemption or devaluation of bonds
A-4-2. The others	B-4-2. The others
	B-5. General and administrative expenses
A-5. Other income	B-6. Other expenses
A-5-1. Gain on sales of stocks	B-6-1. Loss on sales or devaluation of stocks
A-5-2. Reversal of allowance for loan losses/ Recoveries of written off claims	B-6-2. Provision of allowance for loan losses/ Written-off of loans
A-5-3. The others	B-6-3. The others
C. Ordinary profit (loss) (A)-(B)	
D. Extraordinary income	E. Extraordinary losses
F. Profit (loss) before tax (C)+(D)-(E)	
	G. Income taxes
H. Profit (loss) (F)-(G)	

The first of these is PPNR excluding trading income, which represents banks' fundamental profitability and changes over time depending on factors such as lending interest rates, yields on securities holdings, funding rates, and the size of loan portfolios. The second is realized gains/losses on securities holdings, which consist of realized gains/losses on bonds, stocks, and other securities and fluctuate with changes in the market value of securities holdings. The third is credit costs, which vary depending on financial conditions in the corporate sector. The sum of PPNR excluding trading income and gains/losses on securities holdings minus credit costs (a cost item) equals net income before taxes, and subtracting tax expenses from this net income yields the after-tax income.[46] The following subsections explain the structure of the models used for the different items, i.e., PPNR excluding trading income, realized gains/losses on securities holdings, and credit costs.

[45] The use of historical averages, etc., instead of actual values just before the simulation period is due to the large variation in some items over time.

[46] Tax expenses are calculated assuming an effective tax rate of 40 percent for banks and 30 percent for *shinkin* banks provided that their net income before taxes is in the black. On the other hand, the effective tax rate is assumed to be zero for banks whose net income is in the red.

Chart 7. Structure of the periodic profit/loss module



3.2.1. PPNR excluding trading income

PPNR excluding trading income is defined as the sum of net interest income[47] and net non-interest income[48] minus general and administrative expenses.[49] As shown in Chart 8, PPNR excluding trading income is calculated using the results of several models.

For net interest income-related items, interest rates are modeled both for income and expense items, and the amount of net interest income is calculated by combining the simulated values of the interest rates with those of the amount of loans and other items obtained from the investment and funding module discussed earlier. For non-interest income, which mainly derives from fee business, the amount of income itself is modeled.

[47] Net interest income = Interest income – Interest expenses.

[48] Net non-interest income = Net fees and commissions + Net trading income + Other net non-interest income – Realized gains/losses on bondholdings. Net fees and commissions are fees and commissions received as compensation for services provided to customers in the lending, securities, and foreign exchange business, minus fees and commissions paid. Net trading income are the difference between income and expenses arising from securities transactions and derivatives transactions in the trading account (used for trading purposes). Other net ordinary income are profits from banks' basic business operations other than net interest income, net fees and commissions, and net trading income (e.g., gains/losses from the sale and purchase of foreign exchange).

[49] General and administrative expenses are incurred in conducting business activities, including personnel expenses such as salaries and remuneration of executives and employees, property expenses such as depreciation of tangible and intangible fixed assets and advertising expenses, and taxes such as consumption tax.

Chart 8. PPNR excluding trading income

PPNR (excl. trading income)
Net interest income [(A-1-1)+(A-1-2)+(A-1-3)－(B-1)]
Loan interest income [A-1-1]
Domestic：Domestic lending interest rate (★)×Domestic loans
Foreign：Foreign lending interest rate (★)×Foreign loans
Interest and dividends on securities [A-1-2] ： Yields on securities×Securities holdings
The others [A-1-3] ： Yields on other assets×Other assets holdings
Interest expenses [B-1]
Domestic：Domestic funding rate (★)×Domestic fundings [B-1-1]
Foreign：Foreign funding rate (★)×Foreign fundings [B-1-2]
Net non-interest income[(A-2)－(B-2)+(A-3)－(B-3)+(A-4)－(B-4)－((A-4-1)－(B-4-1))]
Net fees and commissions (★) [(A-2)－(B-2)]
The others (★) (Net trading income＋Other net ordinary income -realized gains/losses on bondholdings) [(A-3)－(B-3)+(A-4)－(B-4)－((A-4-1)－(B-4-1))]
General and administrative expenses [B-5]
Domestic
Foreign

Note: The ★ denotes items that are modeled as endogenous variables. The letters and numbers in square brackets show the correspondence to the income statement items in Chart 6.

Starting with net interest income, this is calculated as the sum of loan-related interest income, interest and dividends on securities, and other income[50] (i.e., income items) minus funding costs (i.e., expense items). Loan-related interest income is calculated as the sum of domestic loan-related interest income, which is calculated by multiplying domestic loans by domestic lending interest rates, and foreign loan-related interest income, which is calculated by multiplying foreign loans by the foreign lending interest rates. Interest and dividends on securities are calculated as securities holdings multiplied by the yield on securities. Securities yields include bond yields and dividend yields on stocks, etc. Bond yields are calculated based on each remaining maturity using data[51] on each bank's maturity ladder (amount of bondholdings by remaining period) at the end of the pre-simulation period.[52]

[50] Other income includes income from call loans and interest received on due from other banks.

[51] Regarding bond maturity ladder of Japanese banks, the BOJ conducts a quarterly survey of banks that have a current account at the BOJ. From this survey, the BOJ obtains information on banks' bondholdings by maturity and yields on those bondholdings.

[52] For bond interest income, the average effective yield is used as an approximation of the yield at the time of acquisition. In addition, to reflect the maturity composition of the outstanding amount of bonds in the market and heterogeneity in the maturity composition of the outstanding amount held by banks, (1) banks' composition of bondholdings by remaining maturity is multiplied by (2) the share of bondholdings by original maturity to calculate the composition of outstanding bonds by remaining and original maturity. (2) is assumed to be equal to the share calculated using data on outstanding bond issuances in the market (excluding the holdings by the BOJ). The average effective yield is then calculated using the composition of outstanding bonds. The yield on the proceeds from bonds that

Dividend yield from stocks and other assets is assumed to remain unchanged from the actual values just before the simulation period.[53] Other investment income, calculated by multiplying other asset holdings by the yields on other assets, is assumed to be linked to changes in funding costs so that the profit margin on other assets remains constant over the simulation period. Funding costs are the sum of domestic and foreign funding costs, calculated as the amount of domestic and foreign funding multiplied by the corresponding funding interest rates.

For net non-interest income, net fees and commissions and other net non-interest income are modeled separately. Other net non-interest income is defined as the sum of net trading income and other net ordinary income (excluding realized gains/losses on securities holdings).

General and administrative expenses are calculated as the sum of domestic and foreign expenses. In all scenarios, domestic expenses are assumed to remain unchanged from the actual values just before the simulation period. Conversely, foreign expenses, which have been on an upward trend, are assumed to fluctuate in line with the outstanding amount of foreign funding in the baseline scenario, because they have been stable as a percentage of the outstanding amount of foreign funding. In the stress scenarios, foreign-currency expenses in local currency terms are assumed to be constant, and a downturn in foreign economies during the simulation period itself is assumed to have no effect on the foreign expenses. This is based on the assumption that it is difficult for banks to reduce expenses (in local currency) in the short run even if their foreign business shrinks due to recession.

The following subsections describe the domestic lending interest rate model, the foreign lending interest rate model, the domestic funding interest rate model, the foreign funding interest rate model, the model for net fees and commissions, and the model for other net non-interest income.

Domestic lending interest rate model

Domestic lending interest rates are specified as changing in tandem with changes in market interest rates, changes in credit premiums associated with changes in borrower firms' creditworthiness, and changes in margins associated with changes in the supply-

have matured and are reinvested is specified such that it is linked to interest rates on government bonds with the corresponding remaining and original maturity assumed in each scenario. In addition, it is assumed that during the simulation period banks reinvest the proceeds in line with the investment shares at the end of pre-simulation period, so that banks' current investment policy is reflected in the term composition of their bondholdings going forward.

[53] As a result, the amount of dividends in the simulation fluctuates to the same extent as stock prices.

demand conditions. First, the linkage with changes in market interest rates is expressed by using the (short-term) domestic funding rate and the difference between short- and long-term interest rates (5-year minus 3-month rates) as explanatory variables.[54] Next, the nonperforming loan (NPL) ratio is included as an explanatory variable to proxy credit premiums associated with changes in borrower firms' creditworthiness, and it is assumed that banks add a premium for credit risk to domestic lending interest rates when the NPL ratio increases. Finally, the loan demand index,[55] which is defined as the ratio of the number of borrowing firms to the number of banks' branches in a prefecture, is used as an explanatory variable to proxy for changes in the supply-demand conditions in the loan market.[56] In the domestic lending interest rate model, the sensitivity of lending interest rates to the different variables is assumed to be identical across banks.

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[54] The estimates of the degree of linkage between these variables and domestic lending interest rates are all below one. This is consistent with the results obtained by Kitamura, Muto, and Takei (2016), who examine the spillover effect from market interest rates to lending rates at Japanese banks.

[55] The loan demand index is calculated as the number of borrowing firms divided by the number of banks' branches in each prefecture and can be interpreted as an indicator of the degree of market concentration on the supply side (banks) in the local loan market. The purpose of including this variable in the function of domestic interest rate is to capture the mechanism by which long-term structural factors, such as the shrinking of the population and decline in the number of borrowing firms, exert downward pressure on lending interest rates through a continuous easing of supply-demand conditions for loans. However, it should be noted that (1) with the increase in so-called cross-prefectural lending by regional banks (Ozaki et al. 2019), i.e., lending by banks in prefectures outside that in which their head office is located, potential competitors in a particular prefecture's loan market may include not only banks located in that prefecture but also those in other prefectures; (2) with the advances in digitalization, the link between the number of physical branches and the degree of concentration in the loan market may weaken; and (3) the sign of the correlation between the reduction in the number of branches and lending interest rates is a priori ambiguous. In particular with regard to the third point, if the reduction in the number of branches reduces the degree of competition among banks, this could lead to higher lending interest rates, but if banks reduce the number of branches (to cut fixed costs) in order to create room for lowering lending interest rates and increasing their competitiveness, this could lead to lower lending interest rates. Estimation results suggest that the former effect outweighs the latter, since the loan demand index is positively correlated with lending interest rates. See Chapter VI, Section B, of the October 2019 FSR for a discussion of the effect of different assumptions about the dynamics of the loan demand index during the simulation period on the predictions about profitability and capital adequacy ratios of banks. When calculating the loan demand index, we use the prefecture where the head office is located in the case of regional and *shinkin* banks, while for large banks with a nationwide presence, we use national values (average of all prefectures). Finally, it should be noted that apart from those used in the FMM, there are several other indicators of supply-side market concentration in loan markets (see van Leuvensteijn et al. 2011 for details).

[56] The positive correlation between the degree of market concentration among banks in the loan market and loan spreads has been shown theoretically in the Klein-Monti model (Klein 1971 and Monti 1972), the standard lending interest rate model, and has also been found in empirical studies. See, for example, van Leuvensteijn et al. (2013), for an analysis using eurozone data.

Specification of the domestic lending interest rate model

$$\begin{aligned}&\text{Domestic lending interest rate}_i\\&= \alpha_1 \times \text{Domestic funding rate}_i + \alpha_2 \times \text{Term spread [5-year} - \text{3-month]}\\&+\alpha_3 \times \text{Non-performing loan ratio}_i + \alpha_4 \times \text{Loan demand index}_i\\&+\text{Fixed effect}_i + \text{Constant}\\&\\&\text{Loan demand index}_i\\&\equiv \frac{\text{The number of borrowing firms in the prefecture where } i\text{'s head office is located}}{\text{The number of branches in the prefecture where } i\text{'s head office is located}}\end{aligned}$$

Foreign lending interest rate model

The model for foreign lending interest rates is similar to that for domestic lending interest rates but somewhat simplified. While the explanatory variables for foreign lending interest rates include funding rates as in the model for domestic loans interest rates, the foreign output gap instead of the loan demand index is used to capture supply and demand conditions in the loan markets.[57]

Specification of the foreign lending interest rate model

$$\begin{aligned}\text{Foreign lending interest rate}_i &= \alpha_1 \times \text{Foreign funding rate}_i\\&+\alpha_2 \times \text{Foreign output gap} + \text{Fixed effect}_i + \text{Constant}\end{aligned}$$

Model for domestic funding rates

Domestic funding rates are the weighted average of the interest rate levels projected from the model for the three sources of funding, namely, (1) deposits, (2) borrowings from the BOJ,[58] and (3) market-based funding (which is the sum of all funding sources other than (1) and (2)), using the shares of these funding sources at the end of the pre-simulation period as weights. In other words, it is assumed that in the event of stress there is no major shift in funding sources in terms of (1) through (3). While in the functions for both (1) and (2) the only explanatory variable is the three-month JGB yield, estimating the two functions makes it possible to capture differences in the degree of spillover to the interest rates for the two funding sources. The interest rate for (3) is specified such that it is affected by the level of banks' capital adequacy ratio in addition to the three-month JGB

[57] On the one hand, a deterioration in the foreign output gap may widen credit premiums due to a deterioration in the creditworthiness of borrower firms. On the other hand, it may decrease demand for funds by firms in the loan market, which puts downward pressure on the lending interest rate. Since the estimated coefficient for the foreign output gap is positive, this suggests that the latter effect is larger than the former.

[58] Borrowing from the BOJ refers to the borrowing of funds from the BOJ by banks such as through various operations including the Complementary Lending Facility and the Loan Support Program.

yield.

Specification of the model for domestic funding rates

$$(1)\text{Deposit interest rate}_i = \alpha_1 \times \text{Short-term interest rate [3-month T-Bills]} + \text{Fixed effect}_i + \text{Constant}$$

$$(2)\text{Borrowing interest rate from BOJ}_i = \alpha_1 \times \text{Short-term interest rate [3-month T-Bills]} + \text{Fixed effect}_i + \text{Constant}$$

$$(3)\text{Market-based fundng rate}_i = \alpha_1 \times \text{Short-term interest rate [3-month T-Bills]} + \alpha_2 \times \text{Capital adequacy ratio}_i + \text{Fixed effect}_i + \text{Constant}$$

Model for foreign funding rates

Foreign funding rates are the weighted average of the interest rate levels projected from the model for the three sources of funding, i.e., (1) deposits, (2) repo funding, and (3) the other market-based funding except repo funding, including certificates of deposit/commercial paper (CD/CP) and FX and foreign currency swaps (other market-based funding again is the sum of all funding sources other than (1) and (2)), using the shares of these funding sources at the end of the pre-simulation period as weights. Of these, deposit interest rates are specified as being linked to three-month U.S. Treasury bill yields and individual banks' capital adequacy ratio,[59] and a decline in banks' creditworthiness leads to an increase in the funding rate they face. Next, the repo rates are also specified as being linked to three-month U.S. Treasury bill yields, but since repo transactions are secured transactions, variables representing banks' creditworthiness are not included in the explanatory variables. Finally, (3) the other market-based funding rates are specified such that, in addition to banks' capital adequacy ratio, they are determined by the sum of the (three-month) dollar LIBOR and the (three-month) dollar funding premium,[60] and are affected by stresses in foreign currency funding conditions as well as banks' creditworthiness.[61] In the stress scenarios, the increase in the other market-based

[59] In order to ensure that sufficiently long time series are available, the total capital adequacy ratio (for internationally active banks) and the capital adequacy ratio (for domestic banks) are used, like in the loan models.

[60] The dollar funding premium in the FMM is defined as the difference between the cost of dollar funding using foreign exchange swaps and the (three-month) dollar LIBOR.

[61] The specification of foreign currency funding rates is based on the observation that the stress in repo funding in U.S. and European financial markets was relatively modest during past financial crises (see, e.g., Krishnamurthy, Nagel, and Orlov 2014, Copeland, Martin, and Walker 2014, and Mancini, Ranaldo, and Wrampelmeyer 2016), while market-based funding other than repo transactions, such as CDs/CP and FX and currency swaps, was under considerable stress due to the emergence of counterparty risk and other factors (see, e.g., Baba and Packer 2009, Afonso, Kovner, and Schoar 2011, Covitz, Liang, and Suarez 2013, and Chernenko and Sunderam 2014).

funding rates tends to be particularly large, and the higher a bank's share of the other market-based funding, the more likely is its overall foreign funding rate to rise.

Specification of the model for foreign funding rates

$$\text{(1)Deposit interest rate}_i = \alpha_1 \times \text{Short-term interest rate [3-month T-Bills]} + \alpha_2 \times \text{Capital adequacy ratio}_i + \text{Fixed effect}_i + \text{Constant}$$

$$\text{(2)Repo rate}_i = \alpha_1 \times \text{Short-term interest rate [3-month T-Bills]} + \text{Fixed effect}_i + \text{Constant}$$

$$\text{(3)The other market-based funding rate}_i = \alpha_1 \times (\text{U.S. dollar LIBOR} + \text{U.S. dollar funding premium}) + \alpha_2 \times \text{Capital adequacy ratio}_i + \text{Fixed effect}_i + \text{Constant}$$

Model for net fees and commissions

Net fees and commissions are modeled for major banks only, and the model is specified such that fees and commissions income from services such as foreign exchange business and trust and insurance sales[62] are explained by variables representing economic and financial conditions, such as the output gap, stock prices, and exchange rates.[63] In addition, given the strong increase in this account from the late 1990s to the 2000s due to deregulation,[64] a time trend[65] for this period is added as an explanatory variable to represent deregulation.

Specification of the model for net fees and commissions

$$\text{Net fees and commissions to total assets (Major banks, excl. trust fee)}^i = \alpha_1 \times \text{Output gap} + \alpha_2 \times \text{Stock price [y/y chg.]} + \alpha_3 \times \text{Exchange rates to total assets [USD/JPY]} + \alpha_4 \times \text{Deregulation trend} + \text{Fixed effect}_i + \text{Constant}$$

Model for other net non-interest income

Other net non-interest income is also modeled for major banks only. The types of business

[62] Trust fees, which are fees received as compensation for the management and administration of investment trusts, are also included in net fees and commissions.

[63] For major banks, the exchange rate is included as an explanatory variable only for internationally active banks to take into account the impact of exchange rate changes on the yen value of foreign net fees and commissions.

[64] Specifically, banks have been able to own securities subsidiaries since 1993 and handle over-the-counter sales of investment trusts since 1998, and the ban on insurance sales was completely lifted in 2007.

[65] Specifically, a quarterly time trend is included as an explanatory variable for the period 1997–2007.

included in this account are diverse; however, reflecting their size and variability and their high correlation with macroeconomic variables that represent economic and financial conditions, only (1) gains/losses on interest rate swap transactions and (2) gains/losses on currency and foreign exchange swap transactions (consisting of the sum of gains/losses on currency swap transactions and gains/losses on foreign exchange trading) are assumed to vary with economic and financial conditions. Meanwhile, the other items, including gains/losses on financial derivatives, in all scenarios are assumed to remain unchanged from their historical averages.

For the modeling, variables that show a high correlation with (1) and (2) in the past are selected as common explanatory variables for all banks; however, given the extremely high heterogeneity among banks in the types of business operations included in this account, the estimation was conducted using a specification that allows the coefficients to differ across banks. Specifically, for (1) gains/losses on interest rate swap transactions, the quarter-on-quarter difference in the (three-month) dollar LIBOR, which is negatively correlated with gains/losses on interest rate swap transactions, is used as an explanatory variable,[66] while for (2) gains/losses on currency swap and foreign exchange swap transactions, the U.S.-Japan interest rate differential (three-month U.S. interest rates minus three-month Japanese interest rates), which is positively correlated with gains/losses on currency swap and foreign exchange swap transactions, etc., and the output gap are used as explanatory variables.[67]

[66] The (three-month) dollar LIBOR is used as a proxy for developments in global interest rates, including yen interest rates. In practice, looking at the yen interest rate swap positions of major banks, that of fixed interest receipts/floating interest payments consistently exceed that of fixed interest payments/floating interest receipts, which may be one of the reasons for the increase in profits during periods of declining interest rates.

[67] The positive correlation with the US-Japan interest rate differential suggests that Japanese banks' positions in dollar interest receipts/yen interest payments are larger than their positions in dollar interest rate payments/yen interest receipts. The output gap is used as a variable to capture the volume of transactions in the customer market.

Specification of the model for other net non-interest income

$$(1)\frac{\text{Gains/losses on interest rate swap}_i}{\text{Funding amount}_i}$$
$$= \alpha_i \times \text{U.S. dollar LIBOR [chg. from previous quarter]} + \text{Fixed effect}_i + \text{Constant}$$
$$(2)\frac{\text{Gains/losses on currency swap}_i + \text{Foreign exchange transaction}_i}{\text{Funding amount}_i}$$
$$= \alpha_{1,i} \times \text{U.S.-Japan 3-month interest rate differential [chg. from previous quarter]}$$
$$+ \alpha_2 \times \text{Output gap} + \text{Fixed effect}_i + \text{Constant}$$

3.2.2. Realized gains/losses on securities

Realized gains/losses on securities holdings are the sum of realized gains/losses on bondholdings and realized gains/losses on stockholdings (Chart 9).[68] Realized gains/losses on bondholdings correspond to the balance of five accounts for bonds[69] and realized gains/losses on stockholdings correspond to the balance of three accounts for stocks and other securities.[70]

[68] To simplify the calculation, if the financial variable used as a risk factor is a price, the item is included in realized gains/losses on stockholdings, and if it is an interest rate (or spread), the item is included in realized gains/losses on bondholdings.

