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Financial System Report – Annex

Macro Stress Testing in the *Financial System Report* (October 2016)

FINANCIAL SYSTEM AND BANK EXAMINATION DEPARTMENT
BANK OF JAPAN
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Financial System Research Division,
Financial System and Bank Examination Department, Bank of Japan
post.bsd1@boj.or.jp

Background

The Bank of Japan publishes the *Financial System Report* semiannually, with the objective of assessing the stability of Japan's financial system from a macroprudential perspective and facilitating communication with concerned parties on relevant tasks and challenges in order to ensure such stability. The *Report* provides a regular and comprehensive assessment of the financial system.

The *Financial System Report Annex Series* supplements the *Financial System Report* by providing more detailed analysis and additional investigations on a selected topic on an ad-hoc basis. This paper provides a detailed explanation of the scenarios developed for macro stress testing in the October 2016 issue of the *Report*.

Abstract

In the *Financial System Report*, two macro stress tests are implemented: (1) a "tail event scenario" that assumes a set of severe financial and economic conditions equivalent to the Lehman shock for each regular test, in order to assess the stability of the financial system through fixed-point observations; (2) a "tailored event scenario" that varies according to macroprudential concerns at the time of the test and that which seeks to examine the vulnerabilities of the financial system to these specific concerns. In the October 2016 issue of the *Report*, the tailored event scenario features constraints on the availability of foreign currency, in addition to a widening of foreign currency funding premiums, reflecting the importance of securing stable foreign currency funding for Japanese banks. This paper explains the specifics underlying the stress scenarios, and the background to the approach employed.

1. Introduction

Macro stress testing involves examining financial institutions' capital adequacy and the resilience of the financial system dynamically, from a macro viewpoint, by estimating the extent of capital loss under specific stress events.

The two stress scenarios under consideration are the "tail event scenario" and the "tailored event scenario." The former is designed to assess the stability of the financial system through fixed-point observations, by applying an approximately equal degree of severe stress in every semiannual *Financial System Report*. In particular, the assumed level of stress is comparable to that observed at home and abroad during the Lehman shock. Even if placed under a comparable level of stress each time, the impact of the stress on the financial system could vary depending on financial institutions' risk profiles and their financial bases at the time of the stress test exercise. The latter is designed to be a multi-dimensional analysis of the vulnerabilities inherent in the financial system, with its focus changing every time. Under this scenario, the intensity of the stress may not necessarily be as severe as that observed under the tail event scenario. Nevertheless, the tailored event scenario is developed to assess the manner in which risks materialize, or the mechanism through which a shock is transmitted, by utilizing additional data or by extending the model as necessary. In the October 2016 issue of the *Report*, the tailored event scenario features constraints on the availability of foreign currency, in addition to a widening of foreign currency funding premiums, reflecting the importance of securing stable foreign currency funding for Japanese banks.

Scenarios presented in this stress testing exercise are hypothetical, developed for the purpose of effectively conducting the above-mentioned examination and analysis. It should be noted that the scenarios presented are not an indication of the likelihood of outcomes for the economy, asset prices, or other factors, nor should they be interpreted as the Bank of Japan's outlook.

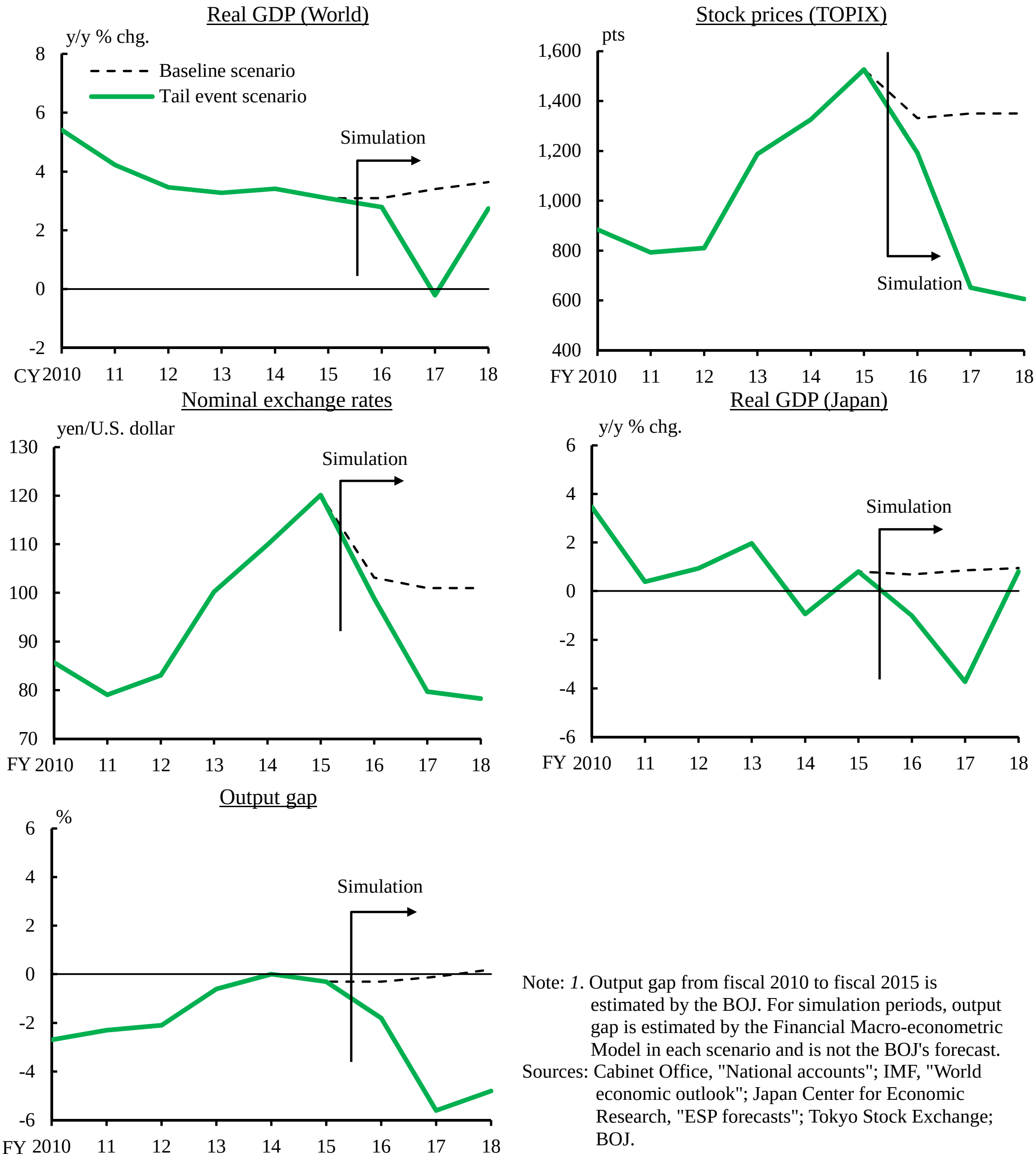
The Financial Macro-econometric Model developed by the Bank of Japan's Financial System and Bank Examination Department is employed in macro stress testing. The model is refined as needed. The stress testing exercise in the October 2016 issue of the *Report* modeled the calculation of overseas credit costs separately from domestic credit costs to examine the risk associated with an increase in overseas lending in recent years more accurately (see Box 1). Furthermore, it incorporates the impact of financial institutions' profitability on lending into the lending function, given the negative interest rate environment, which exerts more downward pressure on the profitability of domestic deposit-taking and lending activities (see Box 2).

The following section will first discuss the baseline scenario, which will be used as a benchmark to assess the results of the stress test simulations, and then elaborate on the background of each of the stress scenarios.

2. Baseline scenario

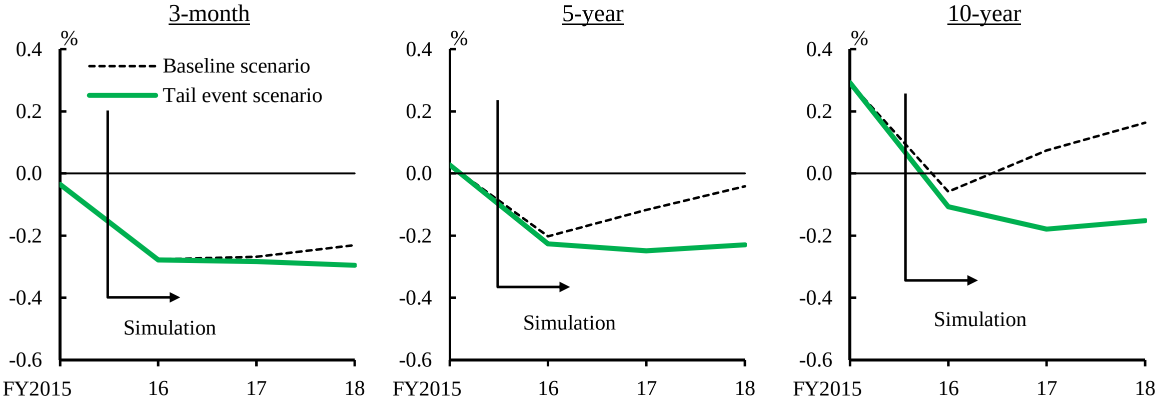
The baseline scenario, based on forecasts by the International Monetary Fund (IMF) and the private sector, assumes that "the growth rate of overseas economies increases moderately, as the steady growth in advanced economies spreads to emerging and developing economies, resulting in a moderate recovery for Japan's economy" (Charts 2-1 and 2-2).