[69] Specifically, realized gains/losses on bondholdings are calculated as follows: Gains on sales of bonds + Gains on redemption of bonds – Losses on sales of bonds – Losses on redemption of bonds – Losses on devaluation of bonds. Gains/losses on the sale of bonds are the difference between the amount realized on the sale of bonds and their book value. While gains/losses on the redemption of bonds to which the amortized cost method is not applied are the difference between the redemption amount at maturity and the book value, gains/losses on the redemption of bonds in the FMM are zero, since it is assumed that the amortized cost method is applied during the simulation period. Losses on the devaluation of bonds consist of (1) the valuation losses on available-for-sale securities for banks that have adopted an accounting method under which only valuation gains are included directly in net assets and (2) impairment losses on held-to-maturity bonds and available-for-sale securities. Since in the FMM it is assumed that all banks adopt an accounting method under which both valuation gains and losses are included directly in net assets, (1) is zero, while (2) varies depending on the magnitude of the stress.

[70] Specifically, realized gains/losses on stockholdings are calculated as follows: Gains on sales of stocks – Losses on sales of stocks – Losses on devaluation of stocks. Gains/losses on sales of stocks are gains/losses on the sales of securities other than bonds. Losses on the devaluation of stocks correspond to (1) the valuation losses on available-for-sale securities for banks that adopt an accounting method under which only valuation gains are included directly in net assets and (2) impairment losses on stocks and other securities. Since in the FMM it is assumed that all banks adopt an accounting method under which both valuation gains and losses are included directly in net assets during the simulation period, (1) is zero, while (2) varies depending on the magnitude of the stress.

Chart 9. Securities in the module for realized gains/losses on securities holdings

- Realized gains/losses on securities holdings [((A-5-1)－(B-6-1))+((A-4-1)－(B-4-1))]
  - Realized gains/losses on bondholdings [(A-4-1)－(B-4-1)]
    - Government bonds, etc
    - Domestic credit products
      - Corporate bonds (AAA, AA, A and BBB rated or lower, incl. bank debentures)
    - Foreign bonds
      - Dollar-denominated
      - Euro-denominated
    - Foreign credit products
      - Coporate bonds (AAA, AA, A, BBB, BB, B and CCC rated or lower, incl. bank debentures)
      - CLO (AAA, AA, A, BBB and BB rated or lower)
      - CMBS (AAA, AA, A and BBB rated or lower)
      - RMBS
      - ABS (AAA and AA rated or lower)
      - Direct lending funds
      - Bank loan funds (BB rated or higher and B rated or lower)
  - Realized gains/losses on stockholdings [(A-5-1)－(B-6-1)]
    - Domestic stocks and stock investment trusts
    - Domestic investment funds and alternative investments
      - Bond investment funds
      - Credit investment funds
      - Real estate investment funds
      - Balanced funds
      - Hedge funds
    - Foreign stocks and stock investment trusts
    - Foreign investment funds and alternative investments
      - Real estate investment funds
      - Hedge funds
      - Private equity

Note: The letters and numbers in square brackets show the correspondence to the income statement items in Chart 6.

Realized gains/losses on securities holdings consist of (1) gains/losses on sales of securities (gains/losses on sales of bondholdings and gains/losses on sales of stockholdings) and (2) losses when the market value of securities falls substantially below their book value and the losses are written off (devaluation of bondholdings and stockholdings). The value of each term is a function of the valuation gains/losses on securities holdings at the end of the previous period (i.e., at the beginning of the current period), and the values calculated in the module for valuation gains/losses on securities holdings are used as arguments in the calculation. Meanwhile, securities sales and

devaluation during a period are deducted from the valuation gains/losses on securities at the beginning of the period to arrive at the valuation gains/losses at the end of the current period (i.e., at the beginning of the next period).

The following paragraphs and Chart 10 explain the items for which we calculate the realized gains/losses and the calculation method. The calculation of realized gains/losses is based on the valuation gains/losses for each type of securities, estimated by the model for valuation gains/losses on securities holdings.

First, as for (2) the devaluation of bondholdings and stockholdings, we calculate the devaluation of credit investments (included in bondholdings) and alternative investments (included in stockholdings) during the simulation period for each type of security. In this calculation, when the market-to-book ratio declines and valuation losses expand to 50 percent or more of the book value, it is assumed that banks sell their holdings to cut losses.

Chart 10. Items calculated in the module for realized gains on securities

		(1)Sales	(2)Devaluation	(3)Redemption
Stocks	Stocks and stock investment trusts	Calculated for stocks altogether	Calculated for stocks and stock investment trusts, altogether	
	Investment funds and alternative investments		Calculated by item	
Bonds	Government bonds	Calculated for bonds altogether	Assumed to be zero	Assumed to be zero (Applying amotized cost method)
	Credit investments (corporate bonds, securitized products)	Not covered	Calculated by item and rating just before simulation period	Assumed to be zero

Next, (1) gains/losses on sales of bondholdings (excluding credit investments) and stockholdings and (2) the devaluation of bondholdings and stockholdings (excluding credit investments and alternative investments) are calculated. For (1), valuation gains/losses on each type of securities are classified into valuation gains/losses on bondholdings and valuation gains/losses on stockholdings, and it is assumed that sales of these securities during the simulation period are made in line with the average amount of the realized gains/losses on bondholdings and stockholdings over the past three years, which are then regarded as gains/losses on sales of bondholdings and gains/losses on sales of stockholdings.[71] If valuation gains on stockholdings are lower than the average

[71] Many regional banks bolster their net income by selling securities (i.e., realizing gains) as the profitability of their domestic deposit-taking and lending activities continues to decline, and the specification here reflects such behavior by banks. For more details, see, for example, the October 2018 FSR. Meanwhile, regarding the strategic stockholdings of banks, although banks may be sitting on valuation gains, they may not be able to sell them at the same pace as in the past due to the strategic relationships with the firms; however, in the simulations it is assumed that they can be sold in the same way as other types of stocks. Finally, in the FMM it is assumed that banks do not sell credit investments to realize gains.

realized gains/losses on stockholdings over the past three years, it is assumed that the difference is made up for by realized gains on bondholdings (excluding credit investments).[72] Moreover, when valuation losses on stockholdings arise, it is assumed that devaluations of stockholding are incurred. Specifically, using the estimated loss-cut rule (obtained using nonlinear least squares estimation for the relationship between the market-to-book ratio of stocks and stock investment trusts and the devaluation ratio), it is assumed that impairment losses corresponding to the extent of the decline in the market-to-book ratio are incurred, where separate loss-cut rules are estimated for banks and *shinkin* banks.

Specification of realized gains/losses on securities

$$\text{Realized gains/losses on securities holdings}_i$$

$$= \text{Realized gains/losses on stockholdings}_i + \text{Realized gains/losses on bondholdings}_i$$

$$\text{Realized gains/losses on stockholdings}_i$$

$$= \begin{cases} min\begin{bmatrix}\text{Avg. realized gains/losses on stockholdings in past 3 years}_i,\\ \text{Valuation gains on stockholdings}_i\\ -\text{Devaluation(alternative investment)}_i\end{bmatrix} \\ \qquad (\text{Valuation gains on stockholdings}_i \geq 0) \\ -\text{Stock devaluation ratio}_i \times \text{Outstanding amount of stockholdings (book value)}_i \\ \qquad -\text{Devaluation of alternative investment}_i \\ \qquad (\text{Valuation gains on stockholdings}_i < 0) \end{cases}$$

$$\text{Stock devaluation ratio}_i$$

$$= \frac{\alpha_1}{\text{Market-to-book ratio(before write-offs)}_i \times (1 + \text{Drop rate of stock prices within the period}) + \alpha_2}$$

$$\text{Realized gains/losses on bondholdings}_i$$

$$= \text{Realized gains/losses on bondholdings(excl. credit products)}_i - \text{Devaluation of credit products}_i$$

$$\text{Realized gains/losses on bondholdings(excl. credit products)}_i$$

$$= \begin{cases} min\begin{bmatrix}\text{Avg. realized gains/losses on bondholdings in past 3 years}_i\\ +\text{Difference in realized gains/losses on stockholdings and its past 3-year avg.}_i,\\ \text{Realized gains on bondholdings (excl. credit products)}_i \times \text{upper limit of realization rate}\end{bmatrix} \\ \qquad (\text{Valuation gains on bondholdings}_i \geq 0) \\ 0 \qquad (\text{Valuation gains on bondholdings}_i < 0) \end{cases}$$

$$\text{Devaluation of alternative investment and credit products}_i = \text{Devaluation ratio}(*) \times \text{Outstanding amount of bondholdings (book value)}_i$$

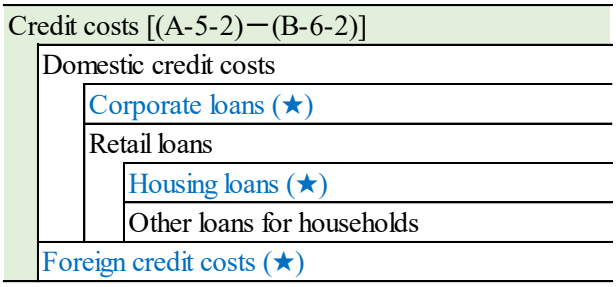
*The product is devaluated once its market value falls below a half of its book value.

[72] However, to ensure consistency with banks' past behavior, an upper limit is set to the percentage of valuation gains on bondholdings that are realized. Specifically, we identify the period when each individual bank realized the largest amount of gains on bondholdings in the past, and the upper limit is set to the median of the percentages for those periods, which is about 30 percent. Moreover, even if realized gains/losses on bondholdings are lower than the average of the past three years, it is assumed that the difference is not made up for by realized gains/losses on stockholdings.

3.2.3. Credit costs

Credit costs are calculated as the sum of domestic and foreign credit costs for internationally active banks, and as domestic credit costs for domestic banks and *shinkin* banks (Chart 11). Domestic credit costs are divided into those on corporate loans[73] and those on loans to individuals, with the latter consisting of credit costs on housing loans and credit costs on the other loans to individuals.[74] While credit costs on corporate loans and on housing loans are modeled separately,[75] those on other personal loans are not modeled due to their small size, and the credit cost ratio for other personal loans is assumed to be the same as that for corporate loans.

Chart 11. Credit costs



Note: The ★ denotes items that are modeled as endogenous variables. The letters and numbers in square brackets show the correspondence to the income statement items in Chart 6.

Credit cost model for domestic corporate loans

Starting with credit costs for domestic corporate loans, for net loan loss provisions and write-offs, the model is constructed using the transition matrix between different risk categories of borrowers (estimated based on the historical amount of loans for each transition) for each individual bank (Chart 12).[76] Losses on sales of nonperforming loans

[73] Corporate loans include not only loans to nonfinancial corporations but also specialized lending (project finance, object finance, real estate finance, etc.) and loans to the financial industry.

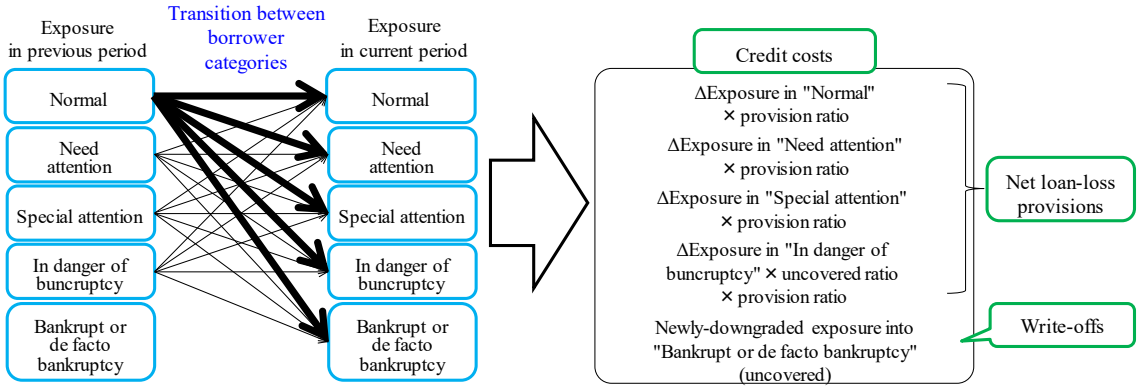
[74] For example, credit card loans fall into this category.

[75] In recent years, accounting regimes overseas, particularly in the United States and Europe, have moved from incurred loss provisioning to expected credit loss (ECL) provisioning (in Europe, ECL provisioning based on IFRS 9 was introduced in 2018, while in the United States the Financial Accounting Standards Board introduced current ECL provisioning in 2020). As a result, there may be structural changes in the relationship between macroeconomic variables such as GDP and credit costs recorded by banks. Going forward, if such structural change arises in Japan, we plan to examine how to deal with this in the model while referring to examples overseas.

[76] The BOJ conducts a questionnaire survey of banks that hold current accounts at the BOJ regarding the classification of their borrowers on a semi-annual basis in the case of banks and on an annual basis

and recoveries of write-offs are assumed to be zero during the simulation period in all scenarios.

Chart 12. Transition between risk categories of borrowers



Banks make loan loss provisions and write-offs when a borrower is downgraded (for example, if the borrower transitions from being a "normal" borrower to one that "needs attention"),[77] 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 losses arise directly).[78] Moreover, for loans to "bankrupt or de facto bankrupt" borrowers, the loan-loss provision ratio is set to 100 percent and the loss is counted toward credit costs. The credit cost calculation for loans to borrowers that are "in danger of bankruptcy" and to "bankrupt or de facto bankrupt" borrowers also takes into account the percentage of loans covered by collateral or guarantees (the coverage ratio), which varies across banks.[79] This model structure is in line with the way that banks calculate credit costs in practice.[80]

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in the case of *shinkin* banks. Borrower classifications are based on the self-assessment categories specified in the Financial Services Agency's Inspection Manual for Financial Institutions. There are five categories: "normal" borrowers, borrowers that "need attention," borrowers that require "special attention," borrowers that are "in danger of bankruptcy," and borrowers that are "bankrupt or de facto bankrupt." The borrower classification transition matrix data obtained from this survey makes it possible to capture the transition of borrowers and their loans from the beginning of the period to each category at the end of the period.

[77] The nonperforming loan ratio used in the aforementioned domestic lending interest rate model is defined as the percentage of firms classified as requiring "special attention" or below in each period, as calculated in the borrower classification transition model. The default rate used in the risk-weighted asset model for exposures to corporate loans, discussed below, is defined as the probability that a firm has been downgraded to "special attention" or below during the past six months in this borrower classification transition model.

[78] Generally, the lower the internal rating, the higher the loan-loss provision ratio.

[79] The coverage ratio is specified such that it is positively linked with land prices.

[80] As noted above, the BOJ's questionnaire survey regarding the classification of borrowers is conducted semi-annually for banks and annually for *shinkin* banks. While the transition probabilities

The transition probabilities between risk categories of borrowers are assumed to be linked to borrower firms' financial conditions and are specified to depend on the GDP growth rate, which is a proxy for borrower firms' sales and profits, and on the ICR, which indicates borrowers' interest payment capacity. The GDP growth rate can be regarded as an indicator of borrower firms' short-term liquidity, while the ICR is an indicator of their medium- to long-term debt repayment capacity. In general, a deterioration in the macroeconomic conditions and/or firms' financial position is seen to have a nonlinear effect on the probability of downgrades and the default rate.[81] For this reason, in the panel estimation of transition probabilities, a logistic model taking such nonlinearities into account is used. Moreover, instead of the economy-wide GDP growth rate and ICR, the weighted averages of industry-level GDP growth rates and ICRs employing the industry composition of individual banks' corporate loans as weights are used. This makes it possible to take into account the heterogeneity in the industry composition of banks' loans.

When calculating the GDP growth rate and ICR for individual banks, the FMM takes into account not only the heterogeneity in the industry composition of loans but also in the composition of borrower firms' size – i.e., whether they are large firms or small and medium-sized enterprises (SMEs) –. In addition, the FMM also considers the heterogeneity among SMEs in terms of whether they are low-return borrowers (i.e., borrowers that, although classified as "normal" borrowers, are in fact in a relatively poor financial condition (so-called medium-risk firms)). The low-return borrowers are defined following the April 2018 FSR (Chapter VI) as firms with a relatively weak financial position (i.e. firms whose ROAs are below the median and whose leverages are above the median of all firms) whose borrowing interest rates are low relative to their credit risk through business cycles, and taking such heterogeneity into account allows for the possibility that the sensitivity of these low-return borrowers to risk factors may differ

between borrower categories therefore are estimated on a semi-annual basis for banks and on an annual basis for *shinkin* banks, in the forward-looking simulations loan-loss provisions and write-offs are calculated on a quarterly basis. For example, to obtain banks' loan loss provisions and write-offs in the April-June quarter of 2022, which is assumed to be the first quarter of the simulation period, we first estimate the values for the semiannual period from January to June 2022. The amounts for the January-March quarter, a rough estimate of which is obtained by dividing the actual values for the semiannual period from October 2021 to March 2022 by two, are then subtracted from the estimate to obtain the values in the April-June quarter. For subsequent quarters, the values are similarly calculated on a semiannual basis and the simulated values for the previous quarter are subtracted.

[81] Using firm-level microdata, the FSR Appendix "A Forecast Model for the Probability of Default Based on Granular Firm-Level Data and Its Application to Stress Testing" (May 2019) shows that (1) firms' probability of default tends to increase nonlinearly as their interest payment capacity decreases, and that (2) such an increase in the probability of default is much larger for more leveraged firms. In addition, it has been shown that, in Japan, the relationship between the ICR and the probability of default is also nonlinear (see the October 2018 FSR for details).

from that of the other borrowers.[82] The share of SMEs and the share of low-return borrowers among SMEs in banks' loan portfolios are assumed to remain unchanged during the simulation period from the actually observed values just before the simulation period.

For the estimation of domestic credit costs, the estimates of the parameters in linear regression are used for the baseline scenario, while for the stress scenario the estimates of the parameters in 90th percentile quantile regression are used. Thus, by using different parameters corresponding to the economic and financial conditions in the scenarios, the nonlinear relationship between the independent and dependent variables is reproduced in the model.

[82] When simulating the credit costs of individual banks, we proceed as follows. We first estimate the borrowers' ICR for each borrower category defined in terms of firms' industry, size, and low-return borrower status separately, taking into account the possibility that the sensitivity to macroeconomic fluctuations of each borrower category may differ. We then create an index by taking the weighted average of the ICRs using individual banks' shares of loans to these different borrower categories as weights. Finally, regarding this as a sufficient statistic to represent borrower firms' financial condition, we calculate banks' credit costs. Meanwhile, low-return borrowers are defined as SMEs that meet one of the following two criteria in two 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 of the most creditworthy firms in the ROA distribution (i.e., firms in the top 10 percent of 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 of firms with a relatively high creditworthiness in the financial leverage distribution (i.e., firms in the bottom 50 percent of the distribution). The estimation uses granular firm-level data, including information on the banks firms transact with. The reason for treating low-return borrowers separately from other firms is that their loans outstanding tend to be large and their ICRs tend to be low, so that their interest payment capacity is likely to be low. As a result, the probability of default of such firms is likely to increase more than that of other firms in the event of a negative macroeconomic shock such as an economic downturn, an increase in procurement costs, and/or an increase in interest rates. In fact, during the global financial crisis, low-return borrowers tended to experience a greater deterioration in their financial indicators (ratio of operating profits to sales and ICR) than non-low-return borrowers. For details, see the April 2018 FSR (Chapter VI). Note that the criteria for determining low-return borrowers are similar to those for so-called zombie firms (see Caballero, Hoshi, and Kashyap 2008, Fukuda and Nakamura 2011, and Kwon et al. 2015), which are defined as firms whose borrowing rates are below the most favorable rates. However, while zombie firms are the result of forbearance lending by banks, low-return borrowers are the result of banks' search for yield, so that the underlying concepts differ somewhat (Kawamoto et al. 2020).