Chart 2-1: Summary of variables (tail event scenario)[1]



Note: *1*. Output gap from fiscal 2010 to fiscal 2015 is estimated by the BOJ. For simulation periods, output gap is estimated by the Financial Macro-econometric Model in each scenario and is not the BOJ's forecast.
Sources: Cabinet Office, "National accounts"; IMF, "World economic outlook"; Japan Center for Economic Research, "ESP forecasts"; Tokyo Stock Exchange; BOJ.

Chart 2-2: JGB yields[1]



Note: *1*. Figures for 3-month indicate the rate of treasury discount bills.
Sources: Bloomberg; Ministry of Finance, "Interest rate"; BOJ.

Specifically, under the baseline scenario, the growth rate of overseas economies (real GDP) rises moderately from 3.1 percent in 2015 to 3.6 percent by 2018.[1] The growth rate of the domestic economy (real GDP) remains above the potential growth rate, at 0.7 percent in fiscal 2016, 0.9 percent in fiscal 2017, and 1.0 percent in fiscal 2018.[2] Based on these growth assumptions, the output gap enters positive territory, improving from minus 0.3 percent in fiscal 2015 to 0.2 percent in fiscal 2018.[3]

In terms of financial markets, in and beyond the fourth quarter of 2016, stock prices (TOPIX) and the nominal exchange rate remain unchanged at the values recorded in September 2016.[4] Furthermore, JGB yields, and swap rates, which serve as benchmarks for bank lending rates, evolve more or less in line with the yield curve after the introduction of the Bank of Japan's Quantitative and Qualitative Monetary Easing with Yield Curve Control (as at late September 2016).

3. Tail event scenario

The tail event scenario is designed such that "Japan's output gap deteriorates to around minus 7 to minus 8 percent, as experienced at the trough of the Lehman shock." Other financial and economic variables are calibrated so that they are generally similar in

[1] Based on IMF forecasts available as at July 2016.

[2] Based on ESP forecasts published in August 2016.

[3] For the estimation of the output gap, the potential growth rate is assumed to remain constant at its average of around 0.7 percent from fiscal 2000 onward.

[4] Specifically, it is assumed that the TOPIX remains at 1,350 points and the nominal exchange rate is 101 yen/dollar.

magnitude to changes during that time (Chart 2-1).[5]

Specifically, the growth rate of overseas economies falls sharply from 3.1 percent in 2015 to 2.8 percent in 2016 and to minus 0.2 percent in 2017. The growth rate of Japan's economy falls deeper into negative territory, at minus 3.7 percent in fiscal 2017. As a result, Japan's output gap deteriorates significantly to minus 1.8 percent in fiscal 2016, then to minus 5.6 percent in fiscal 2017, and remains substantially negative at minus 4.8 percent in fiscal 2018 (Chart 2-1).[6]

As for financial markets, stock prices (TOPIX) fall by 55 percent by the third quarter of 2017, and remain unchanged thereafter. 10-year JGB yields decline from 0.29 percent in fiscal 2015 to minus 0.11 percent in fiscal 2016, and to minus 0.18 percent in fiscal 2017 (Chart 2-2). The nominal exchange rate is 80 yen/dollar in fiscal 2017 and 78 yen/dollar in fiscal 2018.

4. Tailored event scenario

(1) Background to scenario design

In the tailored event scenario in the October 2016 issue of the *Report*, it is assumed that term premiums for U.S. interest rates, which have remained muted until now, widen, due to rising uncertainty in global financial markets, among other factors. At the same time, U.S. and European banks as well as asset management companies, whose risk appetites have declined, sharply reduce their supply of U.S. dollars. As a result, Japanese banks face constraints on the availability of foreign currency funding, in addition to a widening of foreign currency funding premiums.

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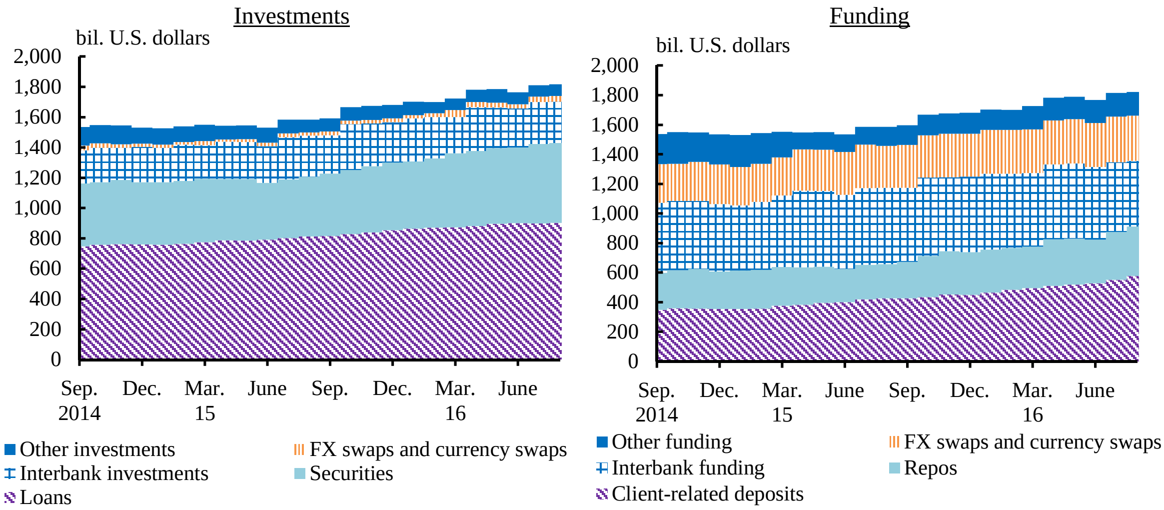
[5] The set of financial and economic conditions assumed in the tail event scenario and the channels through which the shock propagates are the same as that described in the previous issues of the *Report*. For details, see "Designing Scenarios in Macro Stress Testing at the Bank of Japan," *Financial System Report Annex Series*, October 2015.

[6] On a quarterly basis, the output gap deteriorates to approximately minus 7 percent in the third quarter of 2017.

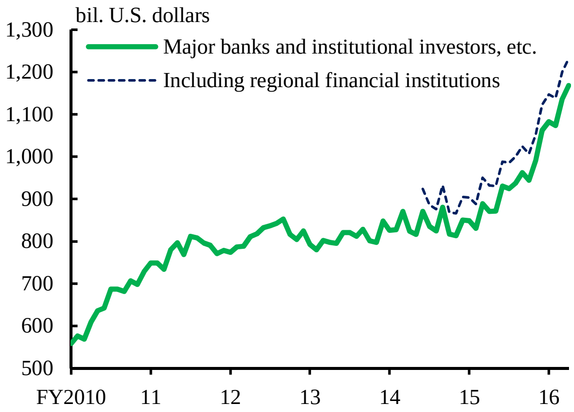
Chart 4-1: Structure of foreign currency funding and investments among banks[1]



Note: *1*. Latest data as at end-August 2016.
Source: BOJ.

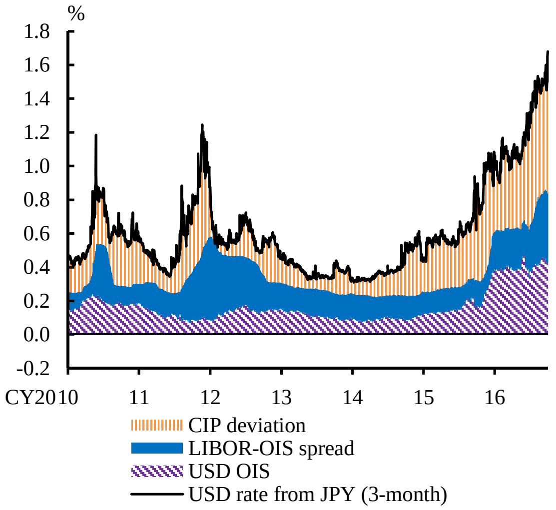
The backdrop to the setting of such a scenario is the increasing demand for foreign currency funding by Japanese financial institutions (Chart 4-1). In response to the decline in the growth prospects and profitability of the domestic market, Japanese banks are becoming actively engaged in overseas business. In addition to significantly increasing overseas lending, they are increasingly investing in foreign currency-denominated financial instruments, such as foreign bonds. Similarly, institutional investors have made moves to accumulate investments in foreign currency-denominated assets. As a result, demand for foreign currency funding from foreign exchange and currency swap markets is increasing rapidly (Chart 4-2). Meanwhile, dollar funding premiums are rising against the background of tightened supply and demand conditions in U.S. dollar funding markets, partly due to the impact of international financial regulations kicking in, such as leverage ratio requirements and U.S. MMF reform (Chart 4-3). It is likely that overseas business of Japanese financial institutions will suffer significantly in terms of profitability and financial strength in a situation where a shortage of foreign currency liquidity occurs due to supply constraints in the U.S. dollar funding markets. In particular, when the foreign currency required for financing overseas loans with low liquidity cannot be secured, disposal of these loans -- which will incur losses -- becomes unavoidable (fire-sales), and this is expected to have a considerable impact on financial institutions.