Credit cost model for domestic corporate loans

$$\text{Domestic credit costs (corporate loans)}_i$$

$$= \text{Net loan-loss provisions}_i + \text{Write-offs}_i$$

$$= \Delta \sum_{n=1}^{4} \left[\begin{matrix} \text{Exposure (to borrowers in } n)_i \times \text{Provision rate (of n)}_i \\ \times \text{Uncovered ratio (only for } n = 4)_i \end{matrix} \right]$$

$$+\text{Exposure (to borrowers in } n = 5)_i \times \text{Uncovered ratio (for } n = 5_i)$$

$$\text{Exposure (to borrowers in } n)_i$$

$$= \sum_{m=1}^{4} [\text{Exposure (to borrowers in } m, \text{previous period})_i \times \text{Probability of transition}_i^{m \to n}] \times \text{Domestic loan growth}_i$$

＜Transition probability of borrower risk category from m to n for bank i ($PT_i^{m \to n}$)＞

$$\ln\left(\frac{PT_i^{m \to n}}{1 - PT_i^{m \to n}}\right) = \alpha_1^{m \to n} \times GDP \text{ growth}_i + \alpha_2^{m \to n} \times ICR_i + \text{Fixed effect}_i + \text{Constant}$$

—— m and n denote risk categories of borrowers. Δ denotes difference. $\alpha_1^{m \to n}$ and $\alpha_2^{m \to n}$ denote the coefficients to predict transition between borrower risk category from m to n.

Credit cost model for domestic housing loans

Credit costs for housing loans are calculated by first estimating the rate of loans overdue by three months or more, then calculating the hypothetical credit cost ratio in the absence of credit guarantees, and finally taking into account the portion of loans covered by credit guarantees. To estimate the rate of overdue loans, the unemployment rate to capture the employment and income situation of borrowers and (three-month) government bond yields to represent the interest rate burden are used as explanatory variables. The rate of overdue loans rises with increases in the unemployment rate[83] and interest rates. The credit cost ratio in the absence of credit guarantees is assumed to be linked to this rate of overdue loans. The credit cost ratio is then calculated by multiplying the hypothetical credit cost ratio in the absence of credit guarantees by the unguaranteed loan ratio of each bank. Finally, credit costs are calculated by multiplying the credit cost ratio by the outstanding amount of housing loans.

[83] The scenario for the unemployment rate assumes that the unemployment rate responds with a certain sensitivity (estimated value) to changes in the domestic output gap. Since the domestic output gap is linked to the level of domestic GDP, given potential GDP, if domestic GDP is treated as an endogenous variable, the unemployment rate is also an endogenous variable.

Credit cost model for domestic housing loans

$$\begin{aligned}
&\text{Domestic credit costs (housing loans)}_i \\
&= \text{Domestic credit cost ratio (housing loans in the absence of guarantees)}_i \\
&\times \text{Unguaranteed loan ratio}_i \times \text{Housing loans}_i \\
&= \begin{pmatrix} \alpha_1 \times \text{Delinquency rate (overdue by more than 3-month)}_i \\ +\text{Fixed effect}_i + \text{Constant} \end{pmatrix} \\
&\qquad \times \text{Unguaranteed loan ratio}_i \times \text{Housing loans}_i \\
&\ln\left(\frac{\text{Delinquency rate}_i}{1 - \text{Delinquency rate}_i}\right) \\
&= \alpha_1 \times \text{Unemployment rate} + \alpha_2 \times \text{Short-term interest rate [3-month T-Bills]} \\
&\qquad +\text{Fixed effect}_i + \text{Constant}
\end{aligned}$$

Credit cost model for foreign loans

The credit cost model for foreign loans is a model using transition probabilities between different risk categories of borrowers and has a similar structure as the credit cost model for domestic corporate loans.[84] While the growth rate of borrower firms' sales is used as an explanatory variable instead of the GDP growth rate, since the sales growth rate is specified such that it is predicted by the GDP growth rate, etc., the GDP growth rate is still used in effect as an explanatory variable. In addition, the ICR is used in the same form as in the model for domestic corporate loans. The same is true for the growth rate of sales and the ICR for each bank, which are calculated by taking the weighted averages of industry-level growth rate of sales and the ICR using the industry composition of banks' loans to foreign corporations as weights.

However, when estimating the sensitivity of the transition probabilities to the sales growth rate and the ICR, data on the transition probabilities of external ratings in the corporate bond market for foreign firms are used, because long-term time series data for those transition probabilities are available.[85] Specifically, the sensitivity of the transition probabilities to foreign firms' sales growth rate (at the sample median) and ICR (at the sample median) are estimated, and the transition probabilities for each bank during the simulation period are estimated by adding the estimated change in transition probabilities during the simulation period (due to changes in the sales growth rate, etc.) to the actually observed transition probabilities just before the simulation period. Note that, due to the small sample size in terms of the number of historical transition probabilities used for this

[84] Losses on nonperforming credit sales and recoveries of write-offs are assumed to be zero during the simulation period in all scenarios.

[85] Data from Moody's credit risk calculator is used.

estimation, linear regression instead of quantile regression is used to estimate parameters.

Credit cost model for foreign loans

$$\text{Foreign credit costs}_{\ i} = \sum_{c=1}^{3} \left(\text{Net loan} - \text{loss provisions}_{c,i} + \text{Write-offs}_{c,i}\right)$$

$$\text{Net loan-loss provisions}_{c,i} + \text{Write-offs}_{c,i}$$

$$= \Delta \sum_{n=1}^{4} \begin{bmatrix} \text{Exposure (to borrowers in } n)_{c,i} \\ \times \text{Provision rate (of } n)_{c,i} \\ \times \text{Uncovered ratio (only for } n = 4)_{c,i} \end{bmatrix}$$

$$+\text{Exposure (to borrowers in 5)}_{c,i} \times \text{Uncovered ratio for n} = 5_{c,i}$$

$$\text{Exposure (to borrowers in } n)_{c,i}$$

$$= \sum_{m=1}^{4} \begin{bmatrix} \text{Exposure (to borrowers in } m, \text{previous period})_{c,i} \\ \times \text{Probability of transition}_{c,i}^{m \to n} \\ \times \text{Foreign loan growth}_{i} \end{bmatrix}$$

＜Transition probability from borrower risk category m to n for bank i in country c ($PT_{c,i}^{m \to n}$)＞

$$ln\left(\frac{PT_{c,i}^{m \to n}}{1 - PT_{c,i}^{m \to n}}\right) = \alpha_1^{m \to n} \times GDP \text{ growth}_{c,i} + \alpha_2^{m \to n} \times ICR_{c,i} + \text{Fixed effect}_{c,i} + \text{Constant}$$

—— m and n denote risk categories of borrowers. c denotes foreign countries and regions (America, Europe and Asia and Pacific). Δ denotes difference. $\alpha_1^{m \to n}$ and $\alpha_2^{m \to n}$ denote the coefficients to predict transition of borrower risk category from m to n.

3.3. Module for valuation gains/losses on securities holdings

The module for valuation gains/losses on securities holdings is used to calculate the valuation gains/losses at the end of each period on securities held by banks. Specifically, valuation gains/losses are determined by adding estimated changes in market value during the period to the valuation gains/losses at the beginning of the period, and then making adjustments based on the sales and devaluation of securities determined in the module for realized gains/losses on securities holdings (Chart 13).[86] Calculations for stocks etc. are made separately for stocks and investment funds, while calculations for bonds are made separately for government bonds and credit products (Chart 14). The following explains how changes in the market values of these financial instruments during the period are estimated.[87]

[86] Proceeds from the sale and devaluation of securities are assumed to be reinvested at current market values at the time. Further, reinvestments of an amount equal to the sale or redemption amount (book value) are assumed to be made in a manner that maintains the composition of banks' portfolios at market values.

[87] The financial variables used to calculate valuation gains/losses on securities holdings are shown in Chart A4 in Appendix 3.

Chart 13. Flow of calculation of valuation gains/losses on securities holdings

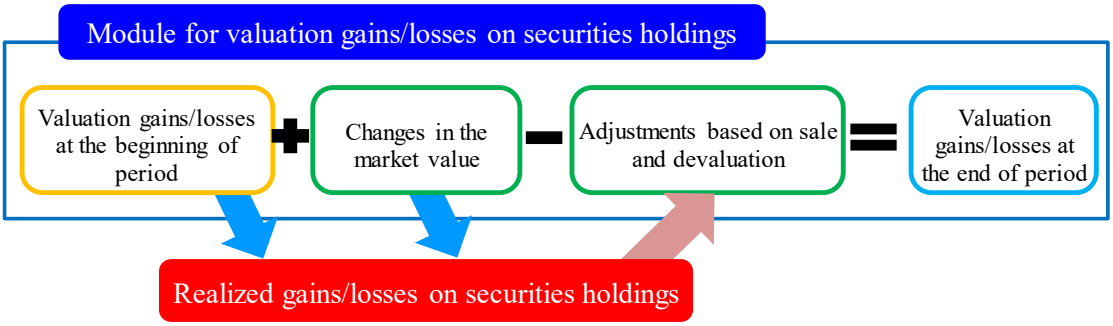

Chart 14. Securities in the module for valuation gains/losses on securities holdings

Valuation gains/losses on securities holdings
Valuation gains/losses on bondholdings
Government bonds, etc
Domestic credit products
Coporate bonds (AAA, AA, A and BBB rated or lower, incl. bank debentures)
Foreign government bonds
Dollar-denominated
Euro-denominated
Foreign credit products
Coporate bonds (AAA, AA, A, BBB, BB, B and CCC rated or lower, incl. bank debentures)
CLO (AAA, AA, A, BBB and BB rated or lower)
CMBS (AAA, AA, A and BBB rated or lower)
RMBS
ABS (AAA and AA rated or lower)
Direct lending funds
Bank loan funds (BB rated or higher and B rated or lower)
Valuation gains/losses on stockholdings
Domestic stocks and stock investment trusts
Domestic investment funds and alternative investments
Bond investment funds
Credit investment funds
Real estate investment funds
Balanced funds
Hedge funds
Foreign stocks and stock investment trusts
Foreign investment funds and alternative investments
Real estate investment funds
Hedge funds
Private equity

Changes in the market value of JGBs etc. and foreign government bonds during the simulation period are calculated as changes in the discounted present value of future principal and coupon income using the domestic and foreign government bond interest rates by remaining maturity in the scenario. While the way that changes in the market value of domestic and foreign credit products are estimated is generally the same as that for JGBs etc., interest rates of these products are calculated by adding exogenously determined credit risk premiums (spreads) for different types of products and ratings to government bond interest rates. In addition, we assume that a decline in external ratings (in the line with the scenario for the transition probabilities of external ratings) leads to a further increase in spreads.[88] For domestic and foreign stocks and alternative investments, changes in market value are calculated in line with changes in stock and fund prices in the scenario for the financial variables.[89]

3.4. Risk-weighted assets module

Risk-weighted assets (RWA) consist of the sum of following three elements: RWA for credit risk, RWA for market risk, and RWA for operational risk.[90] However, what we model in the form of a function are RWA for credit risk items that account for a large share on a value basis – specifically, corporate and sovereign exposures (including securitization exposures), retail exposures, stock exposures, and (among counterparty credit risks) credit value adjustments (CVA) – as well as RWA for operational risk, which make up the largest share of RWA other than RWA for the credit risk items listed above (Chart 15).

[88] The lower the rating of a bond, the larger the spread tends to be in the event of stress, and the scenarios are set on this basis.

[89] For foreign government bonds and stocks as well as foreign credit products and foreign alternative investments, it is assumed that foreign exchange rate risks are fully hedged, so that their market values are not linked to exchange rates.

[90] Credit risk refers to the risk of incurring losses due to defaults by borrowers or issuers of securities, market risk refers to the risk of incurring losses due to securities price fluctuations in trading operations, and operational risk refers to the risk of incurring losses due to operational errors such as clerical errors or fraud by financial institutions' employees or the failure of IT systems.

Chart 15. Risk-weighted assets module

- Risk-weighted assets
  - Credit risk
    - Corporate and sovereign exposures (incl. securitization exposures)
      - Loans (★)
      - Credit products (Coporate bonds, securitized products) (★)
      - The others
    - Retail exposures (★)
    - Stock exposures (★)
    - CVA (★)
    - The others
  - Market risk
  - Operational risk (★)

Note: The ★ denotes items that are modeled as endogenous variables.

RWA for credit risk items other than the ones just mentioned and RWA for market risk are specified as remaining unchanged from the actual values just before the simulation period. While the classification of exposures differs between banks using the standardized approach and those using the internal ratings approach, the above classification is used in the FMM for both types of banks, for the sake of simplicity. The following sections explain the models for RWA for corporate and sovereign exposures, retail exposures, stocks exposures, CVA risks, and operational risks.

Risk-weighted asset model for corporate and sovereign exposures

RWA for corporate and sovereign exposures are divided into RWA for corporate loan exposures (such as loans to corporations and financial institutions),[91] exposures to investments in credit products such as corporate bonds and securitized products, and the other exposures (such as sovereign debt) and calculated as follows.

First, RWA for corporate loan exposures are calculated by multiplying risk weights by the amount of corporate loans. The treatment of risk weights differs for banks using the standardized approach and those using the internal ratings approach: in the case of the former, risk weights are assumed to remain unchanged from their recent actual values,[92] while in the case of the latter they are calculated by multiplying the risk weights specified in accordance with the Basel regulations by a bank-specific level adjustment term

[91] Specialized lending is also included.

[92] In practice, even for financial institutions using the standardized approach, risk weights may increase due to a decline in external ratings, etc. However, due to data limitations, the FMM assumes that their risk weights remain unchanged from the end of the pre-simulation period.

calculated based on banks' historical risk weights. The risk weights for corporate loans of banks using the internal rating approach are specified such that the risk weight increases in line with increases over the preceding six months in the probability of default on domestic corporate loans calculated in the credit cost model. Next, RWA for exposures to credit products are specified such that risk weights change in response to changes in the external ratings of securities by domestic and foreign issuers (due to changes in GDP growth, ICRs, etc.) in line with the external ratings-based approach,[93] which is one approach to calculate the RWA for securitization exposures. The level of computed risk weights is then adjusted using each bank's historical risk weights. In the calculation of exposures to credit products, market values are used for internationally active banks, while book values are used for domestic banks and *shinkin* banks.[94] The other RWA are assumed to remain unchanged from the end of the pre-simulation period.

Risk-weighted asset model for corporate loan exposures

$$\text{RWA for corporate loans}_i$$

$$= \text{RW for corporate loans}_i \times \text{Corporate loans}_i$$

$$\text{RW for corporate loans}_i$$

$$= \begin{cases} \text{Actual RW for corporate loans}_i \\ < \text{For banks adopting standardized approach (SA)} > \\ \text{Level adjustment term}_i \times \text{Estimated RW coefficient}_i \\ < \text{For banks adopting internal rating based approach (IRB)} > \end{cases}$$

$$\text{Estimated RW coefficient}_i \equiv \Phi\left(\sqrt{\frac{1}{1-\rho_i}} \times \Phi^{-1}(PD_i) + \sqrt{\frac{\rho_i}{1-\rho_i}} \times \Phi^{-1}(0.999)\right) - PD_i$$

$\Phi \cdots$ Cummulative distribution function of standard normal distribution,

$PD \cdots$ Averaged probability of default, $\rho \cdots$ Correlation coefficient

[93] The external ratings-based approach is an approach in which risk weights are applied based on the ratings of eligible rating agencies and the remaining maturity of securitized products. Other approaches are as follows: the internal ratings-based approach, in which the underlying assets of securitized products are assumed to be directly held and risk weights are calculated by substituting the required capital ratio calculated based on the internal ratings approach into a prescribed formula; the standardized approach, in which the underlying assets of securitized products are assumed to be directly held and risk weights are calculated by substituting the required capital ratio calculated based on the standardized approach into the prescribed formula; and the internal assessment approach, in which the internal ratings assigned by a bank are linked to the ratings by eligible rating agencies and risk weights are calculated by applying the external ratings-based approach.

[94] Book values are used for the exposures of domestic banks and *shinkin* banks for consistency with the FSA's public notice on domestic banks (the same applies below).

Risk-weighted asset model for retail exposures

RWA for retail exposures consist of RWA for exposures to loans to individuals and RWA for the other retail exposures.

Risk-weighted asset model for exposures to loans to individuals

$$\text{RWA for loans to individuals}_i$$
$$= RW \text{ for loans to individuals}_i \times \text{Loans to individuals}_i$$
$$RW \text{ for loans to individuals}_i$$
$$= \begin{cases} \text{Actual } RW \text{ for retail exposures}_i < \text{For banks adopting SA} > \\ \alpha_{1,i} \times \text{Delinquency rate of housing loan (overdue by more than 3-month)}_i \\ \quad + \text{Fixed effect}_i + \text{Constant } < \text{For banks adopting IRB} > \end{cases}$$

RWA for exposures to loans to individuals are calculated by multiplying the corresponding risk-weights by the amount of domestic loans to individuals. The risk weighting of loans to individuals also differs between banks that use the standardized approach and those that use the internal rating approach: while in the case of the former, risk weights are assumed to remain unchanged from their recent actual values, in the case of the latter they are specified to fluctuate reflecting changes in borrowers' creditworthiness. Specifically, risk weights for loans to individuals are assumed to depend on the rate of loans overdue by three months or more,[95] and risk weights increase as the rate of loans overdue rises.[96] RWA for the other retail exposures are assumed to remain unchanged from the end of the pre-simulation period.

Risk-weighted asset model for stock exposures

RWA for stock exposures are calculated by multiplying exposures to stocks, etc., by the risk weights for stocks, etc. While risk weights for all banks are fixed at their most recent actual values in line with the simple risk weight method under the market-based approach, market values are used for the stock exposures of internationally active banks and book

[95] Since loans to individuals by Japanese banks primarily consist of housing loans, the same rate of loans overdue is used as a proxy for borrowers' creditworthiness in whole retail loans.

[96] The sensitivity of risk weights to the rate of loans overdue by three months or more is assumed to differ across banks, reflecting the fact that it does differ in practice. Meanwhile, the formula for calculating RWA for retail exposures for banks using the internal rating approach is broadly similar to that used for corporate exposures; however, since data on the probability of default, etc., are not available for retail loans, RWA are modeled using a reduced form equation with the rate of loans overdue by three months or more, which is considered to be correlated with the probability of default, by estimating the sensitivity of risk weights to the rate of loans overdue.

values for those of domestic banks and *shinkin* banks.[97]

Risk-weighted asset model for stock exposures

<Internationally active banks>

$$\text{RWA for stocks exposures}_i = \text{Actual RW for stocks, etc.}_i \times \text{Outstanding amount of stocks, etc. (market value)}_i$$

<Domestic banks>

$$\text{RWA for stocks exposures}_i = \text{Actual RW for stocks, etc.}_i \times \text{Outstanding amount of stocks, etc. (book value)}_i$$

Risk-weighted asset model for CVA risk

CVA risk[98] is modeled only for some large banks with large amounts of RWA for CVA risk, while for the other banks RWA for CVA risk are assumed to remain unchanged from the most recent actual values. For the former, U.S. corporate bond spreads (with a BBB rating) are used as an explanatory variable in order to incorporate changes in average external ratings (probability of default) of counterparties into changes in CVA risk.[99]

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[97] There are three methods for calculating RWA for stock exposures: (1) the simple risk weight method under the market-based approach, in which prescribed fixed risk weights are used; (2) the internal models method, in which financial institutions use internal risk measurement models; and (3) the PD/LGD approach, in which stock exposures are regarded as corporate exposures. Due to data constraints, in the FMM RWA for stock exposures are modeled using the simple risk weight method under the market-based approach for all banks.

[98] CVA risk refers to the risk of losses in derivative transactions due to a counterparty downgrade. Of the counterparty losses on derivatives that materialized during the 2008 global financial crisis, only one-third were due to actual counterparty defaults, while the remaining two-thirds were due to CVA losses. Therefore, when Basel III was introduced, capital rules were set out that take CVA risk as part of counterparty credit risk into account (Basel Committee on Banking Supervision 2011).

[99] There are three methods for measuring CVA risk – the advanced risk measurement method, the standard risk measurement method, which is used by many internationally active banks, and the simple method (under which the RWA for CVA risk equal 12 percent of RWA for derivative transactions), which is used by most domestic banks and *shinkin* banks. In the FMM, CVA risk is modeled based on the standard risk measurement method. However, since it is difficult to obtain data such as on the exposure to each counterparty and the maturity and outstanding notional amounts of CVA risk hedging instruments, which are needed for the standard risk measurement method, only changes in CVA risk due to changes in the external credit rating of counterparties are specified and estimated in reduced form. This specification, in which CVA risk changes in line with changes in counterparties' probability of default, is similar to the model used in the Dodd-Frank Act Stress Tests in the United States (Federal Reserve 2021). Meanwhile, since a large share of counterparties (excluding central counterparty clearing houses) in the derivatives transactions of Japanese banks are non-residents, the model uses U.S. corporate bond spreads rather than Japanese ones.

Risk-weighted asset model for CVA risk

$$\begin{aligned}&\text{RWA for CVA risk}_i\\&\quad=\text{Actual values of RWA for CVA risk}_i\\&\qquad\times(1+\alpha_1\times\Delta\,\text{U.S. corporate credit spread (BBB rated)})\end{aligned}$$

Risk-weighted asset model for operational risk

Regulatory requirements for operational risk allow for the use of the basic indicator approach, the gross income allocation approach and the advanced measurement approach.[100] In the FMM, operational risk is linked to gross operating income (excluding realized gains/losses on bondholdings)[101] in a manner that mimics the basic indicator approach for all banks.[102] Since this item represents only a small percentage of each bank's total RWA, a relatively simple specification is used.