Chart 4-2: Amount of foreign currency funding via FX swaps and currency swaps by Japanese financial entities[1,2,3,4]



Notes: *1*. Estimates by the BOJ. Latest data as at end-July 2016.
2. "Major banks and institutional investors, etc." includes major banks, Japan Post Bank, The Norinchukin Bank, Shinkin Central Bank (from end-September 2014), and life insurance companies.
3. Life insurance companies are members of The Life Insurance Association of Japan (latest data on members shows 41 companies).
4. Regional financial institutions are included from end-September 2014.
Sources: Bloomberg; The Life Insurance Association of Japan; Published accounts of each company; BOJ.

Chart 4-3: Breakdown of the short-term U.S. dollar funding costs (FX swaps)[1,2]

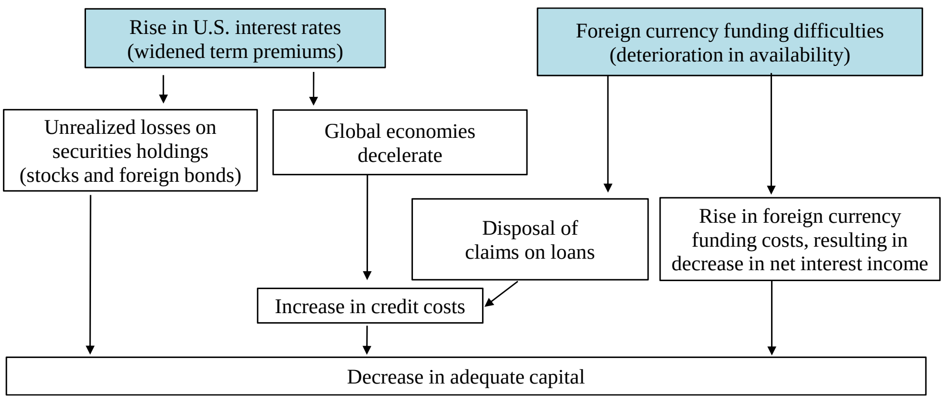


Notes: *1*. Data to September 30, 2016.
2. USD OIS = a forecast of the U.S. policy rate, LIBOR-OIS spread = USD LIBOR – USD OIS, CIP deviation = USD funding costs – USD LIBOR.
Source: Bloomberg.

(2) Overview of the scenario

The specific transmission channels of stresses are outlined below (Chart 4-4).

Chart 4-4: Transmission channels of risks in tailored event scenario



First, the U.S. term premium, which has been muted until recently, widens, causing long-term interest rates to rise, which in turn leads to a slowdown in the U.S. economy. The decline in U.S. economic growth is then transmitted to the world economy, through trade and financial channels, and the Japanese economy slows as well.

The rise in U.S. interest rates and the slowdown in the world economy lead to a deterioration in the financial conditions of firms globally, and credit costs rise. Meanwhile, capital flows out of emerging economies and back to advanced economies, such as the United States, which could cause the growth rate of emerging economies to fall further and the financial conditions of firms in emerging economies with dollar-denominated liabilities to deteriorate. In addition, in this environment, a rise in U.S. long-term interest rates and a fall in stock prices globally will cause deterioration in unrealized gains/losses on securities holdings and reduce the capital levels of internationally active banks.

With regard to foreign currency funding, it is assumed that the supply-demand balance in foreign currency funding, particularly in U.S. dollars, tightens and the foreign currency funding premium widens as uncertainty in global financial markets grows. In addition, part of the market funding that has matured cannot be rolled over by Japanese banks due in part to the compression of risky assets by foreign currency suppliers. In response to the constraint on funding liquidity, Japanese banks pledge highly liquid assets to obtain funding. However, if this proves insufficient, it is assumed that illiquid assets are disposed of to meet funding needs. Specifically, Japanese banks first obtain funding with bonds that are eligible for repo borrowing. However, if the outflow cannot be covered fully, banks are forced to dispose of foreign currency-denominated loans, resulting in losses on disposals (credit costs). Thus, when obtaining foreign currency funding becomes difficult, the decrease in net interest income caused by a rise in foreign currency funding costs and losses on disposal of loans put downward pressure on the profits and capital levels of financial institutions.

Financial and economic variables evolve according to the scenario presented, as follows (Chart 4-5). First, we assume that the U.S. term premium widens by 200 basis points and U.S. long-term interest rates consequently rise.[7] Moreover, the foreign currency funding premium widens by 50 basis points from current levels, with the impact extending to the overseas interbank market, foreign currency swaps, foreign currency-denominated CD and CP issuance, and other market-based funding.

Due to the rise in U.S. long-term interest rates, the growth rate of overseas economies (real GDP) slows from 3.1 percent in 2015 to 1.4 percent in 2017, and the growth rate of the Japan's economy (real GDP) declines from 0.8 percent in fiscal 2015 to minus 0.2 percent in fiscal 2017 (Charts 4-5 and 4-6).[8,9] Meanwhile, Japanese stock prices fall by

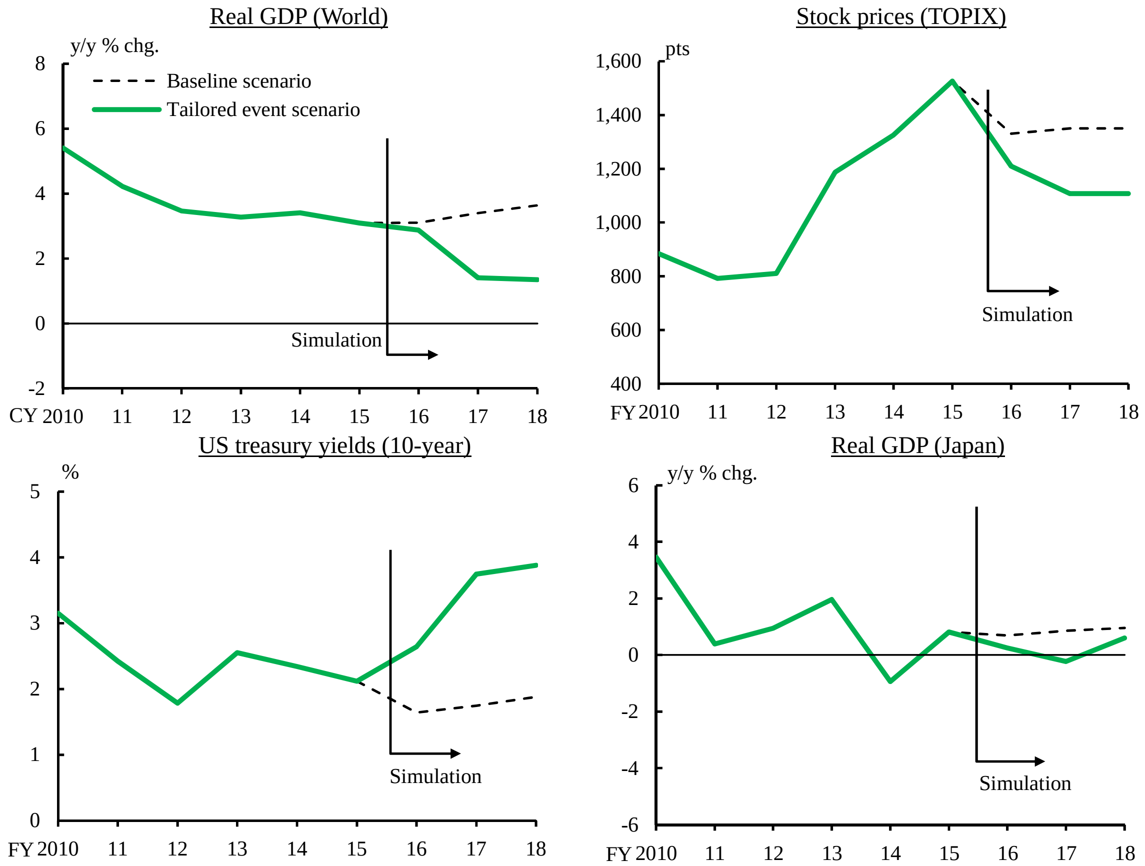
[7] Widening of term premiums does not affect the expected path of the future short-term rate.

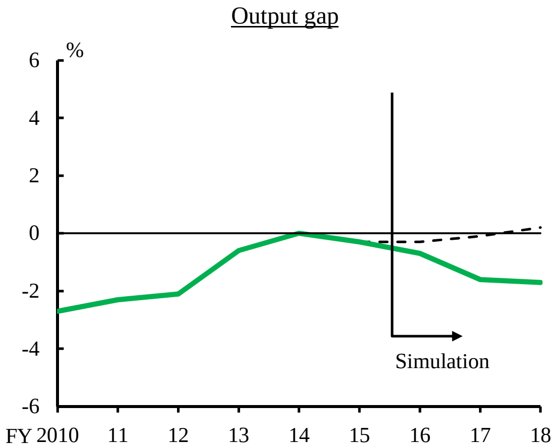
[8] We use models including VAR to estimate the extent of the retraction in economic growth rates in each region following a rise in U.S. interest rates.

[9] In contrast to the tail event scenario, no other shocks (e.g., shocks to income or expected growth)

almost 20 percent, due to the impact of higher U.S. long-term interest rates. The assumptions for the nominal exchange rate and JGB yields are the same as those in the baseline scenario (Charts 2-1 and 2-2).

Chart 4-5: Summary of variables (tailored event scenario)[1]





Note: *1*. Output gap from fiscal 2010 to fiscal 2015 is estimated by the BOJ. For simulation periods, output gap is estimated by the Financial Macro-econometric Model in each scenario and is not the BOJ's forecast.
Sources: Cabinet Office, "National Accounts"; FRB; IMF, "World economic outlook"; Japan Center for Economic Research, "ESP forecasts"; Tokyo Stock Exchange; BOJ.

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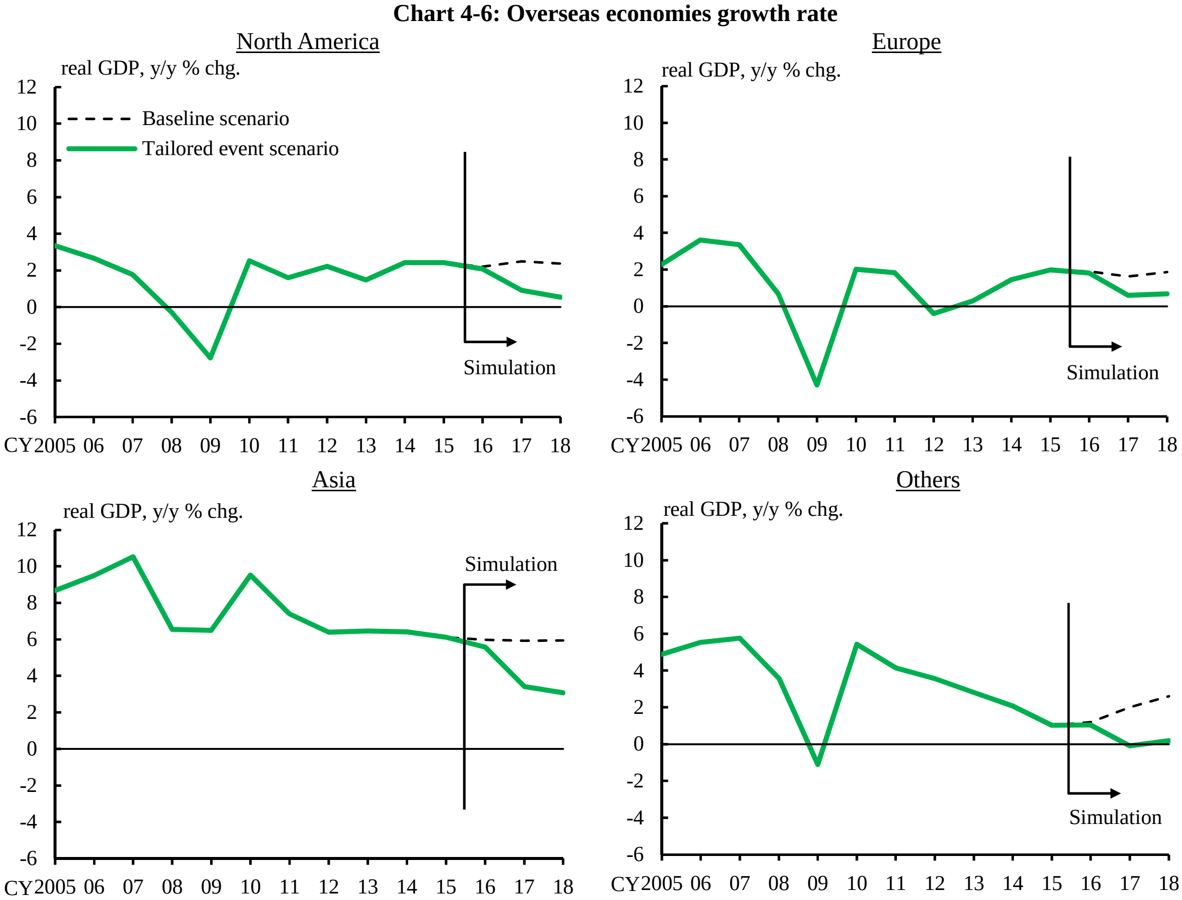
are directly applied to the domestic economy in the tailored event scenario, because the tailored event scenario focuses on the impact of the rise in U.S. interest rates and the increased difficulty of obtaining foreign currency funding.

Chart 4-6: Overseas economies growth rate



Sources: IMF, "World economic outlook"; BOJ.

(3) Calculation of losses on disposal of foreign currency-denominated loans

This subsection explains how the disposal of loans and the amount of losses associated with it (credit costs) are calculated when there are constraints on the availability of foreign currency funding.

First, we calculate the amount of loans that needs to be disposed of to obtain foreign currency, in light of difficulties in the rolling-over of foreign currency funding, as follows:

$$\boxed{\begin{array}{c}\text{required foreign}\\ \text{currency funding}\end{array}} = \max\left(\boxed{\begin{array}{c}\text{outflow}\\ \text{of funding}\end{array}} - \boxed{\begin{array}{c}\text{available repo}\\ \text{borrowing}\end{array}}, 0\right).$$

This implies that there is no need to reduce loan assets when the outflow of funding can be covered through repo borrowing, but that it is necessary to do so when the outflow cannot be covered. We assume that the outflow amounts to more than half (about 60 percent) of market-based liabilities over the simulation period of 2.5 years.

Next, as a certain degree of losses can be expected upon the disposal of loans, an amount in excess of the required foreign currency funding needs to be disposed of. Hence, the required decrease in loans is the sum of required foreign currency funding and the loss on the disposal of loans:

$$\boxed{\begin{matrix}\text{required decrease}\\ \text{in loans}\end{matrix}} = \boxed{\begin{matrix}\text{required foreign}\\ \text{currency funding}\end{matrix}} + \boxed{\begin{matrix}\text{loss on disposal}\\ \text{(credit costs)}\end{matrix}}.$$

Here, we calculate the loss on the disposal of loans (credit costs) as follows:

$$\boxed{\begin{matrix}\text{loss on disposal}\\ \text{(credit costs)}\end{matrix}} = \boxed{\begin{matrix}\text{required}\\ \text{decrease}\\ \text{in loans}\end{matrix}} \times \underbrace{\boxed{\begin{matrix}1-\text{collection rate}\\ =50\%\end{matrix}} \times \boxed{\begin{matrix}\text{discount}\\ \text{on disposal}\\ =10\%\end{matrix}}}_{\alpha \equiv \text{the effective non-collection rate}}.$$

The above equation indicates that the loss on the disposal of loans is the required decrease in loans, multiplied by the share of loans that could not be collected from debtors ($1-$ collection rate) and the discount on the disposal of loans. Putting these two equations together, the following expression can be obtained:

$$\boxed{\begin{matrix}\text{loss on disposal}\\ \text{(credit costs)}\end{matrix}} = \frac{\alpha}{1-\alpha} \times \boxed{\begin{matrix}\text{required foreign}\\ \text{currency funding}\end{matrix}}.$$

That is, since more loans need to be disposed of to secure a given amount of foreign currency funding, as the effective non-collection rate, denoted by α, rises, the losses on disposal (credit costs) grow in a non-linear fashion, and exert a greater impact on capital levels.

In the simulation, the collection rate of loans from debtors is assumed to be 50 percent, taking reference from the Liquidity Coverage Ratio (LCR) regulation. While the discount on disposal of loans is set at 10 percent by default, the impact of its change on capital levels is estimated by varying the discount on disposal, up to 50 percent. For individual financial institutions, it may seem that a 10 percent loss on disposal is a conservative assumption. However, there is a possibility that the discount on disposals deepens by more than expected if many financial institutions dispose of loans simultaneously, creating negative externalities on the markets related to the disposal of such loans. Bearing this in mind, it is desirable to assume a sufficiently wide range for the discount on disposal when conducting stress testing.

5. Conclusion

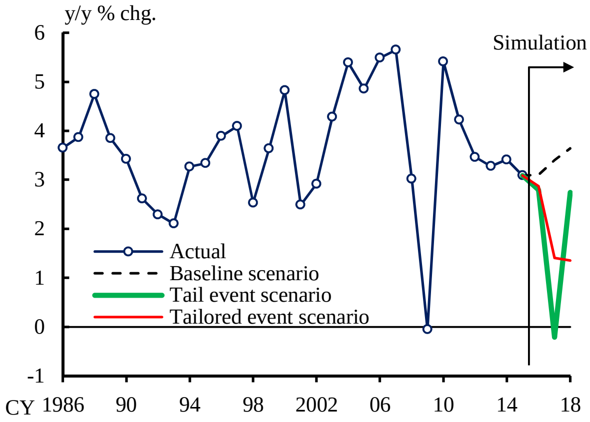
In recent years, financial institutions have been placing increasing emphasis on stress testing as a means of capturing and analyzing varied and complex risks as well as their effects on profitability and financial strength, as part of a risk management framework. Stress testing plays an important role as part of a framework, such as a risk appetite framework, whereby financial institutions comprehensively oversee risk management and risk taking behavior, based on their business strategies. To perform a constructive stress test on a financial institution, it is critical to develop an appropriate scenario that applies suitably severe stress corresponding to its risk profile. Other important elements of a constructive stress test include the appropriate specification and classification of borrower attributes, and the appropriate selection of financial and economic variables that influence credit costs for each borrower attribute (see Box 3). In addition, it should be recognized that the degree of interactions between the financial system and the real economy may vary depending on changes in financial institutions' business models and the structure of the economy. In fact, the comovement between the financial sector and the real economy has risen recently with advances in globalization (see Box 4). It is desirable that individual financial institutions make appropriate refinements to their stress test models with these points in mind.