Risk-weighted asset model for operational risk

$$\text{RWA for operational risk}_i=\alpha_1\times\text{Gross operating income}_i+\text{Fixed effect}_i+\text{Constant}$$

3.5. Capital adequacy module

The capital adequacy module consists of the model to calculate the amount of capital that forms the numerator of the regulatory capital adequacy ratio, i.e., Common Equity Tier 1 capital (CET1 capital) in the case of internationally active banks and core capital in the case of domestic banks and *shinkin* banks. In both cases, the model focuses on changes in banks' capital during the simulation period relative to their actual amount of capital just before the simulation period.

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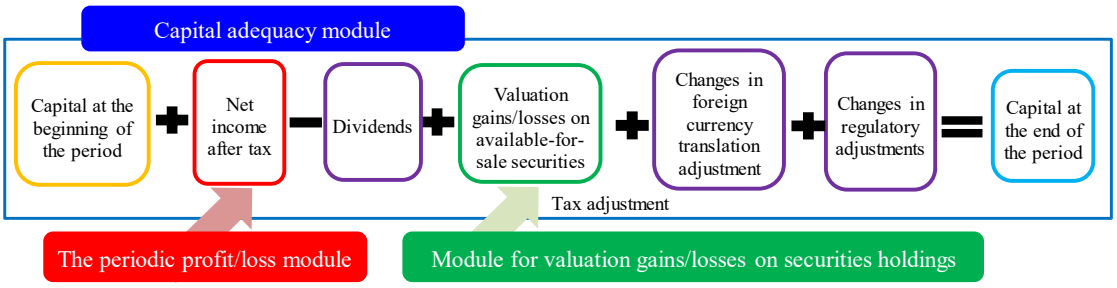
[100] In the basic indicator approach, operational risk is set to 15 percent of the average annual gross income over the preceding three years. In the gross income allocation approach, annual gross income is allocated to eight business segments (retail banking, commercial banking, payment and settlement, retail brokerage, trading and sales, corporate finance, agency services, and asset management). The gross income of each segment is then multiplied by a fixed percentage and the three-year average of the resulting sum is taken as the amount of operational risk. In the advanced measurement approach, the amount of operational risk is assumed to be equivalent to the maximum expected operational risk loss calculated based on the operational risk measurement approach employed in the bank's internal controls.

[101] Gross operating income = Net interest income + Net fees and commissions + Net trading income + Other net non-interest income.

[102] In the basic indicator approach RWA for operational risk is calculated as the average of 15 percent of gross income (= gross operating income – realized gains/losses on bondholdings) + fees and commissions payments over the most recent three years. However, since fees and commissions payments are not modeled in the FMM, the RWA for operational risk is approximated by gross operating income (excluding realized gains/losses on bondholdings).

In terms of internationally active banks, their CET1 capital is divided into CET1 components and CET1 regulatory adjustments. Major items contributing to changes in CET1 components are net income (after tax) calculated in the periodic profit/loss module, dividends, valuation gains/losses on available-for-sale securities calculated in the module for valuation gains/losses on securities holdings, and foreign currency translation adjustments (Chart 16).

Chart 16. Overview of the capital adequacy module (Internationally active banks)



Specifically, net income (after tax) calculated in the periodic profit/loss module is added to the amount of capital at the beginning of the period, and dividend payments calculated based on the dividend model described below are subtracted. Furthermore, any changes in valuation gains/losses on available-for-sale securities or foreign currency translation adjustment related to foreign subsidiaries, etc., are added or subtracted. When valuation gains increase, for example, deferred tax assets on temporary differences shrink, assuming a uniform effective tax rate of 40 percent.

In addition, CET1 regulatory adjustments are specified such that intangible assets and deferred tax assets on temporary differences, which are assets that are difficult to use to absorb losses, are deducted in line with regulations, while double gearing regulations[103] are also taken into account (Chart 17).

[103] Double gearing occurs when one financial institution invests in other financial institutions. Double gearing regulations aim to limit double gearing in order to prevent the propagation of risks within the financial system, such as a chain of financial institution failures, by deducting a certain amount of such investments from banks' capital. In a simplified manner, the FMM takes the specific details of regulations for (1) intentional cross-shareholdings, (2) investments in minority-owned financial institutions (financial institutions in which the investing financial institution holds voting rights of 10 percent or less), and (3) investments in other financial institutions (financial institutions in which the investing financial institution holds voting rights of more than 10 percent as well as fellow enterprises) into account.

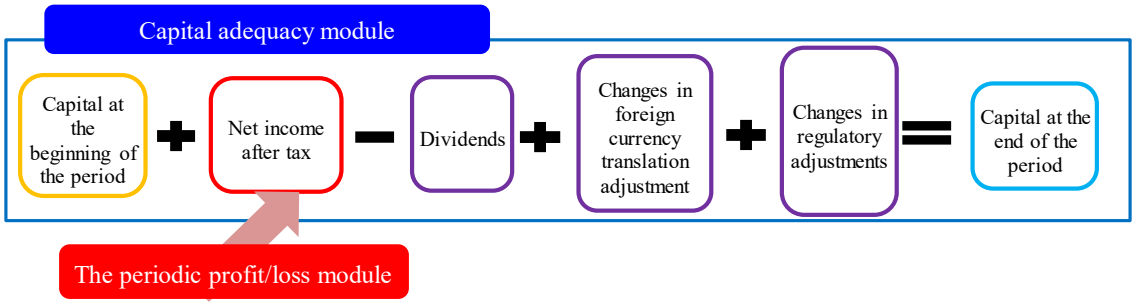
Chart 17. Capital adequacy module (Internationally active banks)

CET1 (Common Equity Tier 1) capital (CET1 components－CET1 regulatory adjustments)
CET1 components
Common share and retained earnings (value at the previous period＋Net income－Dividends)
Net income after tax
Dividends (★)
Accumulated other comprehensive income
Valuation on available-for-sale securities
Foreign currency translation adjustment (★)
The others
CET1 regulatory adjustments
Certain items for limited recognition (10%/15% thresholds)
Deferred tax assets from temporary differences
Other certain items
The others

Note: The ★ denotes items that are modeled as endogenous variables.

As for domestic banks and *shinkin* banks, the core capital ratio is calculated. While the flow of the calculation is identical to that for the CET1 capital of internationally active banks, there are some differences in the items taken into account. The main difference is that valuation gains/losses on available-for-sale securities are excluded from core capital components (Chart 18). Therefore, with regard to changes in the market value of available-for-sale securities, only realized changes such as gains/losses on sales or impairments have an effect on capital adequacy ratios.

Chart 18. Overview of the capital adequacy module (Domestic banks)



Meanwhile, in addition to modeling core capital regulatory adjustments for domestic banks and *shinkin* banks, transitional arrangements related to capital financing instruments and accumulated other comprehensive income (such as revaluation reserves

for land) stipulated only under domestic regulations, are also taken into account (Chart 19).[104,105]

Chart 19. Capital adequacy module (Domestic and *shinkin* banks)

Core capital (Core capital components－Core capital regulatory adjustments＋Transitional adjustments)				
	Core capital components			
		Common share and retained earnings (value at the previous period＋Net income－Dividends)		
			Net income after tax	
			Dividends (★)	
		Part of accumulated other comprehensive income		
	Core capital regulatory adjustments			
	Transitional arrangements for core capital			

Note: The ★ denotes items that are modeled as endogenous variables.

Total capital of internationally active bank and capital of domestic banks, which are the numerators of the total capital adequacy and capital adequacy ratios used as explanatory variables in the loan model and the foreign funding interest rate model, are calculated in accordance with Basel III and regulations for domestic financial institutions. Specifically, internationally active banks' total capital is calculated by adding other Tier 1 capital and Tier 2 capital to the aforementioned CET1 capital, where other Tier 1 capital and Tier 2 capital is, in principle, assumed to remain unchanged over the simulation period.[106] For domestic banks and *shinkin* banks, core capital is used as the successor to capital.[107]

Dividend model

The dividend model assumes that if the net income of a bank in a particular period is positive, the bank pays dividends in line with the average dividend payout ratio over the past three years (dividend payout ratio = dividends/net income). However, because the payout ratio tends to be extremely high during periods when net income is small, an upper limit of 30 percent is set. Meanwhile, if a bank's net income is negative, it is assumed that it does not pay a dividend. Share buybacks are not taken into account.

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[104] Specifically, transitional arrangements for eligible former non-cumulative perpetual preferred stocks, eligible former capital financing instruments, land revaluation differences, non-controlling interests, and capital financing instruments issued through measures related to the strengthening of capital bases by public authorities are taken into account.

[105] As in the case of internationally active banks, foreign currency translation adjustments are also taken into account, but their contribution to changes in core capital is tiny.

[106] General provisions are specified to fluctuate in line with changes in loans.

[107] While the components included in capital and core capital differ slightly, core capital is used because the discrepancies in the time-series data for the two are small.

Dividend model

$$\text{Common share and retained earnings}_i \ [\text{chg. from previous year}]$$
$$= \text{Net income (after tax)}_i$$
$$- max[\text{Net income (after tax)}_i \times min[\gamma, \text{Average payout ratio in past 3 years}_i], 0]$$

—— where γ is set to 0.3 in order to exclude outliers.

Foreign currency translation adjustment model

The foreign currency translation adjustment model assumes that the foreign exchange differences that arise when translating the financial statements of banks' foreign subsidiaries, etc. into yen depend on the net assets of those subsidiaries and the exchange rate (dollar/yen). The exchange rate sensitivity of foreign currency translation adjustments is estimated assuming that it is identical across banks. Meanwhile, for simplicity, the net assets of foreign subsidiaries are assumed to remain unchanged during the simulation period.

Foreign currency translation adjustment model

$$\text{Foreign currency translation adjustment}_i$$
$$= \text{Foreign currency translation adjustment}_i \ [\text{previous quarter}]$$
$$+ \alpha_1 \times \text{Exchange rates [USD/JPY, q/q chg.]} \times \text{Foreign subsidiaries' net assets}_i$$

—— Foreign subsidiaries' net assets are assumed constant during the simulation period.

4. Example of Macro Stress Testing

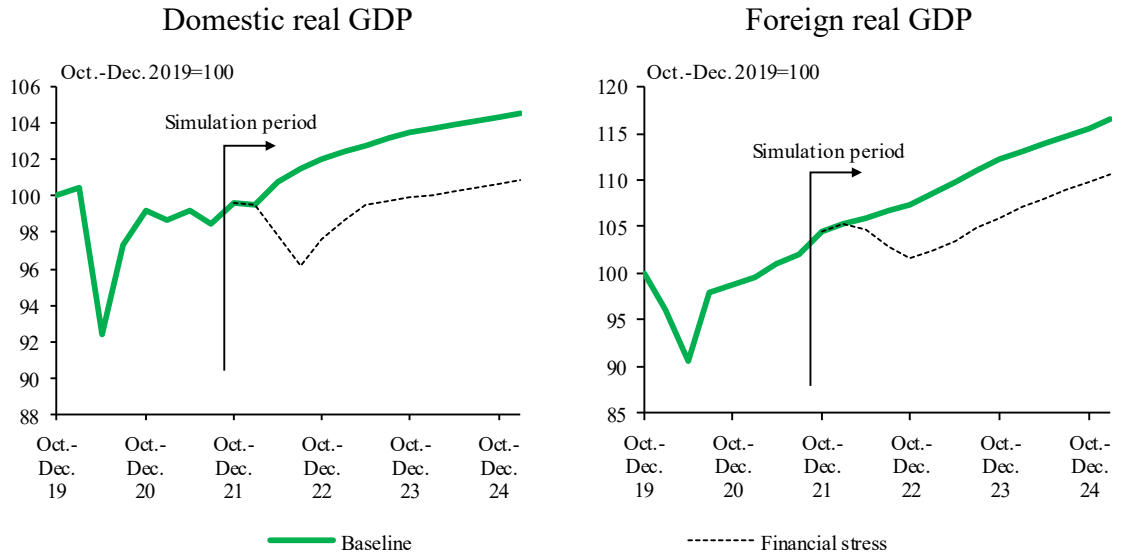
In this section, we demonstrate the detail of the analysis using the FMM and a hypothetical stress scenario in which a crisis equivalent to the global financial crisis of 2008 materializes in the April-June quarter of 2022 (hereinafter referred to as the "financial stress scenario"), where the end of pre-simulation period is July-September 2021.[108] As mentioned earlier, from the perspective of identifying the risk characteristics of banks, it is useful to examine the deviation of the simulation results in the financial stress scenario from the baseline scenario. We show such comparison in the latter part of this section.

[108] The analytical example presented in this section corresponds to the one analyzed and published as the macro stress test under the "Financial Stress Scenario" in the April 2022 FSR.

4.1. Scenario

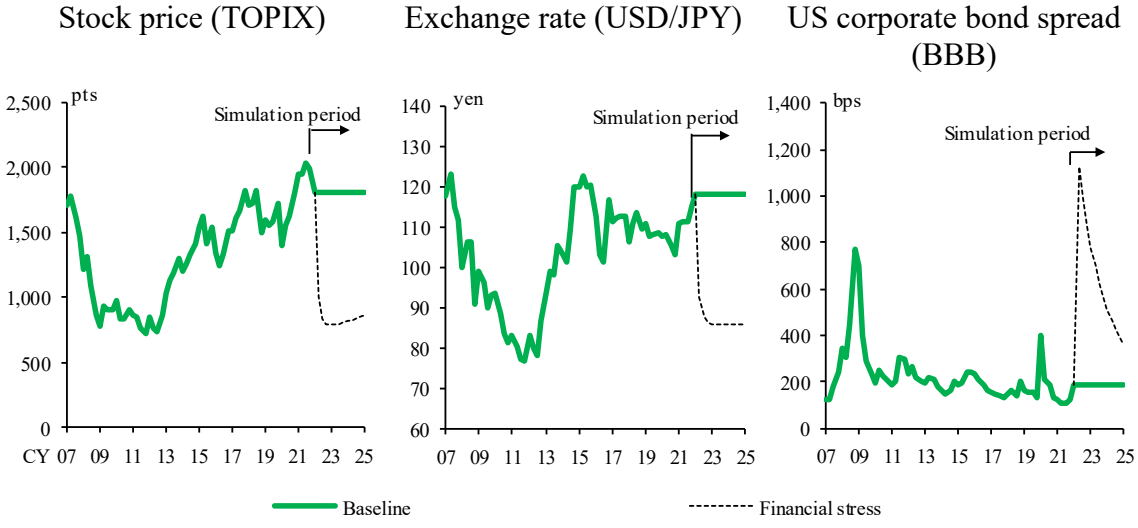
The baseline scenario assumes that the real economy follows the average forecasts by professional forecasters as of March 2022 (Chart 20). In terms of financial variables, we assume that asset prices in the market as of mid-March 2022 reflect forecasts of the domestic and foreign economies by market participants. Furthermore, government bond interest rates follow the forward rates factored into the yield curve as of the same date, and stock prices, exchange rates, and domestic and foreign credit spreads remain unchanged from their March 2022 levels (Chart 21).

Chart 20. Scenarios for real economy



Source: BEA; Cabinet Office; Eurostat; Haver Analytics; IMF; Japan Center for Economic Research.

Chart 21. Scenarios for financial variables



Source: Bloomberg; FRB; Haver Analytics.

In the financial stress scenario, we consider a situation in which international financial market experiences a significant deterioration comparable to the global financial crisis in the April-June quarter of 2022, which has a negative impact on financial intermediation and exerts downward pressure on the real economy at home and foreign, causing a feedback loop between domestic economy sector and domestic banking sector.[109]

We assume that the paths of foreign economies after April-June 2022 follows a trajectory similar to that observed during the global financial crisis (Chart 20). For the Japanese real economy, we conduct a simulation to estimate the effects of an exogenous shock similar to the global financial crisis on the Japanese economy.

For most financial variables, we assume that a large and rapid adjustment comparable to the global financial crisis occurs in the international financial markets between April and June 2022 (Chart 21).[110] However, for some financial variables, we take into account the possibility that the fluctuations in financial variables during times of stress may have changed in recent years, as investment funds have increased their presence in the global financial system. More specifically, we assume that spreads on relatively highly rated bonds are more likely to widen than they did during the global financial crisis, as evidenced by the rapid market downturn in March 2022.[111] We assume that government bond interest rates fall to record lows and remain unchanged thereafter.

4.2. Simulation results[112]

This sub-section illustrates the simulation results in line with the description of the model

[109] At the time of the global financial crisis, the capital adequacy ratios of Japanese banks were relatively low compared to the current level, which may have had a strong feedback loop of restraining lending behavior of banks and further depressing the real economy. Since the crisis, Japanese banks have increased their capital, and assuming the same level of stress in the real economy, the current feedback loop is likely to be relatively muted. In this regard, when constructing scenarios, the paths of foreign real economies and financial variables are exogenously given, and then domestic real GDP is calculated endogenously from the model by incorporating the feedback loop. See, for example, the April 2021 FSR for a discussion of the effect of the accumulation of capital by Japanese banks after the global financial crisis on GDP through the suppression of feedback loop under stress.

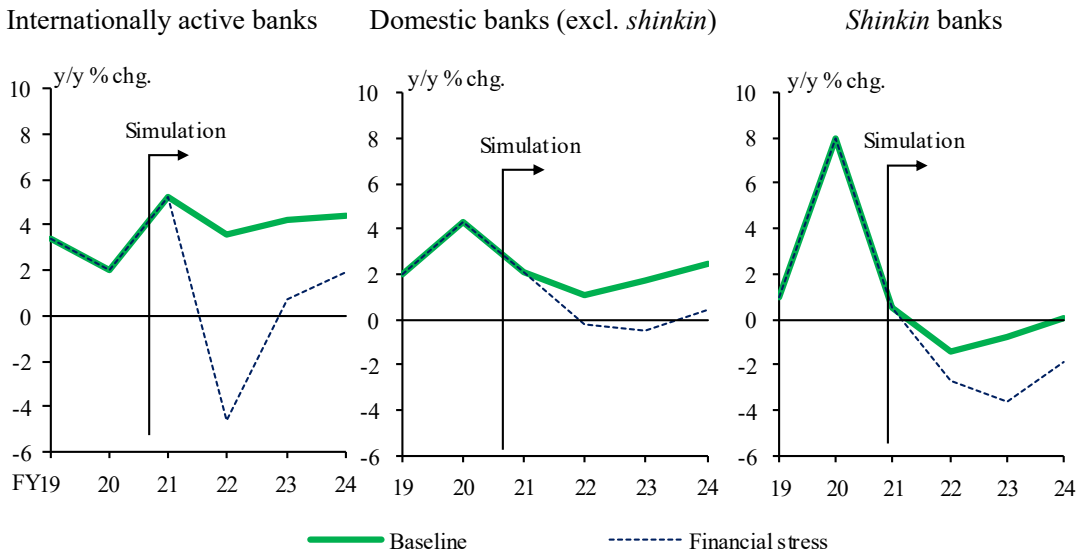
[110] We assume that the dollar funding premium for all Japanese banks also expand to the same level as during the global financial crisis. The simulation estimates the increase in foreign currency funding costs for each bank, taking into account the shift of each bank's funding source towards deposits after the global financial crisis.

[111] For U.S. corporate bonds and securitized products, we assume a situation where the increase in the spread for high-rated bonds is larger than that during the global financial crisis. To do this, we first take the ratio of the spread for low-rated bonds during the global financial crisis to that during the March 2020 market turmoil, which is about three for U.S. corporate bonds. We then multiply the ratio with the spread increase for each rating in March 2020 to obtain the degree of increase in the spread during the simulation period.

[112] The simulation takes into account the effects of policy responses by the government and the BOJ

structure in Section 3. First, we look at loan outstanding, which is the only factor that fluctuates among the investment and funding accounts. In the baseline scenario, the loan outstanding for both internationally active banks and domestic banks excluding *shinkin* banks maintains a positive year-on-year growth rate (Chart 22). The loan outstanding for *shinkin* banks temporarily decreases during fiscal 2022 and 2023, but recovers to positive growth in 2024. The temporary decrease is due to the assumption on the repayment of effectively interest-free loans, which were introduced by the government as a funding support measure for small and medium-sized enterprises (SMEs) after the spread of Covid-19 in 2020 and which contributed to large growth in the loan outstanding for *shinkin* banks in fiscal 2020.[113] Next, in the financial stress scenario, the loan outstanding for all types of banks is significantly lower than in the baseline scenario, and it declines in fiscal 2022 compared to the previous year. The decline is partly due to the supply side effect, in addition to the demand side effect such that the demand for loans from corporates declines. Specifically, in the financial stress scenario, the capital adequacy ratios of banks, especially internationally active banks, significantly decline to the level close to that required by the capital buffer regulation, suppressing the loan supply of banks. A feedback loop, mentioned in the previous subsection, denotes such phenomenon.