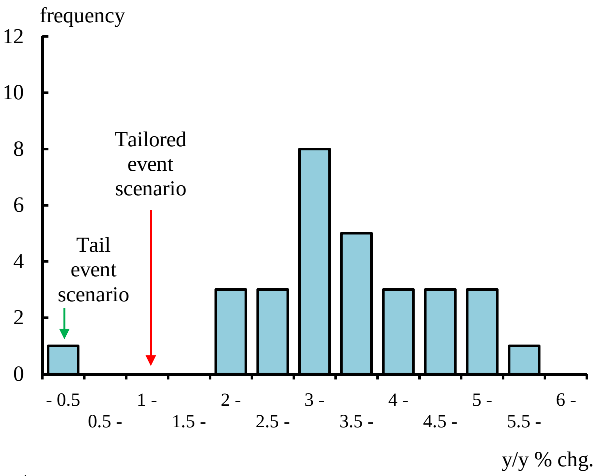
In addition to refining the models used in macro stress testing, the Bank of Japan will continue to enhance communication with financial institutions while making detailed disclosures of the scenarios and test results. The results of this round of macro stress testing can be found in Chapter V of the October 2016 issue of the *Report*. The major economic variables for each scenario can also be downloaded from the Bank of Japan's website (Chart 5-1).[10] Going forward, upon request, the Bank of Japan will set out to compare the results of individual financial institutions' stress tests with its own, during its on-site examinations and on other occasions.

[10] http://www.boj.or.jp/en/research/brp/fsr/data/fsrb161026b.zip

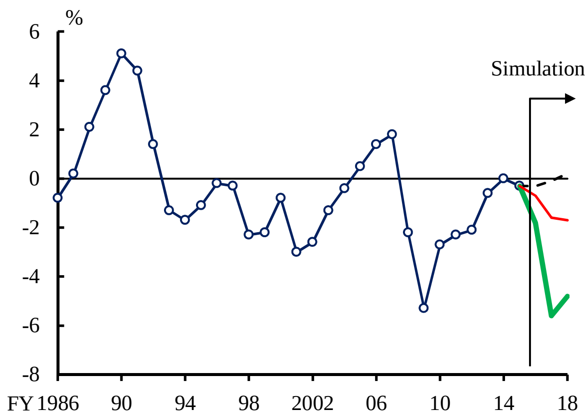
Chart 5-1: Characteristics of variables for each scenario[1,2]

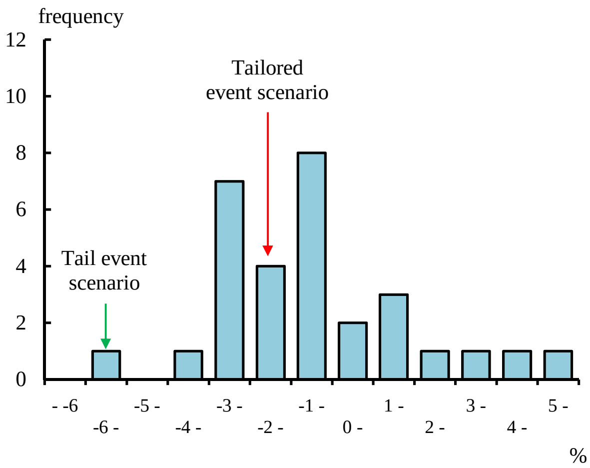
Real GDP (World)



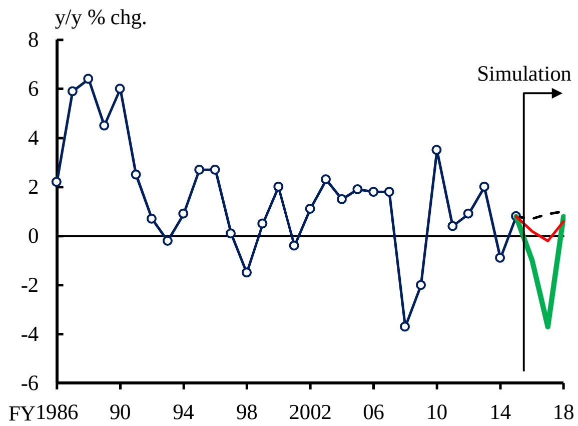


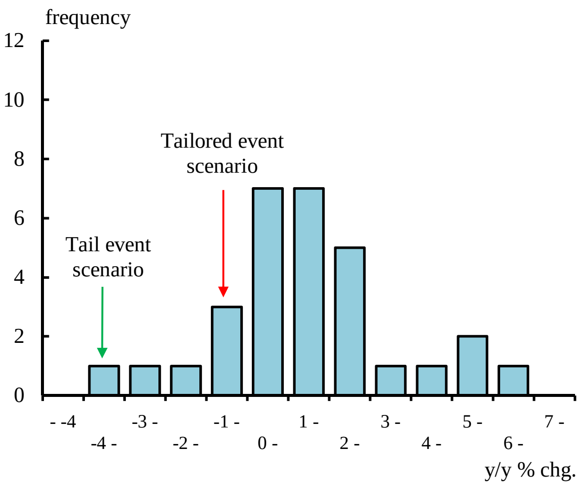
Output gap



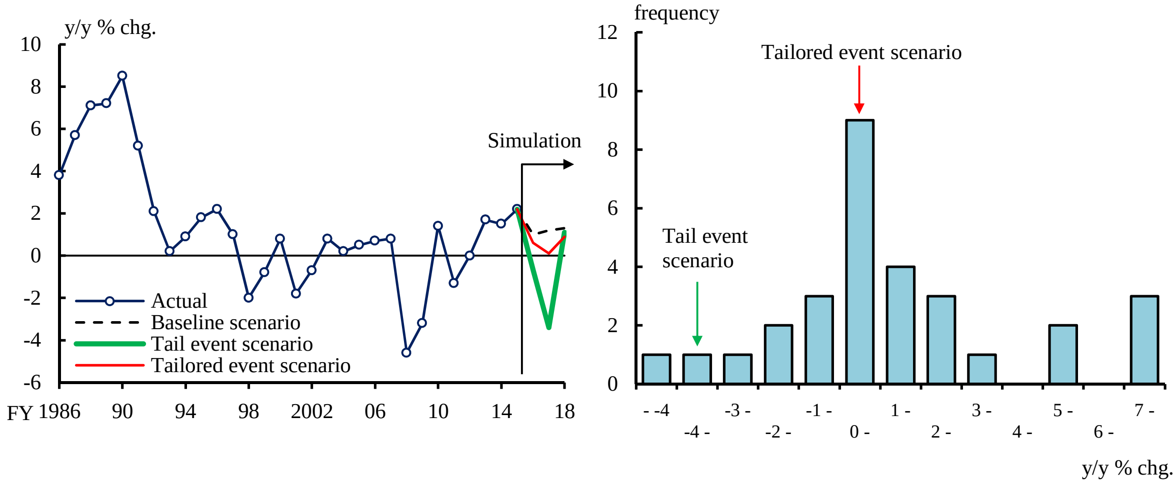


Real GDP (Japan)