Chart 22. Loans outstanding

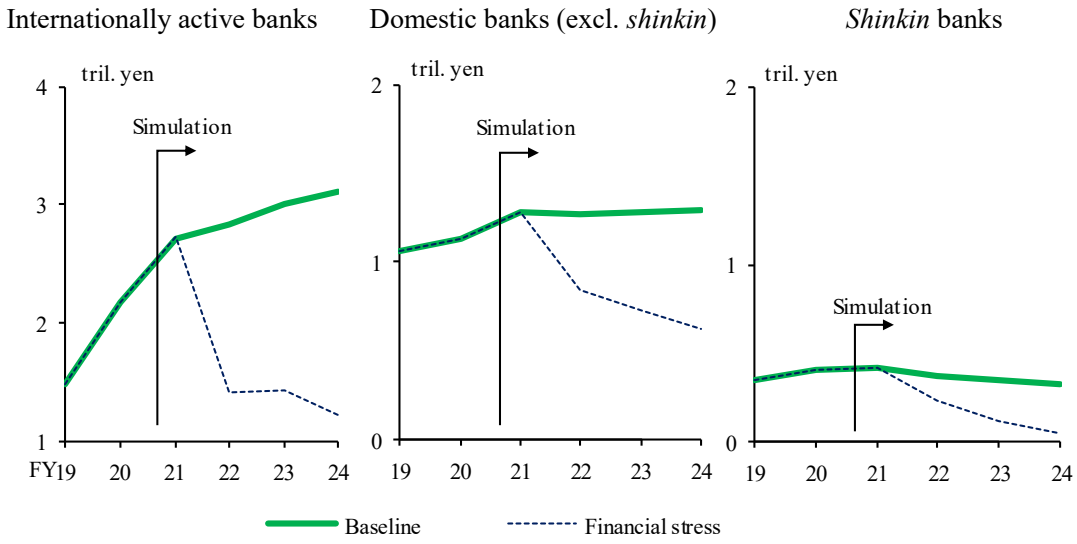


as well as lending by banks since the outbreak of Covid-19 in 2020 through February 2022. For more details, see the macro stress test in the April 2022 FSR. Also, see Appendix 5 for specific implementation of the support measures into the simulation using the FMM.

[113] After the spread of Covid-19, effectively interest-free loans by private banks have been introduced from May 2020 to March 2021 as a measure to support liquidity of SMEs. As a result, the loan outstanding to domestic firms increased in fiscal 2020, especially at regional banks, which tend to lend to SMEs.

Second, we break down the simulation results for periodic profits/losses into three components: PPNR excluding trading income, realized gains/losses on securities holdings, and credit costs. In the baseline scenario, on the one hand, PPNR excluding trading income increases for internationally active banks as their loans outstanding grow steadily, especially to foreign borrowers, while their lending margins do not change significantly (Chart 23). On the other hand, even as loans outstanding for domestic banks and *shinkin* banks continue to increase, their PPNR excluding trading income remains flat due to the impact of a shrinking trend in lending margins caused by fiercer competition in the loan market.[114] In contrast, in the financial stress scenario, loans outstanding of internationally active banks decline due to a sharp drop in demand for loans as the real economy deteriorates.[115] At the same time, the squeeze in foreign lending margins due to higher foreign currency funding costs contributes to a large decline in PPNR excluding trading income. Due to a slowdown in the domestic economy, domestic banks and *shinkin* banks experience a decrease in loan demand, resulting in a decline in their loans outstanding, although they are relatively unaffected by the rise in foreign currency funding costs.

Chart 23. PPNR excluding trading income

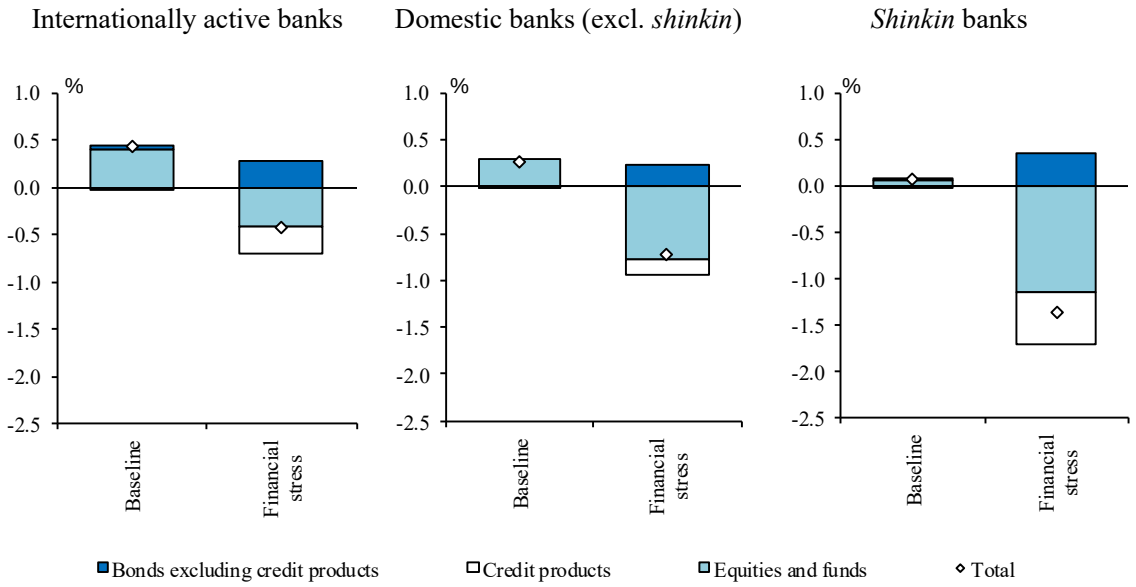


[114] This shrink in lending margin reflects a gradual decline of the loan demand index, an explanatory variable in the domestic loan interest rate model, in line with historical trend.

[115] The sensitivity of the foreign loans to changes in the foreign GDP is higher than that of the domestic loans to changes in the domestic GDP. This is based on the average sensitivity during past recessions, including the global financial crisis when foreign lending declined considerably. However, the model may not be able to capture the impact of the increased importance of foreign operations by Japanese banks in recent years.

Realized gains/losses on securities holdings (cumulative values for fiscal 2021-2024) in the baseline scenario are positive due to the realization of gains on stockholdings, while valuation gains/losses on securities holdings just before the simulation period are generally positive in all types of banks (Chart 24). In contrast, in the financial stress scenario, realized gains/losses on securities holdings exhibit loss by large impairment losses on stocks, funds, and credit products due to the shocks to financial variables. In the meantime, the negative impact is partially offset by realized gains on bondholdings, mainly among banks that continue to post positive valuation gains on the holdings of bonds excluding credit products.[116]

Chart 24. Realized gains/losses on securities holdings
(cumulative totals of fiscal 2021-24)



Note: Ratio relative to RWA as of the end of fiscal 2020.

Credit costs in the baseline scenario remain almost unchanged from the period just before the simulation period. In the financial stress scenario, credit costs sharply increase due to the impact of downturn in domestic and foreign economies (Chart 25). Moreover, the credit cost ratios peak in fiscal 2022, when the real economy is most depressed. For internationally active banks with a large share of foreign loans among their portfolio,

[116] The increase in realized gains from bonds in the financial stress scenario relative to the baseline scenario is due not only to the mechanism by which losses from stocks are offset by gains from bonds, but also to the fact that valuation gains on bonds increase during the simulation period as government bond interest rates decline.

foreign credit costs substantially contribute to the overall credit cost ratios (Chart 26).[117]

Chart 25. Credit cost ratios

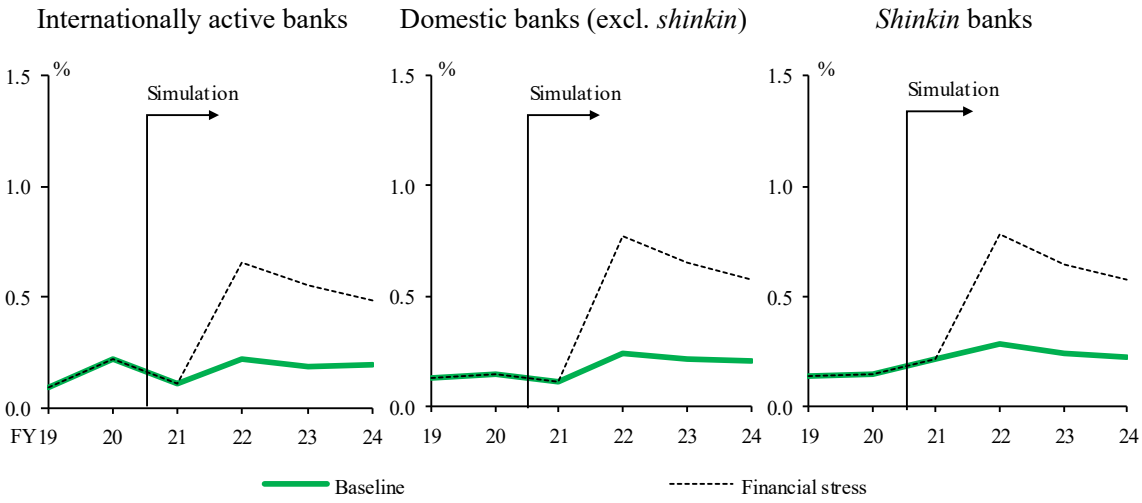
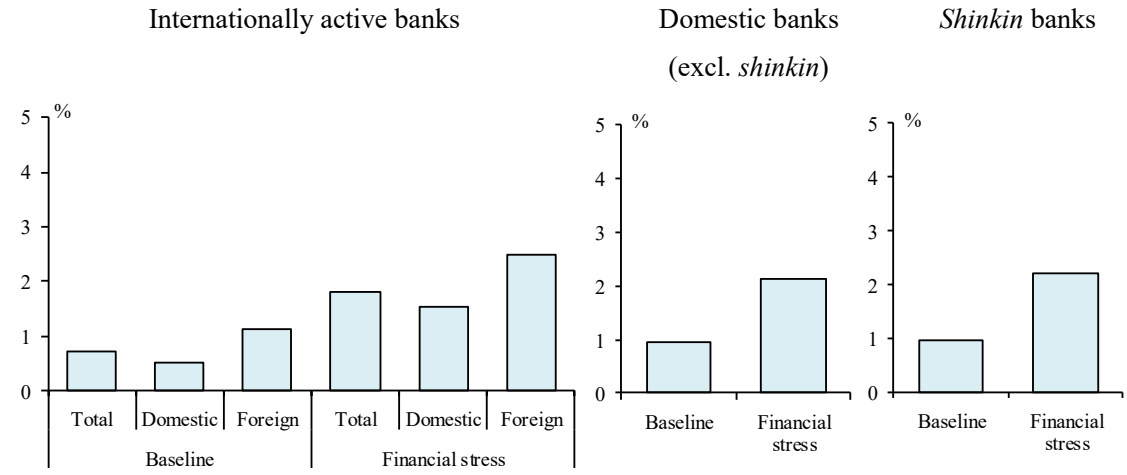


Chart 26. Credit cost ratios (cumulative totals of fiscal 2021-24)

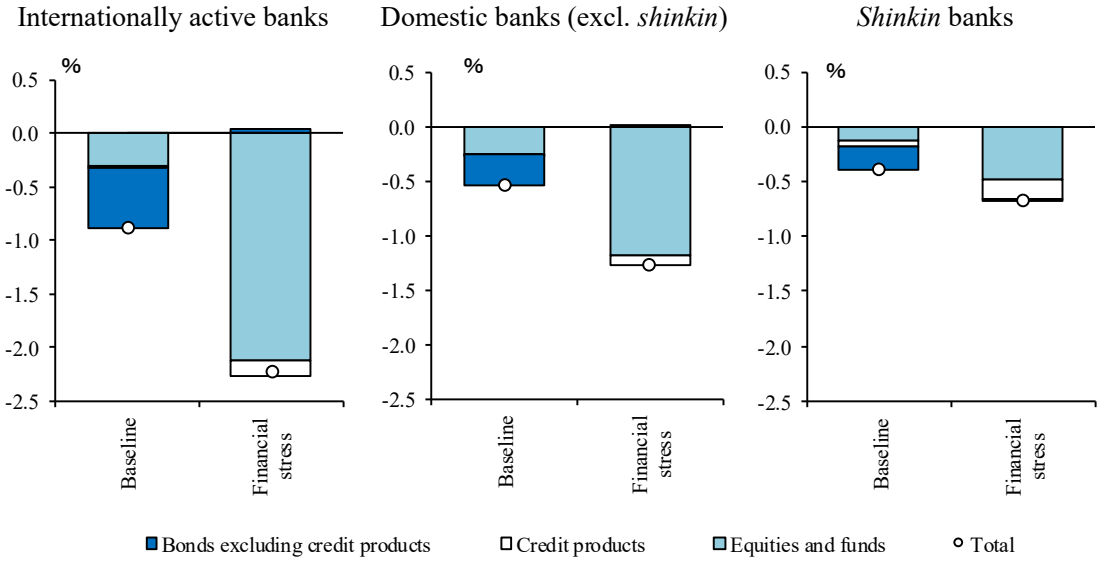


Third, with regard to valuation gains/losses on securities holdings (change from fiscal 2020 to 2024), in the baseline scenario, valuation gains/losses on bondholdings, excluding credit products, decline in all types of bank, as government bond interest rates rise

[117] The reason why the dynamics of the credit cost ratio of banks and that of *shinkin* banks are slightly different is that the frequency of banks' credit cost models is semiannual, while that of *shinkin* banks' models is annual. For instance, when calculating semi-annual and annual changes based on the same quarterly GDP scenario, annual GDP changes are less sensitive to short-term GDP fluctuations. As a result, the fluctuation in the estimates of the credit cost ratio based on annual model tends to be less volatile than that based on semi-annual model.

moderately (Chart 27). In contrast, in the financial stress scenario, valuation gains/losses deteriorate significantly with contributions from the decrease in the values of stocks, fund investments, and credit investments. It should be noted that such valuation gains/losses on securities holdings affect the capital adequacy ratio only for internationally active banks.

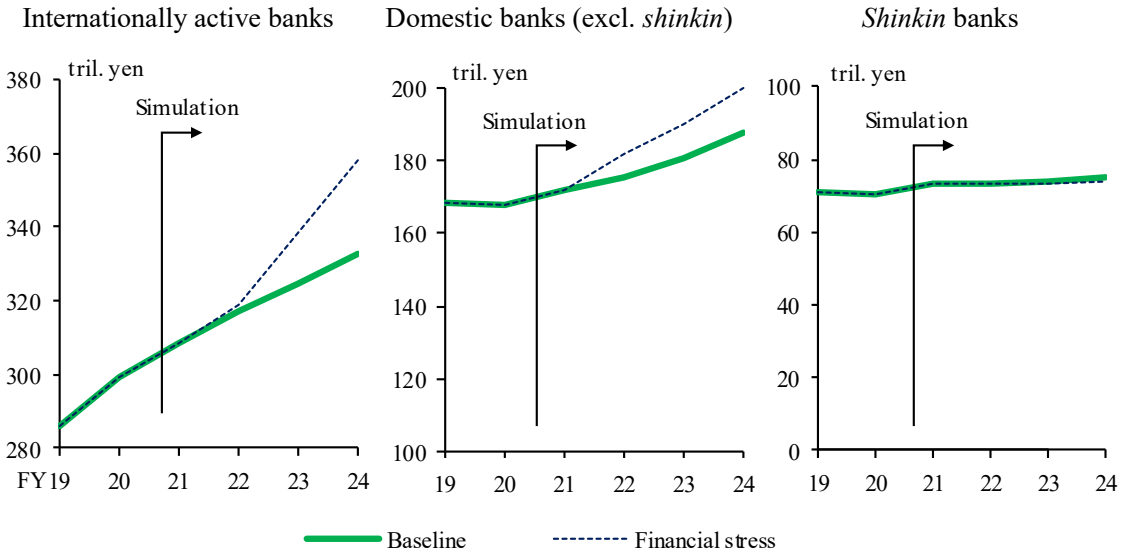
Chart 27. Valuation gains/losses on securities holdings
(change from fiscal 2020 to 2024)



Note: The estimates take tax effects into account. Ratio relative to RWA as of the end of fiscal 2020.

Fourth, with regard to risk-weighted assets, in the baseline scenario internationally active banks, whose loans outstanding exhibit relatively fast growth, shows a large increase. Conversely, risk-weighted assets of domestic banks excluding *shinkin* banks show a moderate increase, and those of *shinkin* banks remain almost unchanged (Chart 28). In the financial stress scenario, the risk-weighted assets of internationally active banks and domestic banks excluding *shinkin* banks are, on the one hand, pushed up by the increase in the risk weights due to the deterioration of their portfolio, mainly among banks using the internal rating approach. On the other hand, the decrease in loans outstanding push down their risk-weighted assets. The former effect outweighs the latter, so their risk-weighted assets exceed those of the baseline scenario. In contrast, the risk-weighted assets of *shinkin* banks in the financial stress scenario are similar to those in the baseline scenario, as risk-weights remain unchanged due to the use of the standardized approach, while the degree of decrease of loans outstanding is limited.

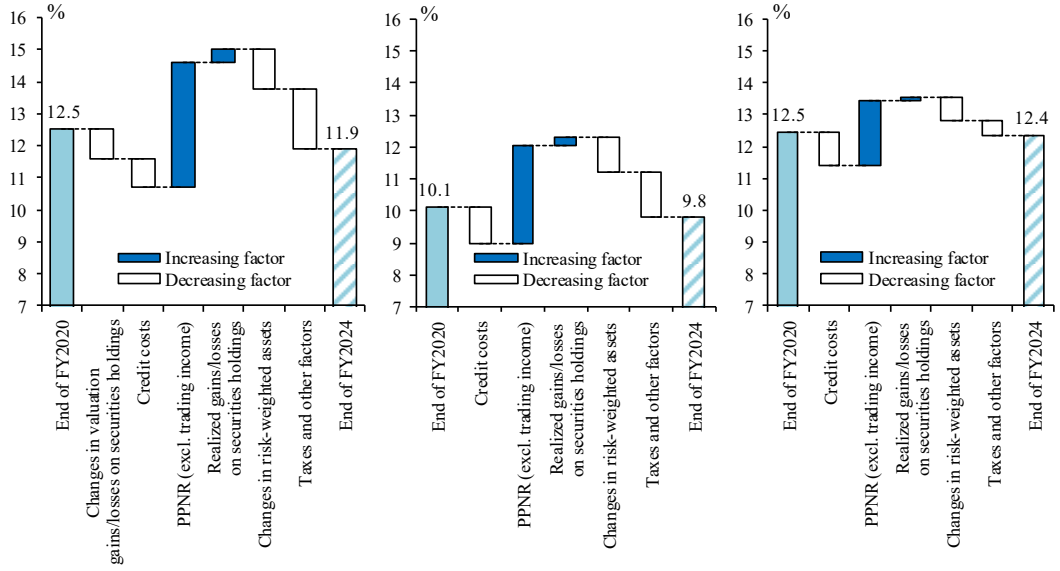
Chart 28. Risk-weighted assets



Based on the aforementioned simulation results in each module, the capital adequacy ratio at the end of fiscal 2024 in the baseline scenario deteriorates somewhat from the fiscal 2020 level (Chart 29), as the increase in PPNR excluding trading income is offset by the increase in credit costs and risk-weighted assets, as well as a deterioration in valuation gains/losses on securities holdings for internationally active banks. In the financial stress scenario, PPNR excluding trading income, realized gains/losses on securities holdings, and credit costs all contribute to downward pressure relative to the baseline scenario, and the capital adequacy ratio at the end of fiscal 2024 is significantly lower than in the baseline scenario (Chart 30). In particular, the capital adequacy ratios of internationally active banks, where valuation gains/losses on securities holdings decline and risk-weighted assets increase due to higher risk weight, are significantly depressed. The capital adequacy ratios of some banks fall below the level required by their capital buffer regulation.