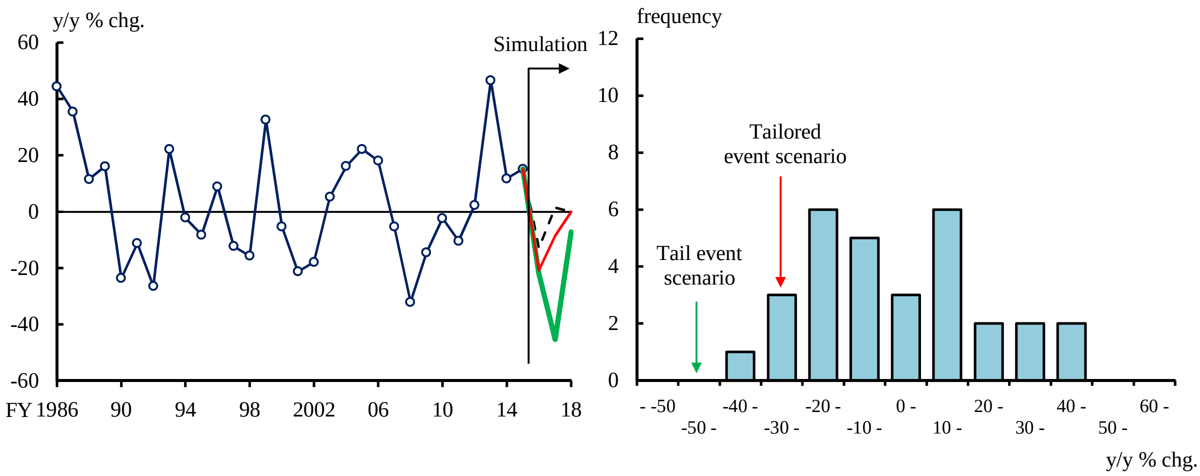




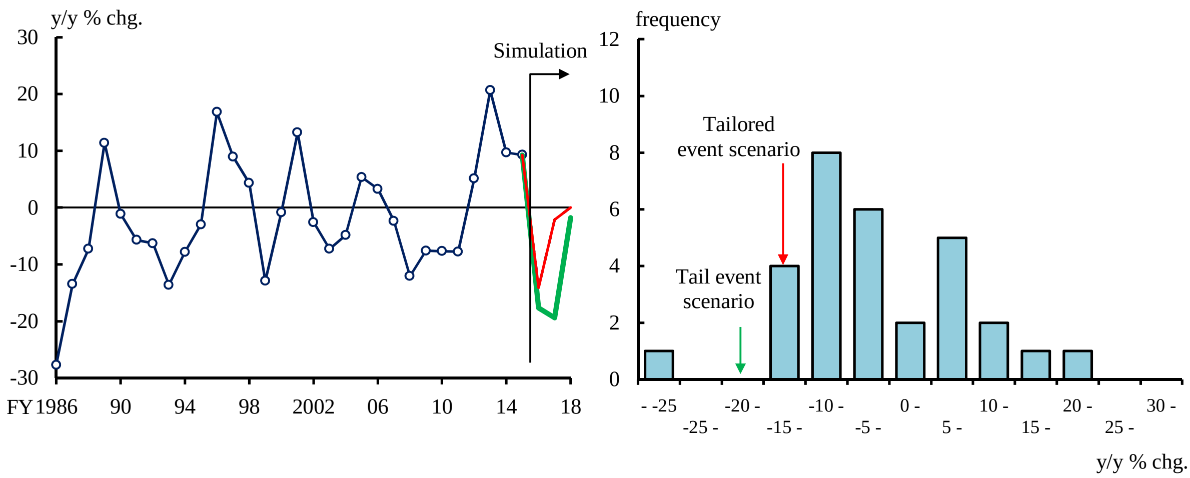
Nominal GDP (Japan)



Stock prices (TOPIX)



Nominal exchange rates (yen/U.S. dollar)



Notes: 1. Distribution of world real GDP is compiled with data from 1986 to 2015; distributions of other variables are compiled with data from fiscal 1986 to fiscal 2015.

2. Output gap from fiscal 1986 to fiscal 2015 is estimated by the BOJ. For simulation periods, output gap is estimated by the Financial Macro-econometric Model in each scenario and is not the BOJ's forecast.

Sources: Cabinet Office, "National accounts"; IMF, "World economic outlook"; Japan Center for Economic Research, "ESP forecasts"; Tokyo Stock Exchange; BOJ.

Box 1: Modeling credit costs associated with overseas lending

The outstanding amount of overseas loans extended by Japanese financial institutions, especially major banks, continues to increase as the profitability of domestic lending is on a declining trend. It is thus becoming more important to accurately assess the impact of credit costs associated with overseas lending on profits and capital.

When calculating credit costs, the former Financial Macro-econometric Model did not distinguish between domestic and overseas credit costs. For example, overall credit costs, including the overseas component, were estimated by determining the overall borrower classification transition probability, which took into account the financial strength of domestic firms and domestic macro factors. In the stress testing exercise this time, however, credit costs associated with overseas lending are modeled separately from the domestic lending component, in order to appropriately estimate the impact of a shock originating overseas on the credit costs associated with overseas lending.

Here, Moody's credit rating transition matrices by region (North America, Europe, Asia, and other regions), which provide long-term time-series data, are mapped into borrower classification transition matrices, which are used to calculate credit costs. The transition matrices allow the relationship between regional financial and economic variables and the borrower classification transition probabilities to be estimated.[11] Specifically, the transition probability $P_{k,t}^{ij}$ from borrower classification i to j in region k at time t and its explanatory variables are specified as follows.

$$\ln\left(\frac{P_{k,t}^{ij}}{1-P_{k,t}^{ij}}\right) = \alpha_k^{ij} + \beta_k^{ij}\left(\text{real GDP growth}_{k,t}\right) + \gamma_k^{ij}\left(\text{rate of change in stock prices}_{k,t}\right)$$
$$+ \rho_k^{ij}\left(\text{borrowing interest rates}_{k,t}\right)$$

Considering a case in which $P_{k,t}^{ij}$ is the downgrade probability of borrower classification, the signs of parameters $\beta_k^{ij}, \gamma_k^{ij}$ are expected to be negative because a rise in real GDP growth or a rise in the rate of increase in stock prices should lower the downgrade probability of borrower classification.[12] On the other hand, the sign of parameter ρ_k^{ij} is expected to be positive because an increase in borrowing interest rates increases the

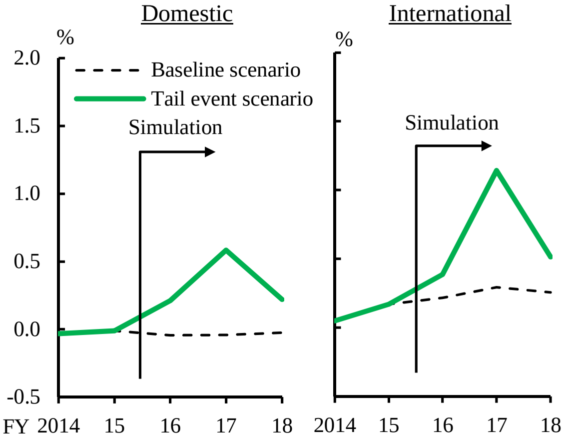
[11] The rating transition in Moody's available from 1987 was used to create a borrower classification transition matrix by mapping the Moody's rating classifications against the borrower classifications of Japanese financial institutions (normal, need attention excluding special attention, special attention, in danger of bankruptcy, and de facto bankrupt or bankrupt).

[12] The sign criteria are reversed when determining the probability of upgrade.

burden of interest payments by firms, which raises the downgrade probability.[13] For all transition probabilities $P_{k,t}^{ij}$ in the borrower classification transition matrices for each region k, we estimate the above equation. Based on the estimation results, only variables that satisfy the sign criteria and are statistically significant are employed in the model.

The stress testing results (tail event scenario) using the Financial Macro-econometric Model, which incorporates the modeling of credit costs associated with overseas lending, show that the credit cost ratio associated with overseas lending rises to a large extent (Chart B1-1). By region, credit costs in various regions have increased in tandem with a decrease in the growth rate. In particular, the increase in Europe is sizable (Chart B1-2).

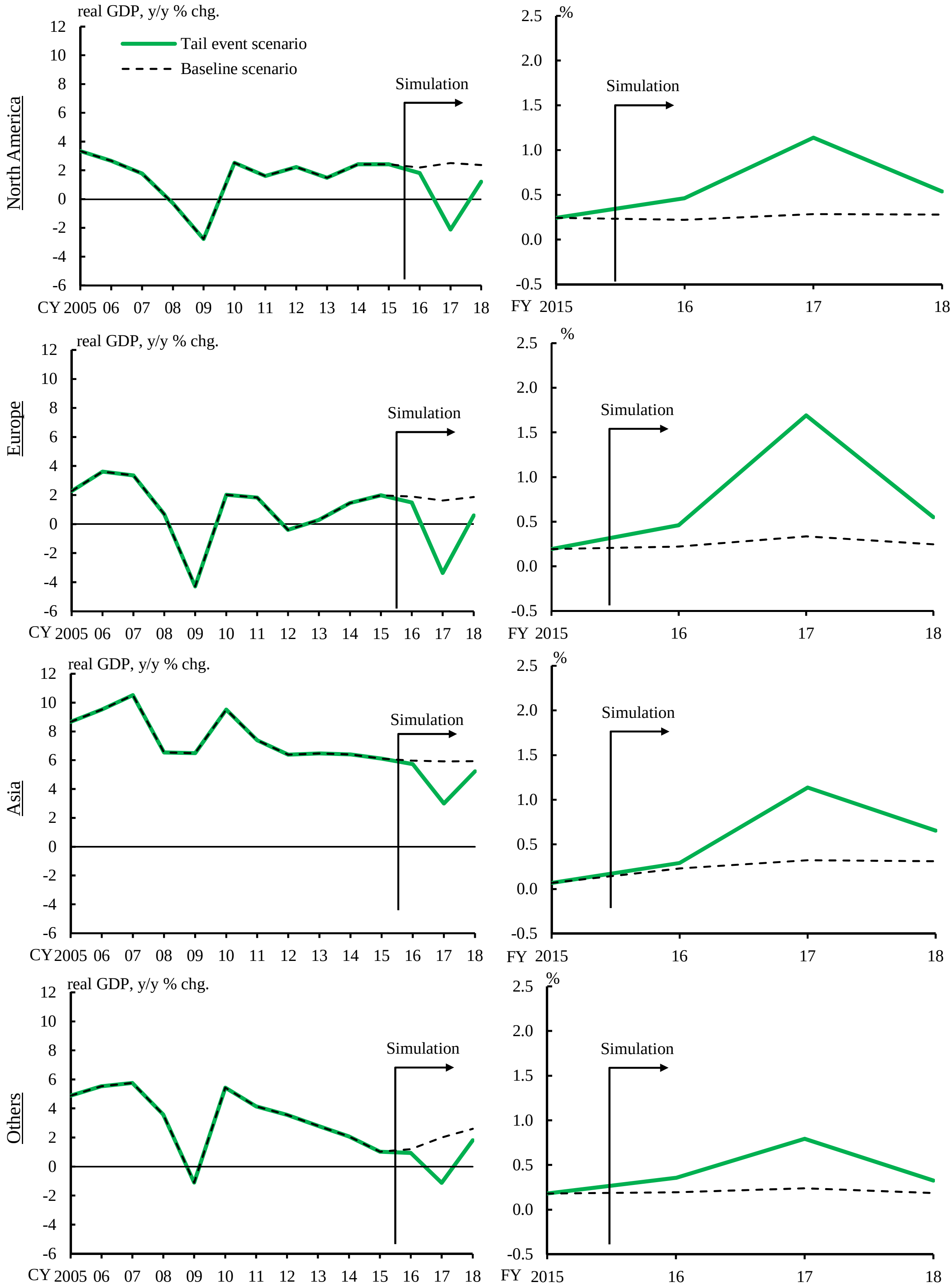
Chart B1-1: Credit cost ratio (tail event scenario)[1]