Chart 29. Decomposition of capital adequacy ratio (baseline scenario)

Internationally active banks　　Domestic banks (excl. *shinkin*)　　*Shinkin* banks

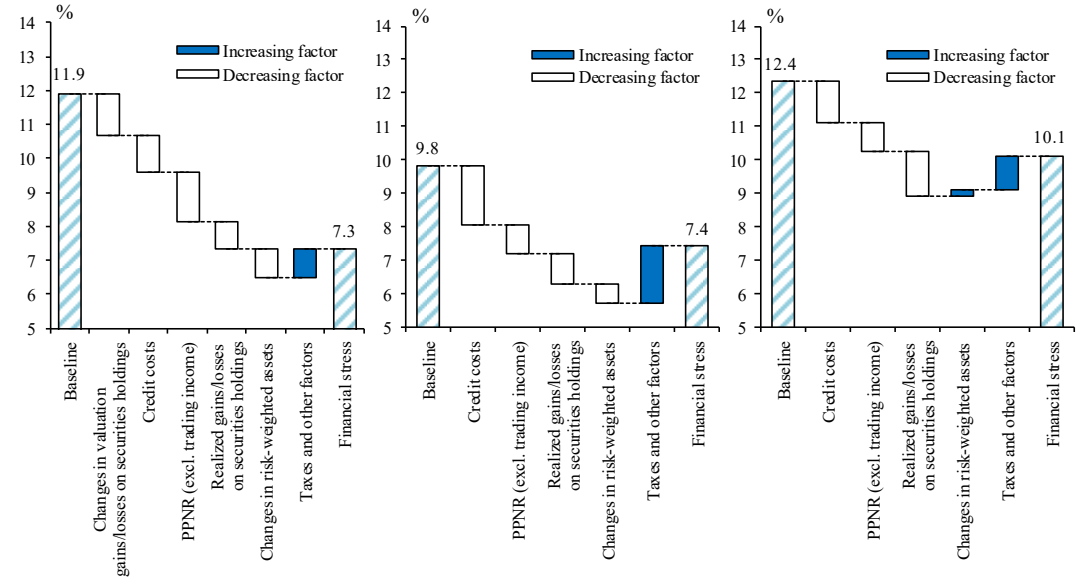


Note: 1. The charts indicate the contribution of each factor to the difference between the capital adequacy ratios as of end-March 2021 and the end of the simulation period (as of end-March 2025) under the baseline scenario.

2. The left-hand chart shows the CET1 capital ratio of internationally active banks. The middle and right-hand charts show the core capital ratio of domestic banks.

Chart 30. Decomposition of capital adequacy ratio (financial stress scenario)

Internationally active banks　　Domestic banks (excl. *shinkin*)　　*Shinkin* banks



Note: 1. The charts indicate the contribution of each factor to the difference between the capital adequacy ratios as of the end of the simulation period (end-March 2025) under the baseline and the financial stress scenario.

2. The left-hand chart shows the CET1 capital ratio of internationally active banks. The middle and right-hand charts show the core capital ratio of domestic banks.

So far, we explain the simulation results of the baseline scenario and the financial stress scenario, with a particular emphasis on the contribution of each module described in Section 3 to the difference in the capital adequacy ratios of the two scenarios. Instead, here we consider the contribution of each sector (domestic economy sector, foreign economies sector, and domestic and foreign financial markets sector) (Chart 31).[118] First, the CET1 ratio for internationally active banks, which is 11.9% at the end of fiscal 2024 in the baseline scenario, declines to 7.3% in the financial stress scenario. The decline is attributed to the deterioration of the domestic economy sector by -1.3 percentage points, the deterioration of the foreign economies sector by -0.8 percentage points, and the deterioration of the domestic and foreign financial markets sectors by -2.5 percentage points.[119] The deterioration of the domestic and foreign economies substantially affects the capital adequacy ratios mainly through higher credit costs resulting from the deterioration of borrowers' creditworthiness. The deterioration in the domestic and foreign financial markets affects the capital adequacy ratios through the deterioration in realized and valuation gains/losses on securities holdings, which results from the decline in the market value of securities holdings, and through the decrease in PPNR excluding trading income, which results from higher funding interest rates and lower interest and dividend income. Next, for domestic banks excluding *shinkin* banks, the capital adequacy ratio, which is 9.8% at the end of fiscal 2024 in the baseline scenario, declines to 7.4% in the financial stress scenario. The decline is attributable to the deterioration of the domestic economy by -1.3 percentage points and the deterioration of domestic and foreign financial markets by -1.1 percentage points.[120] The deterioration in the domestic economy, as in the case of internationally active banks, affects the capital adequacy ratios of domestic banks mainly through an increase in the credit costs. The deterioration in domestic and foreign financial markets affects the capital adequacy ratios through a deterioration in realized gains/losses on securities holdings, which results from a decline in the market value of securities holdings, and through PPNR excluding trading income, which results from a decrease in interest and dividend income. Unlike internationally active banks, the

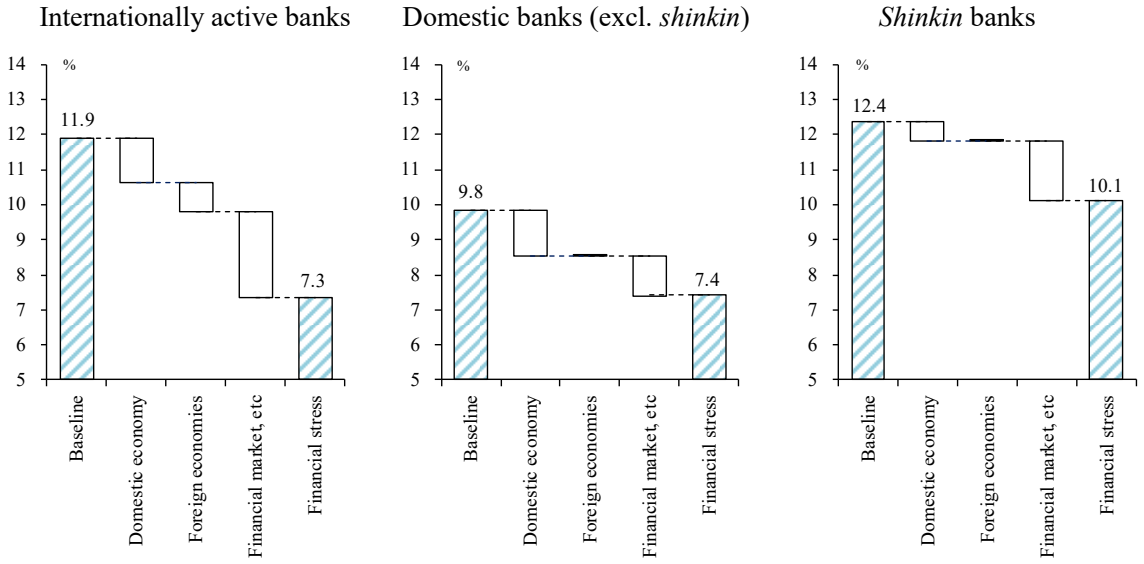
[118] Specifically, for example, the contribution of the domestic economy sector is calculated as the difference between the capital adequacy ratio in the baseline scenario and that obtained by running a simulation based on the scenario variables (exogenous variables), among which those belonging to the domestic economy sector are equal to the values in the financial stress scenario and those belonging to other sectors are equal to the values in the baseline scenario.

[119] The impact of a nonlinear term and other factors are included in the deterioration of the domestic and foreign financial markets sector. The impact of the deterioration in domestic and foreign financial markets alone is -2.5 percentage points.

[120] The impact of a nonlinear term and other factors are included in the deterioration of the domestic and foreign financial markets sector. The impact of the deterioration in domestic and foreign financial markets alone is -0.9 percentage points.

domestic banks excluding *shinkin* banks are largely unaffected directly by the deterioration in the foreign economies sector due to the relatively small size of their foreign business. In terms of *shinkin* banks, the capital adequacy ratio, which is 12.4% at the end of fiscal 2024 in the baseline scenario, declines to 10.1% in the financial stress scenario. This is because of a -0.5 percentage point contribution from the deterioration in the domestic economy sector and a -1.7 percentage point contribution from the deterioration in the domestic and foreign financial markets sector.[121] While the qualitative features of the contributions of each sector are similar to those of the domestic banks excluding *shinkin* banks, their relatively high ratio of credit investments to risk-weighted assets makes *shinkin* banks more susceptible to deterioration in the domestic and foreign financial markets sector.

Chart 31. Decomposition of capital adequacy ratio by sector (financial stress scenario)



Note: 1. The charts indicate the contribution of each sector to the difference between the capital adequacy ratios as of the end of the simulation period (end-March 2025) under the baseline scenario and the financial stress scenario.

2. The left-hand chart shows the CET1 capital ratio of internationally active banks. The middle and right-hand charts show the core capital ratio of domestic banks.

Relatedly, to demonstrate the nonlinearity in the simulation results of the FMM against the degree of stress on the scenario variables, Appendix 4 provides simulation results in the "1/2 financial stress scenario," which assumes that the degree of stress on each scenario variable is equal to a half of that in the financial stress scenario.

[121] The impact of a nonlinear term and other factors are included in the deterioration of the domestic and foreign financial markets sector. The impact of the deterioration in domestic and foreign financial markets alone is -1.6 percentage points.

5. Conclusion

The Financial Macro-econometric Model (FMM) employed by the BOJ is a model constructed to simulate the financial conditions of the domestic banking sector in the event of stress and is used mainly for the assessment of risks to the financial system overall, including in the macro stress tests in the FSR.

This paper described the framework of the FMM as of September 2022, focusing on the specification of the domestic banking sector. Compared to the original model in 2011, when the Bank of Japan started using the FMM, the coverage of the model has been substantially expanded, so that the current version of the FMM is able to describe endogenous changes in banks' balance sheets and profits and losses in the event of stress, and also includes the modeling of risk-weighted assets, dividends, and other capital adequacy variables. Moreover, the current FMM also incorporates a variety of complex transmission mechanisms of shocks to the economy. For example, an increase in credit costs in the FMM leads to both a deterioration in periodic profits/losses and an increase in risk-weighted assets, which lower capital adequacy ratios, which then reduces the supply of loans. In addition, lower capital adequacy ratios result in an increase in foreign currency funding costs due to a decline in banks' own creditworthiness.

However, it should be noted that even with these improvements, the FMM still represents only an approximation of certain aspects of the actual financial system and the real economy. Although the FMM has been developed to well explain the developments in historical data and ensure a certain degree of consistency with economic theory, like all other economic models, it cannot perfectly capture economic and financial developments. Moreover, even if the model itself represents a more or less accurate description of reality, quantitative assessments based on the model are subject to technical limitations. For instance, the estimation of parameters is based on historical average relationships between macroeconomic and financial variables and the parameters may not sufficiently incorporate structural changes that have occurred recently. In addition, some of the estimates are based on the assumption that the parameters related to financial variables are the same for all banks of a particular type, and thus may not sufficiently incorporate the heterogeneity across individual banks.

The followings are some points regarding the direction of future improvements to the FMM. The first point concerns work to continue deepening the understanding of the risk characteristics of various exposures held by banks and reflect them in the model. For example, while the model for credit risks related to corporate loans in the FMM is designed to reflect differences in the risk characteristics of individual borrowers to a

reasonable degree, it is important to continue to refine the model in this regard, because of the borrowers' heterogenous risk characteristics, as shown by the differences in the variation in corporate profits across industries and firms observed in the wake of outbreak of the Covid-19 pandemic in 2020 and by the differences in risk characteristics in the real estate industry highlighted in the April 2022 edition of the Financial System Report. In addition, using granular data, it would be desirable to analyze the impact of firm-level shocks on the banking sector and the economy at the macro level[122] and the transmission of shocks through transaction relationships among firms and banks[123] and to reflect these in the model.

The second point concerns the refinement of the modeling of the behavior of economic and financial variables during crises, including liquidity crises. Since the FMM currently focuses on sufficiency of banks' capital adequacy, liquidity risks are not explicitly considered. However, once a fire sale, for example, occurs – i.e., a situation arises in which debt-related stress at a particular financial institution results in the deterioration of the securities portfolios of many financial institutions through the dumping of the value of assets – the scale of stress may increase. From the perspective of assessing the resilience of the financial system to stress, it is necessary to deepen our understanding of the phenomena that occur at times of crisis but are rarely observed during normal times, for example by using high-frequency data, and incorporate them into the model.

The third point concerns the expansion of coverage. From the perspective of expanding the coverage of the range of risks faced by individual financial institutions, it is important to model financial institutions' total exposure, including off-balance sheet items, and subsidiaries. Moreover, in terms of risks faced by the financial system, it is also important to appropriately take the role of non-bank financial institutions, including liquidity risks in the non-bank sector, into account in the model. Another issue to be considered in the future is incorporating the impact of the implementation of the Basel III Finalization, such as in the risk-weighted asset models.[124] Going forward, it will be essential to continue improving the FMM in order to appropriately respond to new issues arising from changes in the environments surrounding Japan's financial system.

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[122] See Arata and Miyakawa (2021, 2022) for details.

[123] See, for example, Fukunaga and Miyakawa (2022).

[124] Specifically, the Basel III Finalization stipulates revisions to the standardized and internal ratings approaches for credit risk, CVA risk measurement methods, and measurement methods for market risk and operational risk, as well as the introduction of a capital floor (see Basel Committee on Banking Supervision 2017b).

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Appendix 1: Structure of the Model of the Domestic Economy Sector

This Appendix shows how the domestic economy sector in the FMM responds to external stress (Chart A1). The stress for domestic economy in stress scenarios of macro stress testing is often derived from changes in economic and financial conditions outside domestic economy, such as the downturn in foreign economies and substantial adjustment in international financial market. In such scenarios, we in principle estimate the stress for banks by using the estimates on the endogenous response of domestic economy sector, represented by each component of GDP, due to the external stress.

The FMM predicts year-on-year rate of changes in GDP and its components using year-on-year rate of changes in explanatory variables. This is in contrast to typical macroeconomic models used to predict future developments of GDP, in which GDP is estimated by monthly or quarterly changes in variables seasonally adjusted by programs such as X-12-ARIMA. The contrast is due to the fact that many modules in the FMM include variables from financial statements of banks, to which it is not easy to reliably apply seasonal adjustments; we therefore use year-on-year rate of changes to remove seasonality.

Chart A1. Models for domestic GDP

Nominal GDP (Household expenditure＋Private non-residential investment ＋Private inventory＋Government expenditure＋Net export)
Nominal household expenditure (★)
Nominal private non-residential investment (★)
Nominal changes in private inventory
Nominal government expenditure
Nominal net export (Nominal export - Nominal import)
Nominal export (★)
Nominal import (★)
GDP (Household expenditure＋Private non-residential investment ＋Private inventory＋Government expenditure＋Net export)
Household expenditure
Private non-residential investment
Changes in private inventory
Government expenditure
Net export (Export－Import)
Export (★)
Import (★)

Note: The ★ denotes items that are modeled as endogenous variables.

Nominal GDP is composed of nominal household expenditure (the sum of private consumption and private residential investment), nominal private non-residential

investment, changes in nominal private inventories, nominal government expenditure, nominal exports and nominal imports. Among these components, the FMM simulates the movement of nominal household expenditure, nominal non-residential investment, nominal exports and nominal imports using the economic and financial conditions assumed in a scenario. In contrast, the FMM assumes that changes in nominal private inventories remain zero, because their large fluctuations are mainly caused by factors that are independent of macroeconomic developments. The FMM further assumes that nominal government expenditure remains unchanged from the actual value at the end of the pre-simulation period.

Most of the components of real GDP are calculated by dividing the corresponding component of nominal GDP by the deflator, which is exogenously set based on the forecasts by professional forecasters. The exceptions are the exports and imports, whose nominal and real values are estimated separately, because the fluctuations in real exports and imports are often smaller than those in nominal exports and imports in time of stress, such as the global financial crisis (GFC).[125]

Model for nominal household expenditure

The explanatory variables for nominal household expenditure include nominal compensation of employees and stock prices.[126] The former is regarded as a proxy of disposable income, while the latter is a proxy of the value of assets held by households. In addition, as some of household expenditure is funded by debt, the explanatory variables include the amount of loans to individuals and domestic lending interest rates. These variables work as the channel through which the stress on domestic banks influence real economy. For example, when the tightening of credit supply decreases loans to individuals and increases domestic lending interest rates, the household expenditure in the model decreases due to the severer borrowing constraints for households.

[125] An alternative way would be to construct the models for nominal export/import and export/import deflator, and obtain real export/import by dividing the nominal values by the corresponding deflator. However, we could not establish suitable models that satisfactorily explain the time series data of export/import deflator by macroeconomic variables included in the FMM. We therefore ended up adopting the models that directly explain real export/import.

[126] Nominal compensation of employees (year-on-year rate of changes) are determined by nominal GDP (year-on-year rate of changes) and labor share (change from previous year). The labor share during the simulation period is exogenously determined.

Specification of the nominal household expenditure model

$$\begin{aligned}&\text{Household expenditure [y/y chg.]}\\&= \alpha_1 \times \text{Nominal employee compensation [y/y chg.]} + \alpha_2 \times \text{stock prices [y/y chg.]}\\&+\alpha_3 \times \text{household loans [y/y chg.]}\\&+\alpha_4 \times \text{Domestic lending interest rate [chg. from previous year]} + \text{Constant}\end{aligned}$$

Model for nominal non-residential investment

The explanatory variables for nominal non-residential investment include the expected growth rate of the domestic economy for the coming three years, which is a proxy of expected returns of the investment.[127] In addition, as some firms face large costs of external funding and some are even subject to borrowing constraints, the explanatory variables of the model include corporate profitability, the amount of corporate loans, and domestic lending interest rates.[128] The latter two variables work as the channel through which the stress on domestic banks influence real economy. For example, when the tightening of credit supply decreases corporate loans and increases domestic lending interest rates, the non-residential investment in the model decreases due to the severer financial constraints for corporates.

Specification of the nominal non-residential investment model

$$\begin{aligned}&\text{Private investment [y/y chg.]}\\&= \alpha_1 \times \text{Expected economic growth rate}\\&+\alpha_2 \times \text{Domestic lending interest rate [chg. from previous year]}\\&+\alpha_3 \times \text{Domestic corporate loans [y/y chg.]}\\&+\alpha_4 \times \text{Domestic corporate profit ROA [chg. from previous year]} + \text{Constant}\end{aligned}$$

Model for nominal exports

It is assumed that nominal exports primarily depend on the GDP for the countries or regions to which Japan mainly exports and the nominal effective exchange rate. Here, the GDP represents the demand from the foreign countries or regions, while the nominal effective exchange rate reflects the relative prices of the goods exported from Japan. As for the GDP, we multiply it by the contemporaneous shares of the countries or regions

[127] The expected growth rate of the macro economy, in turn, depends on the growth rate of potential GDP.

[128] The increase in the internal funding for firms, represented by higher profitability, may lead to the increase in investment, given that the cost of obtaining external funding is more expensive than the cost associated with internal funding. This is empirically confirmed by, for example, Fazzari, Hubbard, and Peterson [1988] and Nagahata and Sekine [2002].

among the whole export destinations in order to take into account the gradual shift of the destination from the United States and Europe to Asia and Pacific over the estimation period.[129] Note that the GDP of each destination shows strongly positive correlation with the nominal exports at the following events: the burst of the IT bubble in the early 2000s and the GFC for the United States; the GFC and European sovereign debt crisis in the early 2010s for Europe; and Asian financial crisis in the late 1990s and the GFC for Asia and Pacific.

In addition, the explanatory variables for nominal exports include the oil price, which is regarded as a proxy of commodity prices, whose change influences the cost of producing the goods to be exported and thus leads to fluctuations in the export deflator. Furthermore, the four-quarter lag of nominal exports are also included to remove technical and deterministic fluctuations due to the fact that the export function features year-on-year rate of changes of variables.

Specification of the nominal export model

$$
\begin{aligned}
&\text{Nominal exports [y/y chg.]} \\
&= \alpha_1 \times \text{U.S. GDP growth [y/y chg.]} \times \text{Export share of U.S.} \\
&+ \alpha_2 \times \text{EU GDP growth [y/y chg.]} \times \text{Export share of EU} \\
&+ \alpha_3 \times \text{Asia and Pacific GDP grwoth [y/y chg.]} \times \text{Export share of Asia and Pacific} \\
&+ \alpha_4 \times \text{Nominal effective exchange rate [y/y chg.]} \\
&+ \alpha_5 \times \text{Crude oil prices [y/y chg.]} \\
&+ \alpha_6 \times \text{Nominal exports [4-quarter lag, y/y chg.]} + \text{Constant}
\end{aligned}
$$

Model for nominal imports

It is assumed that nominal imports depend on the nominal effective exchange rate just as the nominal exports do. In addition, the explanatory variables for nominal imports include the oil price, which captures the fluctuations in commodity price, and the nominal exports, which capture the contribution of the imports of intermediate goods. Note that while it is in principle reasonable to include some proxies of domestic demand such as household consumption and GDP of Japan as the explanatory variables of imports, we do not do that in order to decrease the number of variables simultaneously determined during the simulation and thus reduce computational complexity. The four-quarter lag of nominal imports are included to remove technical and deterministic fluctuations due to the fact that the import function, just as the export function, features year-on-year rate of changes

[129] The export share of each country/region during the simulation period is assumed to remain the same as the actual value at the end of the pre-simulation.

in variables.

Specification of the nominal import model

$$\begin{aligned}&\text{Nominal imports [y/y chg.]}\\&=\alpha_1\times\text{Crude oil prices [y/y chg.]}+\alpha_2\times\text{Nominal effective exchange rate [y/y chg.]}\\&+\alpha_3\times\text{Nominal exports [1-quarter lag, y/y chg.]}\\&+\alpha_4\times\text{Nominal imports [4-quarter lag, y/y chg.]}+\text{Constant}\end{aligned}$$

Model for real exports

On the one hand, the function for real exports is similar to that of nominal exports in that it depends on the GDP for the destination countries or regions, representing the demand from the destination. The explanatory variables also include the four-quarter lag of the dependent variable. On the other hand, the explanatory variables include not nominal effective exchange rate but real effective exchange rate as a proxy for the competitiveness of Japanese firms in international markets. They do not include oil price either.

Specification of the real export model

$$\begin{aligned}&\text{Real exports [y/y chg.]}\\&=\alpha_1\times\text{U.S. GDP growth [y/y chg.]}\times\text{Export share of U.S.}\\&+\alpha_2\times\text{EU GDP growth [y/y chg.]}\times\text{Export share of EU}\\&+\alpha_3\times\text{Asia and Pacific GDP grwoth [y/y chg.]}\times\text{Export share of Asia and Pacific}\\&+\alpha_4\times\text{Real effective exchange rate [y/y chg.]}\\&+\alpha_5\times\text{Real exports [4-quarter lag, y/y chg.]}+\text{Constant}\end{aligned}$$

Model for real imports

The set of explanatory variables for real imports is different from that for nominal imports in that nominal effective exchange rate is replaced by real effective exchange rate and that the oil price, reflecting the fluctuation of import deflator, is removed.

Specification of the real import model

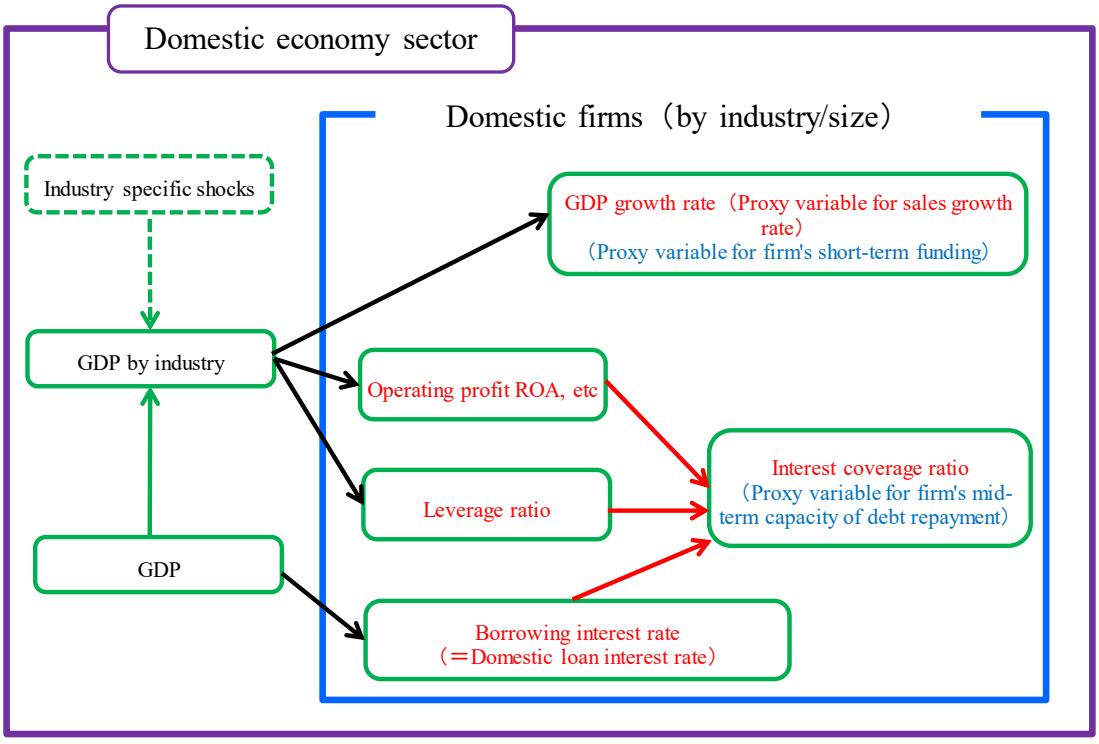
$$\begin{aligned}&\text{Real imports [y/y chg.]}\\&=\alpha_1\times\text{Real effective exchange rate [y/y chg.]}\\&+\alpha_2\times\text{Real exports [y/y chg.]}\\&+\alpha_3\times\text{Real imports [4-quarter lag, y/y chg.]}+\text{Constant}\end{aligned}$$

Appendix 2: Structure of the Model of the Domestic and Foreign Corporate Sectors

The FMM includes system of equations that explains variables in the financial statements of corporates using macroeconomic variables. Important subset of the FMM models such as the model for credit costs is based on those variables and equations.

The models of domestic corporate sector include equations for corporates by industry, size, and profitability (Chart A2). The classification by industry is composed of four industries: (1) processing industries, including food products and beverages, fabricated metal products, general-purpose, production and business oriented machinery, electrical machinery, equipment and supplies, transport equipment, and some parts of other manufacturing; (2) services for individuals, including accommodation and food services, living-related services, amusement, learning support, medical, health care and welfare; (3) transport and postal services; and (4) the others. The classification by size has two categories, large corporates and SMEs, while the classification by profitability also has two categories, low return borrowers and the other corporates. The growth rate of GDP (change from half a year ago, a proxy of the growth rate of sales) and the interest coverage ratio (hereafter ICR) are adopted as the variables that capture creditworthiness of corporates of each industry. The growth rate of GDP is regarded as a proxy for the short-term liquidity, while the ICR is regarded as a proxy for medium-term solvency.

Chart A2. Summary of domestic economy sector



The ICR is calculated by dividing ROA by the product of leverage ratio and borrowing interest rate. Both the ROA and the leverage ratio depend on the GDP, or more specifically the output gap for the corresponding sector.[130] The borrowing interest rate is assumed to be linked with the lending interest rate for domestic banking sector.

Specification of the models of domestic corporate sector

$$ICR_j = \frac{\text{Operating profits}_j + \text{Interest and dividends received}_j}{\text{Interest payment}_j}$$

$$= \frac{\text{Operating ROA}_j}{\text{Borrowing interest rate}_j \times \text{Leverage ratio}_j}$$

$$ROA_j = \alpha_1 \times \text{Output gap}_j + \alpha_2 \times \text{Import price index} + \alpha_3 \times \text{Exchange rates [USD/JPY]}$$

$$+\text{Fixed effect}_j + \text{Constant}$$

$$\text{Leverage ratios}_j \text{ [chg. from previous year]} = \alpha_1 \times \text{Output gap}_j \text{ [chg. from previous year]}$$

$$\text{Borrowing interest rate}_j \text{ [chg. from previous year]}$$

$$= \text{Domestic lending interest rate [chg. from previous year]}$$

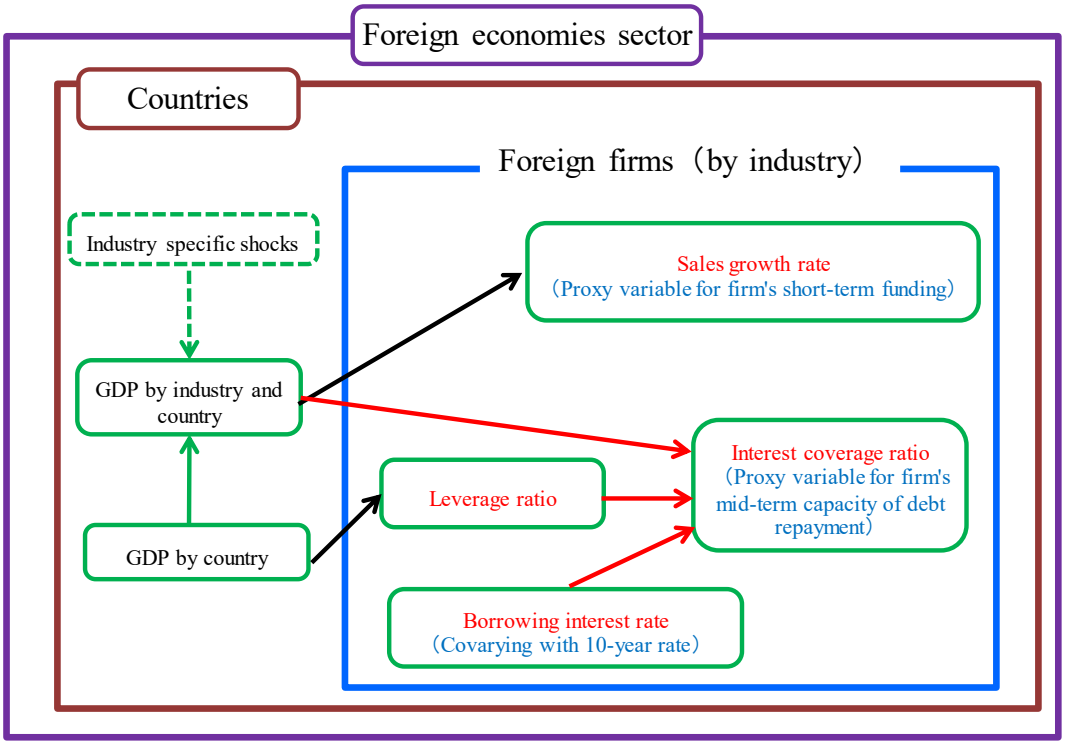
—— j denotes industry.

The models of foreign corporate sector include equations for corporates by region and industry (Chart A3). The classification is based on three regions, America, Europe and Asia-Pacific, and on five industries, (1) processing industries, (2) services for individuals, (3) transport, (4) energy, and (5) the others.[131]

[130] As for the output gap, historical values are based on the estimates by the Bank of Japan, while the values during the simulation period are estimated using Hodrick-Prescott filter.

[131] Unlike the domestic corporate sector, the foreign corporates are not classified by size. As is the case for the domestic corporate sector, the ICR and the growth rate of sales, both of which are the explanatory variables for foreign credit costs, are calculated as the weighted average using each industry's share among total loans outstanding for the bank as a weight.

Chart A3. Summary of foreign economies sector



The models of foreign corporate sector are primarily explained by the GDP of the corresponding region and industry.[132] Specifically, we adopt the growth rate of sales (change from half a year ago) and ICR as the variables that represent the creditworthiness of the firms belonging to each region and industry. As in the models of domestic corporate sector, the growth rate of sales is regarded as a proxy of borrowers' liquidity, and the ICR is regarded as a proxy of borrowers' solvency. In addition, for the energy industry, the sales and ICR are assumed to depend on oil prices as well. The formulation of ICR is slightly different from that for the domestic corporate sector, as it is explained by output gap of the region, the leverage ratio which depends on the output gap as well, and borrowing interest rates.

The borrowing interest rates of America and Asia and Pacific are assumed to depend on 10-year Treasury bond yield, while the borrowing interest rates of Europe are assumed to depend on 10-year German bond yield. For Asia and Pacific, we simply use the U.S. interest rates, as the interest rates in this region were to some extent correlated with the U.S. interest rates in the past.

[132] The financial variables for firms among energy sector are assumed to depend on the oil prices, represented by WTI.

Specification of the models of foreign corporate sector

$$\text{Sales growth rate}_{c,j} = \alpha_{1,c} \times \text{Real GDP growth rate}_{c,j}\ [\text{h/h chg.}]$$
$$+\alpha_{2,c,j} \times \text{GDP deflator}_{c,j}\ [\text{h/h chg.}] + \alpha_{3,c,\text{Energy industry}} \times \text{Crude oil prices}$$
$$+\text{Fixed effect}_{c,j} + \text{Constant}$$

$$ICR_{c,j} = \alpha_{1,c} \times \text{Output gap}_{c} + \alpha_{2,c,j} \times \text{Leverage ratios}_{c,j} + \alpha_{3,c} \times \text{Borrowing interest rate}_{c}$$
$$+\alpha_{4,c,\text{Energy industry}} \times \text{Crude oil prices} + \text{Fixed effect}_{c,j} + \text{Constant}$$

$$\text{Leverage ratios}_{c,j}[\text{chg. from previous year}] = \alpha_{1,c} \times \text{Output gap}_{c}\ [\text{chg. from previous year}]$$

—— j denotes industry, c denotes foreign countries and regions.

Appendix 3: Variables of Domestic and Foreign Financial Markets

For some of the variables for domestic and foreign financial markets, the path during simulation period is exogenously assumed for each scenario, often based on the historical developments of the variables (Chart A4). Such variables include those that are regarded as quantitatively important risk factors that significantly contribute to the movement of market prices of securities held by Japanese banks. The variables also include those that significantly influence consumption, investment and/or external trade of households and firms.

Chart A4. List of financial market variables

Domestic financial market		
	Bonds	
		Yields on government bonds (3 month - 40 years)
	Credit products	
		Corporate credit spread (AAA, AA, A, BBB or lower)
	Stocks	
		Stock price (TOPIX)
	Investment funds and alternative investments	
		Bond investment fund's price
		Credit investment fund's price
		Real estate investment fund's price
		Balanced fund's price
		Hedge fund's price
	The others	
		Exchange rates (USD/JPY)
Foreign financial market		
	Bonds	
		Yields on U.S. government bonds (3 month - 30 years)
		Yields on Germany government bonds (3 month - 30 years)
	Credit products	
		U.S. corporate credit spread (AAA, AA, A, BBB, BB, B, CCC or lower)
		CLO spread (AAA, AA, A, BBB, BB or lower)
		CMBS spread (AAA, AA, A, BBB or lower)
		RMBS spread
		ABS spread (AAA, AA or lower)
		Direct lending fund's price
		Bank loan fund's price (BB, B or lower)
	Stocks	
		U.S. Stocks (S&P500)
	Investment funds and alternative investments	
		Real estate investment fund's price
		Hedge fund's price
		Private equity investment fund's price
	The others	
		Oil price (WTI)
		Dollar interbank offered rate
		Dollar funding premiums

Note: Option-adjusted spreads are used for credit products in the foreign financial market.

Appendix 4: Simulation Results of "1/2 Financial Stress Scenario"

This appendix shows the simulation results of "1/2 financial stress scenario," which assumes a half of the stress of "financial stress scenario" examined in Section 4, and compares the results of "1/2 financial stress scenario" with those of "financial stress scenario."[133] This comparison enables us to grasp the degree of nonlinearity of the FMM somewhat comprehensively.

For internationally active banks, CET1 ratio as of the end of the simulation period (fiscal 2024) for the financial stress scenario (7.3 %) is lower than that for baseline scenario (11.9 %) by 4.6 percentage points. On the other hand, the decrease in CET1 ratio for the 1/2 financial stress scenario (9.9 %) is by 2.0 percentage points, which is smaller than a half of the corresponding figure for the financial stress scenario (Chart 30 and A5). Among the components of the CET1 ratio, significant nonlinearity exists for credit costs, PPNR excluding trading income, realized gains/losses on securities holdings, and changes in risk-weighted assets. The nonlinearity in the credit costs and changes in risk-weighted assets is primarily due to the fact that, to calculate credit costs and risk weights for loans, logistic function is adopted for the model of transition probabilities between different borrower categories. There is nonlinearity in realized gains/losses in securities holdings because realized losses in stocks and credit product investments arise only when the market price substantially falls and banks need to realize impairment losses. As for the PPNR excluding trading income, the nonlinearity is related to the assumption of the FMM that, facing significant realized losses in stockholdings, banks sell bondholdings to realize the gains in order to make up the losses. After selling bondholdings, it is assumed that banks repurchase bonds whose income gains are typically low because the financial stress scenario assumes the lowest interest rates in the history, thus leading to the lowering of PPNR. Since the realized losses in stockholdings are due to impairment losses, so are nonlinear as mentioned above, the lowering of PPNR is also nonlinear.

For domestic banks excluding *shinkin* banks, the core capital ratio as of the end of fiscal 2024 for the financial stress scenario (7.4 %) is lower than that for baseline scenario (9.8 %) by 2.4 percentage points. Conversely, the decrease in the core capital ratio for the 1/2 financial stress scenario (8.9 %) is by 0.9 percentage points, which is again smaller than a half of the corresponding figure for the financial stress scenario. Among the components of the core capital ratio, credit costs and realized gains/losses on securities

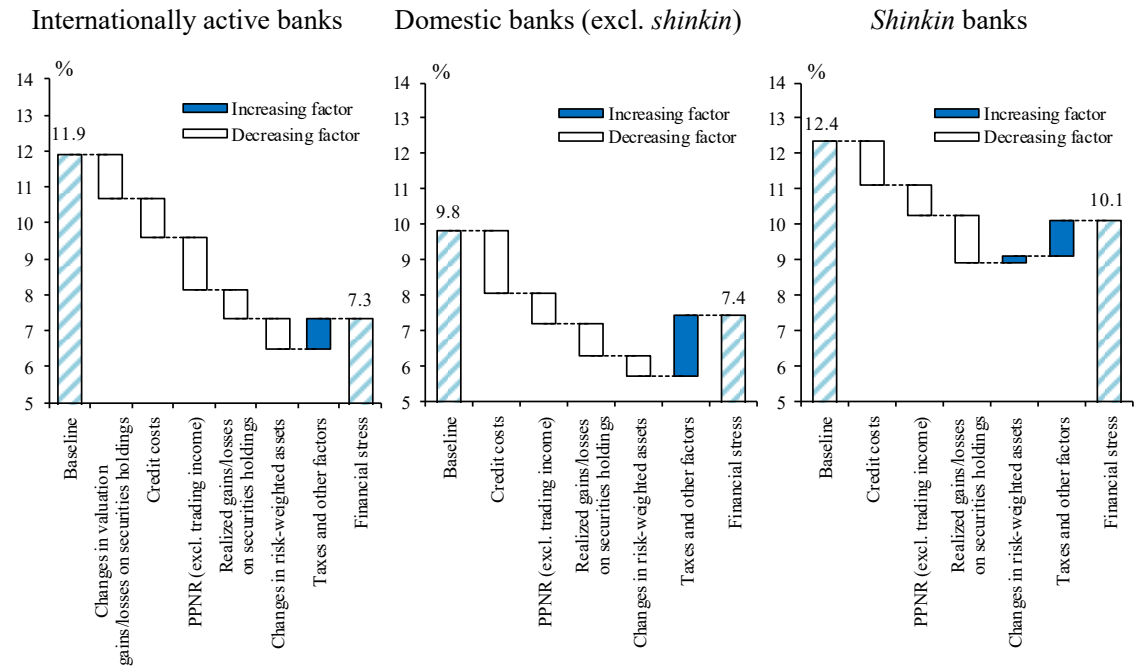
[133] Specifically, the path of each economic and financial variables in the 1/2 financial stress scenario is set to be equal to the simple average of the corresponding variable in the financial stress scenario and that in the baseline scenario.

holdings primarily drive the nonlinearity.

For *shinkin* banks, due to the similar factors as the domestic banks excluding *shinkin* banks, the core capital ratio as of the end of fiscal 2024 for the 1/2 financial stress scenario (11.5 %) is lower than that for baseline scenario (12.4 %) by only 0.9 percentage points, compared with 2.3 percentage-point decrease for the financial stress scenario (10.1 %).

Finally, we compare each sector's contribution to capital adequacy ratio in the 1/2 financial stress scenario with that in the financial stress scenario (Chart 31 and A6). For all types of banks, the result of the comparison is consistent with the nonlinearity explained above for each component of capital adequacy ratio. Namely, for internationally active banks, significant nonlinearity arises primarily due to domestic and foreign economies sectors, while, for domestic banks including *shinkin* banks, the domestic economy sector and domestic and foreign financial markets sector primarily contribute to pushing down the core capital ratio in a nonlinear manner.

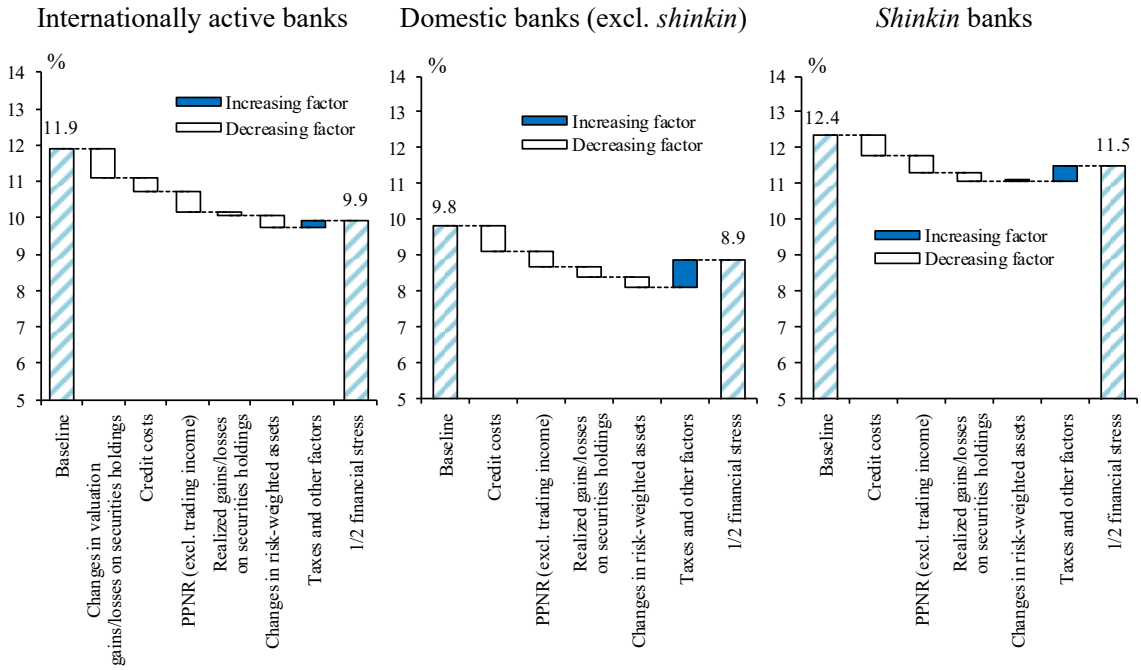
Chart 30. Decomposition of capital adequacy ratio (financial stress scenario)



Note: 1. The charts indicate the contribution of each factor to the difference between the capital adequacy ratios as of the end of the simulation period (end-March 2025) under the baseline scenario and the financial stress scenario.