Note: *1*. Includes five major banks with a considerable share of overseas loans.
Source: BOJ.

[13] As for borrowing interest rates, we incorporate the mechanism that a decrease in nominal GDP exerts upward pressure on borrowing interest rates through a widening of credit spreads.

Chart B1-2: Overseas economies and credit cost ratio



Sources: IMF, "World economic outlook"; BOJ.

Box 2: Modeling the impact of financial institutions' profitability on their lending behavior

When modeling lending behavior of financial institutions in macro stress testing, capital adequacy ratios (CAR) of individual financial institutions in addition to macroeconomic variables, such as the expected growth rate of the economy and asset prices, are usually employed as explanatory variables as shown in the following equation ($\alpha > 0$):[14]

$$\text{lending growth}_{i,t} = \alpha \times \left(CAR_{i,t-1}\right) + \lambda \times (\text{other variable}_t) + \cdots$$

Here, *i* denotes each financial institution and *t* denotes each point in time. In such a model, only the *level* of the capital adequacy ratio has an impact on lending by financial institutions. However, in reality, the *change* in the capital adequacy ratio ($\Delta(CAR_{i,t-1})$) may also have an impact on lending as depicted in the following equation ($\beta > 0$):

$$\text{lending growth}_{i,t} = \alpha \times \left(CAR_{i,t-1}\right) + \beta \times \Delta\left(CAR_{i,t-1}\right) + \lambda \times (\text{other variable}_t) + \cdots$$

For example, even if the capital adequacy ratio exceeds regulatory requirements, if the capital adequacy ratio declines ($\Delta(CAR_{i,t-1}) < 0$), a financial institution may begin to restrain lending as early as the current period to avoid the risk of falling foul of regulatory requirements. Conversely, when the capital adequacy ratio increases ($\Delta(CAR_{i,t-1}) > 0$), the growth in lending may accelerate.

The above equation can be rewritten as follows, because the return on assets (ROA) of a financial institution is linked to changes in capital through retained earnings.

$$\text{lending growth}_{i,t} = \alpha \times \left(CAR_{i,t-1}\right) + \gamma \times \left(ROA_{i,t-1}\right) + \lambda \times (\text{other variable}_t) + \cdots$$

The impact of a financial institution's profits on its lending (the parameter γ) becomes larger (i) when ROA is negative, i.e. when there is downward pressure on the capital adequacy ratio, and (ii) when the level of the capital adequacy ratio is already low.[15] In fact, a panel estimation of domestic banks to discern the impact of ROA on lending to domestic companies produces results aligned with this view (Chart B2-1).

[14] The Financial Macro-econometric Model applies a lag to the capital adequacy ratio (the deviation from regulatory requirements) to alleviate the endogeneity between financial institutions' capital adequacy ratios and their lending.

[15] This stress testing exercise is carried out based on the formulation below:

$$\gamma = \theta + \phi \times DUM_{i,t}^{ROA} + \varphi \times DUM_{i,t}^{CAR}$$

where $DUM_{i,t}^{ROA}$ is a dummy variable that takes the value of 1 when $ROA_{i,t-1}$ is negative (0 when positive). $DUM_{i,t}^{CAR}$ is a dummy variable that takes the value of 1 when $CAR_{i,t-1}$ is low (0 when high).

Chart B2-1: Effects of ROA on lending (estimation results of parameter γ)[1]

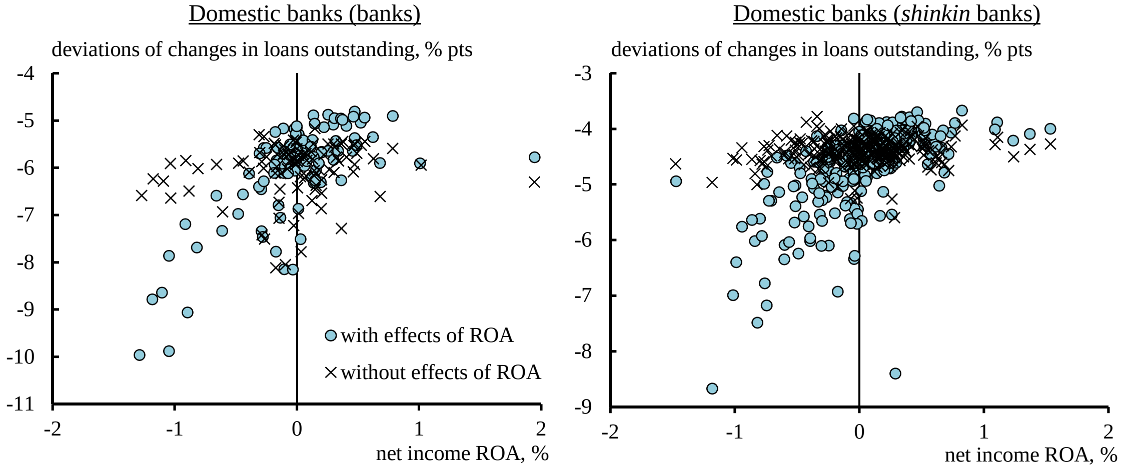
<table>
<tr><th rowspan="2"></th><th colspan="2">Domestic banks (banks)</th><th colspan="2">Domestic banks (shinkin banks)</th></tr>
<tr><th>positive
net income ROA</th><th>negative
net income ROA</th><th>positive
net income ROA</th><th>negative
net income ROA</th></tr>
<tr><td>high capital adequacy ratio</td><td rowspan="2">0.91</td><td>1.42</td><td>--</td><td>2.52</td></tr>
<tr><td>low capital adequacy ratio</td><td>2.27</td><td>0.90</td><td>3.42</td></tr>
</table>

Note: *1*. Estimation period is from fiscal 1989 to fiscal 2015.
Source: BOJ.

Therefore, even if capital is at adequate levels, the incentive to extend loans weakens and loan growth decelerates when profits turn negative. Furthermore, if profits decline when the capital adequacy ratio is already low and close to the level of regulatory requirements, the downward pressure on lending becomes larger as financial institutions become more cautious about taking risks.

The macro stress testing conducted in the October 2016 issue of the *Report* incorporates the above-mentioned non-linear impact of financial institutions' ROA on their lending. To quantify the impact of this channel, we compare the difference in the change in lending growth between the baseline scenario and tail event scenario in the case where this channel is considered against the case where it is not (Chart B2-2). As expected, the level of each financial institution's ROA does not result in a significant difference in the rate of decrease in lending when there is no direct channel between ROA and lending by financial institutions. However, when we incorporate the non-linear impact of ROA on lending by financial institutions as presented above, the rate of decrease in lending by financial institutions with negative ROA is substantially greater than that by financial institutions with positive ROA.

Chart B2-2: Distribution of profitability and loans outstanding (tail event scenario)[1]



Note: *1*. The vertical axis shows how the cumulative changes in loans outstanding to domestic firms from end-March 2016 to end-March 2019 deviate from the baseline scenario. Net income ROA = (cumulative net income from fiscal 2015 to fiscal 2017) / (total assets in fiscal 2017). "with effects of ROA" refers to the case where the Financial Macro-econometric Model incorporates non-linear effects of the level of financial institutions' net income ROA on their lending stance.

Source: BOJ.

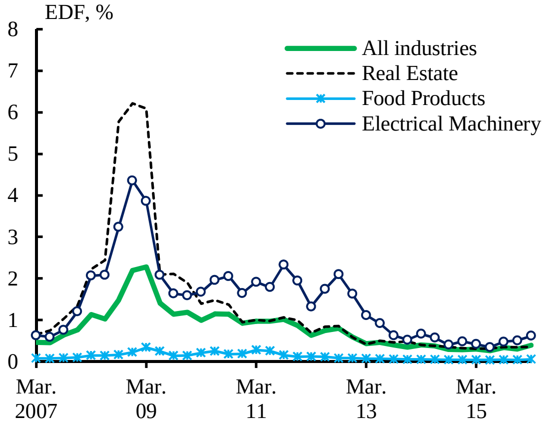
These results suggest that for financial institutions whose core profitability is lowered due to the impact of the low interest rate environment and the population decline, when stresses occur, the probability that they experience losses increases and there is a risk that their lending decreases.