2. The left-hand chart shows the CET1 capital ratio of internationally active banks. The middle and right-hand charts show the core capital ratio of domestic banks.

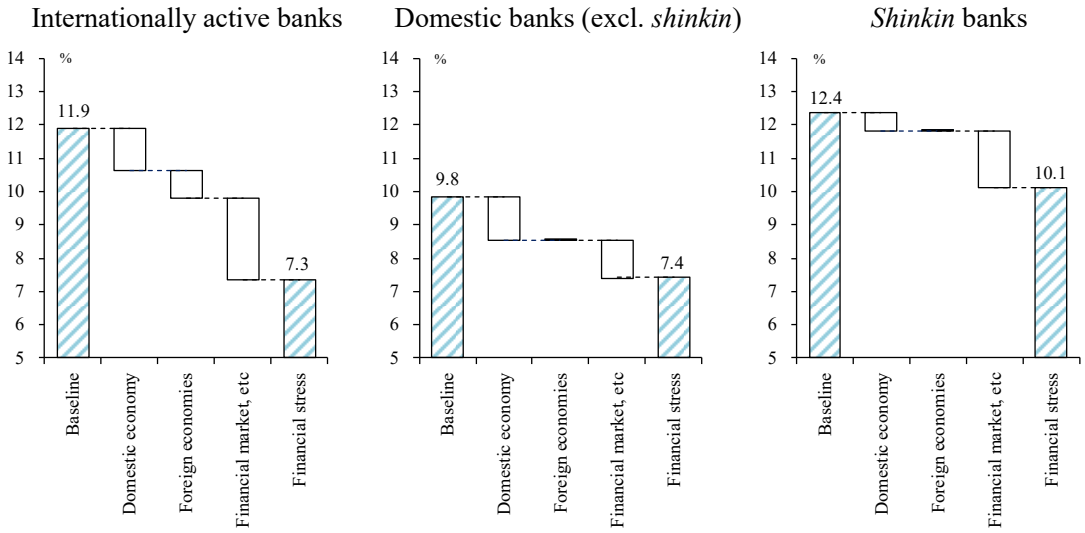
Chart A5. Decomposition of capital adequacy ratio (1/2 financial stress scenario)



Note: 1. The charts indicate the contribution of each factor to the difference between the capital adequacy ratios as of the end of the simulation period (end-March 2025) under the baseline scenario and the 1/2 financial stress scenario.

2. The left-hand chart shows the CET1 capital ratio of internationally active banks. The middle and right-hand charts show the core capital ratio of domestic banks.

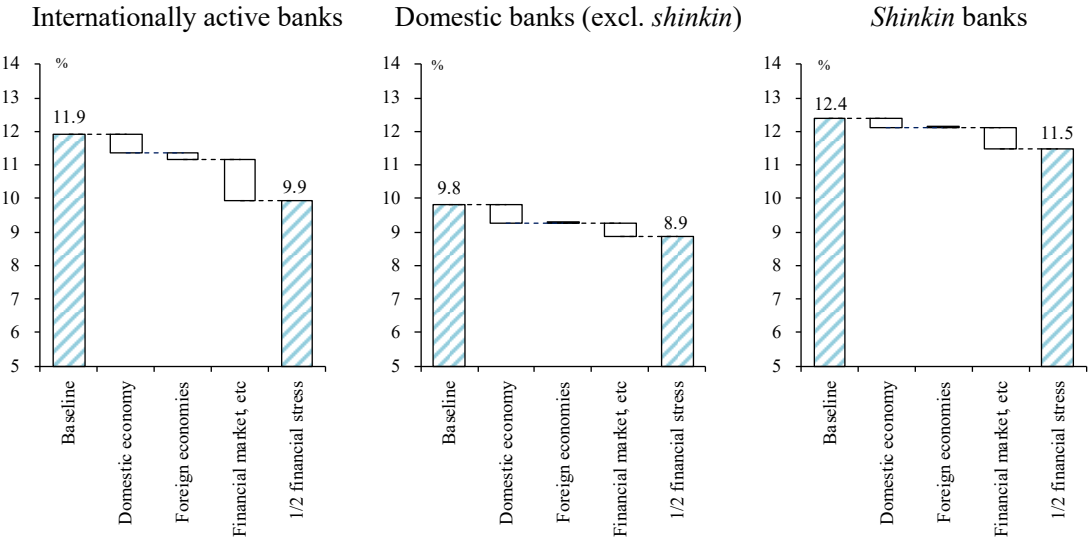
Chart 31. Decomposition of capital adequacy ratio by sector (financial stress scenario)



Note: 1. The charts indicate the contribution of each sector to the difference between the capital adequacy ratios as of the end of the simulation period (end-March 2025) under the baseline scenario and the financial stress scenario.

2. The left-hand chart shows the CET1 capital ratio of internationally active banks. The middle and right-hand charts show the core capital ratio of domestic banks.

Chart A6. Decomposition of capital adequacy ratio by sector (1/2 financial stress scenario)



Note: 1. The charts indicate the contribution of each factor to the difference between the capital adequacy ratios as of the end of the simulation period (end-March 2025) under the baseline scenario and the 1/2 financial stress scenario.

2. The left-hand chart shows the CET1 capital ratio of internationally active banks. The middle and right-hand charts show the core capital ratio of domestic banks.

Appendix 5: Simulation under the Pandemic

During the period of economic downturn due to the spread of Covid-19 since March 2020, various corporate financing support measures were implemented, including effectively interest-free loans and cash payments by the government. By modifying various aspects of the FMM to incorporate these measures, the macro stress testing shown in the issues of the Financial System Report (FSR) between October 2020 and April 2022 takes into account the effect of such policy measures on the health of banks through helping borrower firms' liquidity and solvency.

This section outlines those modifications of the model regarding the corporate financing support measures, and then examines how accurately the modified FMM can predict the changes in capital adequacy ratio of banks during that period. Specifically, by inputting the FMM both the financial statements of banks in FY 2019 as a starting point of the simulation and the set of actual values of macroeconomic and financial variables during FY 2020 as a "scenario," we calculate the developments in capital adequacy ratio during FY 2020. We then compare the calculated values to the actual values of capital adequacy ratio. Note that the actual values of macroeconomic and financial variables are qualitatively different from those variables assumed for the baseline scenario in macro stress testing shown in FSR. [134]

The spread of Covid-19 is generally considered as the major tail event since the global financial crisis, while the parameters of the FMM are estimated based on historical time series data mostly including the global financial crisis period. Therefore, the simulation results based on the "scenario" of the pandemic is important as a natural out-of-sample tail-event simulation. One should, however, keep in mind that the characteristics of the pandemic recession is qualitatively different from the global financial crisis because the stress from the pandemic originates not from financial markets but from the real economy.

A.5.1. Models for domestic corporate financing support measures[135]

The corporate financing support measures implemented in Japan since the spread of

[134] The baseline scenario for the macro stress testing shown in FSR assumes that real economy and interest rates follow the forecasts by professional forecasters and the market participants, respectively. It further assumes that the prices of risky assets remain the same as the actual value just before the simulation period. The assumed paths of those variables are clearly different from the actual values during the corresponding period.

[135] The simulation by the FMM does not take into account the effect of corporate financing support measures by foreign governments. This is partly due to the practical difficulty in comprehensively examining and considering foreign policies. Note also that foreign loans by Japanese banks are concentrated on large firms, which are less likely to be supported by governments than smaller firms.

Covid-19 in fiscal 2020 are primarily composed of cash payments by the government and effectively interest-free loans, both of which aim at supporting SMEs. The cash payments by the government represent various subsidies to firms, such as "subsidies for sustaining businesses," "rent assistance subsidies," and "expansion of employment adjustment subsidies program."[136] Under certain assumptions, the total amount actually transferred to firms during fiscal 2020 is estimated to be about 1.5 trillion yen for large and medium-sized firms and about 9 trillion yen for smaller firms.[137] As for the effectively interest-free loans, we consider those loans by private and government-affiliated financial institutions that are accompanied with a transfer to make up the interest payments and guaranteed by the credit guarantee corporations.

The simulation by the FMM takes into account the effect of the cash payments and effectively interest-free loans. Note that the volume outstanding of the effectively interest-free loans, as estimated based on the data provided by credit guarantee corporations, is about 21 trillion yen, of which about 3 trillion yen are by internationally active banks, about 10 trillion yen by domestic banks excluding *shinkin* banks, and about 9 trillion yen by *shinkin* banks. Those amount to 1 percent, 6 percent, and 15 percent of total corporate loans outstanding by each bank type. Thus, it was domestic banks that significantly increased lending as a result of the corporate financing support measures. This was probably due to the fact that SMEs occupy major part of the lending by regional banks. In addition, it was also due to the fact that the face-to-face services industries, which experienced especially severe shortage in demand during the spread of Covid-19, also occupy a large portion of their lending.[138]

The specific method of considering each policy measure in the FMM is the following. As

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[136] In addition to these measures, various other measures were implemented by the government, including the tax payment moratorium, which allowed firms to defer payments of national and local taxes and/or social insurance contributions for one year. However, the simulation in this Appendix only considers cash payments and effectively interest-free loans, because of their large impact.

[137] As for the details of this estimation, we follow the methods shown in Section A of Chapter IV "Domestic credit risk" from October 2020 issue, April 2021 issue, and October 2021 issue of the FSR.

[138] This can be seen from the "loans and bills discounted by sector," the official statistics compiled and published by the BOJ. The statistics indicate that the share of face-to-face services industries among total loans is higher for *shinkin* banks than other banks. Note that the face-to-face services industries include hotels and accommodations, food services, living-related services and amusement, all of which were significantly impacted by the spread of Covid-19. In addition, loans outstanding by the size of borrower firms indicate that the amount of loans outstanding to SMEs in face-to-face services industries is larger than that to large firms in the same industries. This implies that, since most of borrowers for major banks are large firms, they are less exposed to face-to-face services industries than regional banks. Note that, since most domestic banks are regional banks, we use the two words interchangeably.

for the effectively interest-free loans, we first divide domestic corporate loans by each bank into the effectively interest-free loans and the other loans. Then we assume that the effectively interest-free loans incur no risk-weighted assets and no credit costs.

Risk-weighted asset model with financing support measures

Risk-weighted assets for corporate loans_i

$= \text{Risk weights for corporate loans}_i \times \text{Corporate loans}_i^*$

—— $*$ denotes loans excluding effectively interest-free loans.

Moreover, both the cash payment and the effectively interest-free loans are assumed to support corporate finance of borrower firms and thus reduce credit costs that are accompanied with "the other loans." Specifically, the credit cost model in the FMM adopts the growth rate of GDP as a proxy of borrowers' short-term liquidity and the ICR as a proxy of borrowers' medium- to long-term solvency. Here, the effectively interest-free loans lower the contribution of the decline in the growth rate to the historically average level. In addition, as for the cash payments, we simply set the ROA of firms higher by the amount comparable to the amount of the cash payments throughout fiscal 2020, which automatically pushes up ICR.[139]

[139] The methods to take into account corporate financing support measures outlined in this Appendix follow those adopted in the macro stress testing shown in the October 2020 issue, the April 2021 issue, the October 2021 issue and the April 2022 issue of the FSR.

Credit cost model for domestic corporate loans with financing support measures

$$\text{Net loan-loss provisions}_i + \text{Write-offs}_i$$

$$= \Delta \sum_{n=1}^{4} \left[\begin{matrix} \text{Exposure (to borrowers in } n)_i^* \times \text{Provision rate (for } n)_i \\ \times \text{Uncovered ratio (only for } n = 4)_i \end{matrix} \right]$$

$$+ [\text{Exposure (to borrowers in } 5)_i^* \times \text{Uncovered ratio (for } n = 5)_i]$$

$$\text{Exposure (to borrowers in } n)_i$$

$$= \sum_{m=1}^{4} \left[\begin{matrix} \text{Exposure (to borrowers in } m \text{ in previous period)}_i^* \\ \times \text{Probability of transition}_i^{m \to n} \end{matrix} \right]$$

$$\times \text{Domestic loan growth}_i$$

—— $*$ indicates exposures excluding effectively interest-free loans.

<Probability of transition from m to n for bank i ($PT_i^{m \to n}$)>

$$\ln\left(\frac{PT_i^{m \to n}}{1 - PT_i^{m \to n}}\right) = \alpha_1^{m \to n} \times GDP \text{ growth}_i \text{(Average as of before pandemic)}$$

$$+ \alpha_2^{m \to n} \times ICR_i \text{(pushed up by the contribution of cash payment measures)}$$

$$+ \text{Fixed effect}_i + \text{Constant}$$

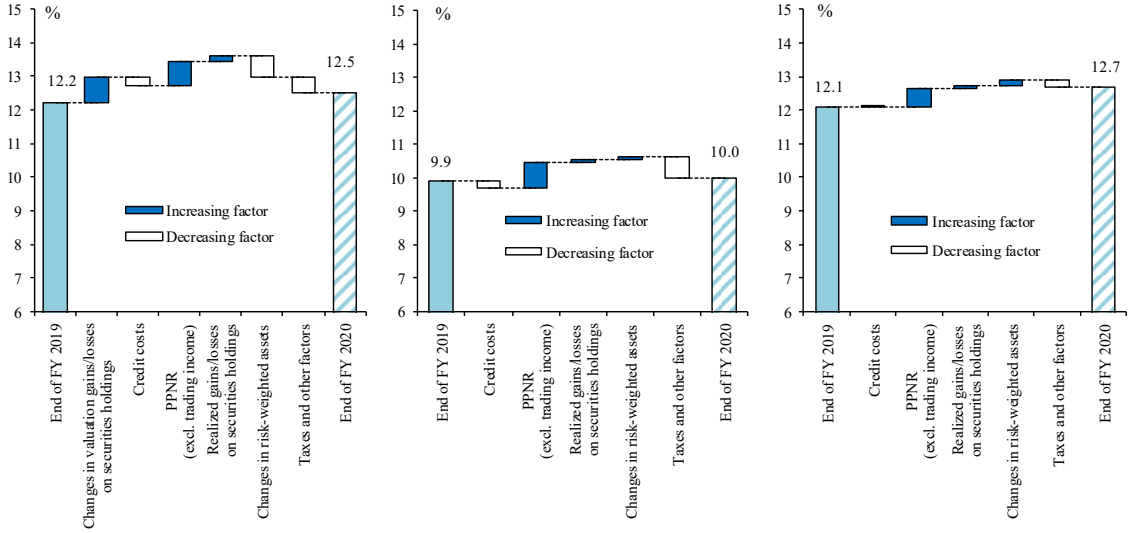
—— m and n denote risk categories of borrowers. Δ denotes difference. $\alpha_1^{m \to n}$ and $\alpha_2^{m \to n}$ denote the coefficients to predict transition from m to n.

A.5.2. Simulation results

The followings show the results of simulation based on the aforementioned scenario and the assumptions on corporate financing support measures (Chart A7). By comparing the simulation results of capital adequacy ratio as of the end of fiscal 2020 with the actual values, we observe that they are quantitatively similar, suggesting that the simulation by the FMM captures the reality rather accurately.

Chart A7. Factors behind changes in capital adequacy ratio (simulation)

Internationally active banks　　Domestic banks (excl. *shinkin*)　　*Shinkin* banks

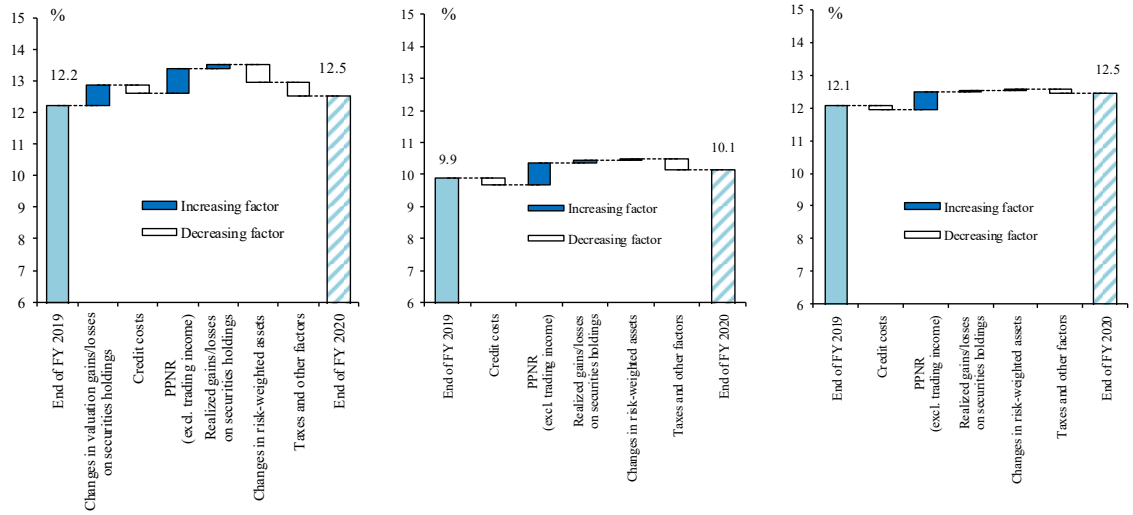


Note: 1. The charts indicate the contribution of each factor to the difference between the capital adequacy ratios as of the end-March 2020 and the end of the simulation period (end-March 2021).

2. The left-hand chart shows the CET1 capital ratio of internationally active banks. The middle and right-hand charts show the core capital ratio of domestic banks.

Chart A8. Factors behind changes in capital adequacy ratio (actual)

Internationally active banks　　Domestic banks (excl. *shinkin*)　　*Shinkin* banks



Note: 1. The charts indicate the contribution of each factor to the difference between the actual capital adequacy ratios at end-March 2020 and at end-March 2021.

2. The left-hand chart shows the CET1 capital ratio of internationally active banks. The middle and right-hand charts show the core capital ratio of domestic banks.

Appendix 6: Stress Testing Models Developed by the Central Banks in America and Europe

Central Bank (legal region)	Model		Scope of the model	Feedback loops btw the bank lending and the real economy	Reference
	Abbreviation	Official name			
FRB (US)		Supervisory stress test models	Financial holding companies covered in Dodd-Frank Act Stress Test	No	FRB [2021]
	FLARE	Forward-Looking Analysis of Risk Events model	All financial holding companies (200 largest financial institutions in asset size are modeled individually and the others are modeled altogether)	One way loop from the economic fluctuation to the bank lending	Correia et al. [2020], Correia, Seay, and Vojtech [2022]
NY Fed (US)	CLASS	Capital and Loss Assessment under Stress Scenarios model	All financial holding companies (200 largest financial institutions in asset size are modeled individually and the others are modeled altogether)	No	Hirtle et al. [2016]
ECB (Euro)	BEAST	Banking Euro Area Stress Testing Model	Major 89 banks (approximately 70 percent of total loans outstanding of financial institutions)	Yes	Budnik et al. [2019], Budnik et al. [2020], ECB [2021b]
	STAMP€	Stress-Test Analytics for Macroprudential Purposes in the euro area	Major banks (Approximately 100 banks which differs according to the model)	Yes	Henry and Kok [2013], Dees, Henry, and Martin [2017]
Bundesbank (Germany)		Satellite models	Major 12 banks and small financial institutions	No	Bundesbank [2015]
BdF/ACPR (France)	MERCURE	Modele d'Evaluation des Risques du seCteUR financiEr	Major banks and small financial institutions	No	Camara et al. [2015]
BOE (The UK)	RAMSI	Risk Assessment Model of Systemic Institutions	Major banks (Approximately 10 banks)	One way loop from the economic fluctuation to the bank lending	Aikman et al. [2011], Alessandri et al. [2009], Oliver et al. [2012]
BOC (Canada)	MFRAF	Macrofinancial Risk Assessment Framework	Major banks (D-SIBs)	No	Fique [2017]
(Reference) Bank of Japan	FMM	Financial Macro-econometric Model	109 banks and 247 *shinkin* banks (approximately 80 to 90 percent of total loans outstanding of depository financial institutions)	Yes	

Note: 1. This chart is based on the most recent literature on each model.
2. The supervisory stress test models are used in the stress testing for approval of capital plans for banks in US jurisdictions.