Box 3: On the estimation of the probability of default in stress testing

In order to estimate credit costs under stress events, stress testing usually employs a model linking the change in the probability of default (PD) to changes in the economic environment. In order to build an appropriate model, it is important to (1) specify and classify borrower attributes and (2) for each borrower attribute, identify macroeconomic variables that affect the PD. In this box, we estimate the impact that the above two considerations have on the expected losses of listed companies in a stress situation, by applying the PD calculated using stock prices, financial data, and other data sources.

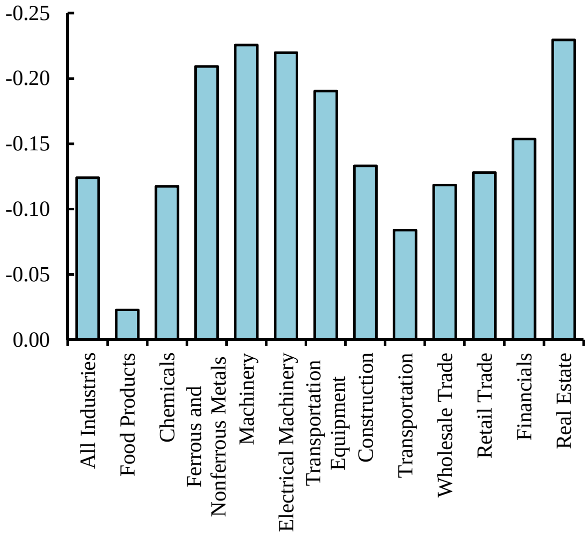
First, the attributes of a borrower can be classified according to many categories, such as industry, size, and credit rating. Here, we focus on the PD of the industry to which the borrower belongs. In the wake of the Lehman shock, changes in the PD varied greatly, suggesting that the sensitivity of the PD to stress varies from industry to industry (Chart B3-1). For example, when the industry-specific sensitivity of the PD is estimated by taking the output gap as the macroeconomic indicator representing the business cycle -- in other words, by regressing the PD on the output gap -- the result shows that while sensitivity is high in industries such as real estate and machinery, it is low in food products (Chart B3-2). This reflects the weak relationship between business conditions in industries that deal with daily necessities, such as food products, and business cycles.

Chart B3-1: PDs by industry[1,2]



Notes: *1*. Latest data as at end-March 2016.
2. PDs are calculated based on the median Expected Default Frequencies (EDFs) for listed companies.
Source: Moody's.

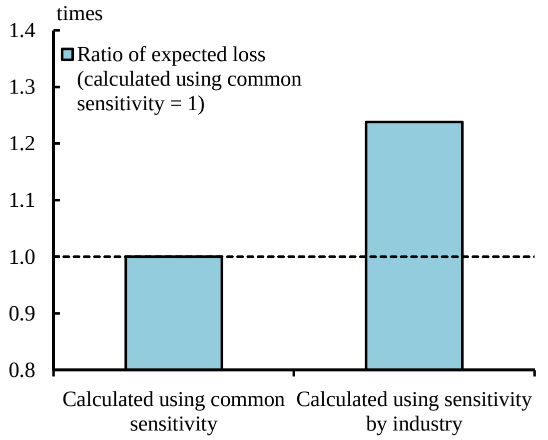
Chart B3-2: Sensitivity of PD to output gap by industry[1,2,3,4]



Notes: *1*. Includes industries that meet the following conditions: (1) the share of outstanding corporate loans is over 2 percent, and (2) the corresponding industry EDF includes 50 firms or more.
2. "All industries" includes industries not covered in this estimation.
3. Estimation period is from end-June 2006 to end-March 2016.
4. Output gap is estimated by the BOJ.
Sources: Moody's; BOJ.

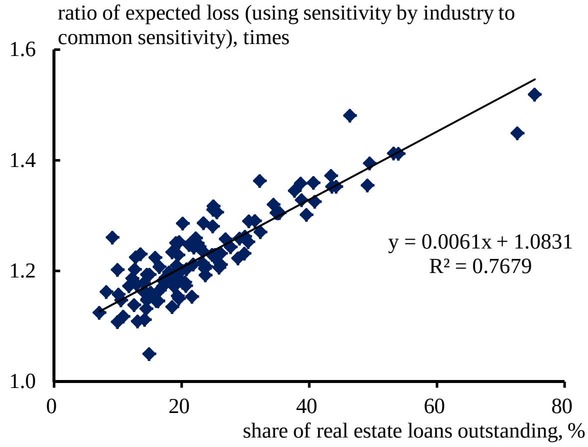
By applying the above-mentioned industry-specific sensitivity to estimate the PD under the economic downturn scenario (the tail event scenario in section 3), it is found that the sum of expected losses for the banking sector as a whole (the sum of major banks and regional banks) is 1.2 times that obtained by using all-industry sensitivity (Chart B3-3). Estimation results for individual banks show that the difference in expected losses under the two simulations becomes greater for banks with a higher share of real estate lending, whose PD is highly sensitive to the business cycle (Chart B3-4).

Chart B3-3: The impact of incorporating sensitivity by industry[1,2,3]



Notes: *1*. Includes major banks and regional banks.
2. Each bank's expected loss is calculated based on the outstanding corporate loans as at end-March 2016. Cumulative expected loss is computed over the stress scenario horizon (3 years).
3. LGD is assumed to be 100 percent.
Sources: Moody's; BOJ.

Chart B3-4: Share of real estate loans outstanding and ratio of expected loss[1,2,3,4]



Notes: *1*. Includes major banks and regional banks.
2. Each bank's expected loss is calculated based on the outstanding corporate loans as at end-March 2016. Cumulative expected loss is computed over the stress scenario horizon (3 years).
3. LGD is assumed to be 100 percent.
4. Real estate loans outstanding as at end-March 2016.
Sources: Moody's; BOJ.

Next, we specify the macroeconomic indicators that affect the PD for each industry. Among business cycle indicators, the output gap (which represents the level of the business cycle) is found to explain PD far better than the GDP growth rate (which represents changes in the business cycle) for most industries. It is also observed that expected losses tend to be underestimated when stress testing is conducted in an economic downturn scenario where the GDP growth rate is used as a business cycle indicator. In order to improve the fit of PD estimations, we employ the exchange rate and the interest rate in addition to the output gap, and choose the combination of variables (among the three) that best explains the PD in each industry. In export-oriented industries, such as machinery, the exchange rate is found to have a large effect, while it does not have a significant effect in domestic demand-oriented industries, such as food products and real estate. The interest rate is found to have an especially large effect on the PD of the real estate industry, which has a high debt ratio.

The amount of expected losses is estimated under the aforementioned economic downturn scenario, by utilizing a model where macro variables for each industry are added as appropriate (Chart B3-5). Results indicate that the amount of expected losses is smaller compared to a case where the output gap is the only explanatory variable. This is because, while expected losses in the export industries are higher due to the yen's appreciation, expected losses are lower in the real estate industry due to declining interest rates, and those latter effects dominate the former effects. Depending on the scenario, there may be cases where expected losses turn out to be higher. As such, both upside and downside biases in the estimation of expected losses could occur depending on the choice of macroeconomic variables in explaining the PD.

Chart B3-5: The impact of incorporating interest rates and exchange rates[1,2,3]

Notes: *1*. Includes major banks and regional banks.
2. Each bank's expected loss is calculated based on outstanding corporate loans as at end-March 2016. Cumulative expected loss is computed over the stress scenario horizon (3 years).
3. LGD is assumed to be 100 percent.
Sources: Bloomberg; Moody's; BOJ.

Therefore, when conducting stress testing, it is essential to carefully examine the content of the portfolio of each financial institution, as well as select the appropriate macroeconomic variables affecting the PD, for each borrower attribute. Moreover, as the relationship between the PD and macroeconomic variables could change over time, it is desirable to review the PD estimation model regularly and refine it according to the findings.

Box 4: Rise in comovement between the financial sector and the real economy

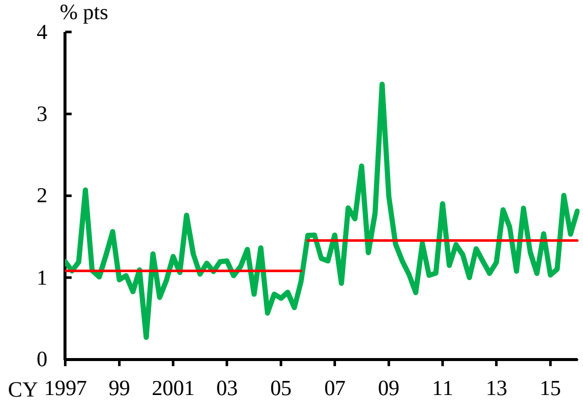
In this box, we examine the comovement between the financial sector and the real economy with CoVaR, which is utilized in measuring systemic risk.[16]

In general, CoVaR is a method of measuring the systemic risk posed by shocks from individual banks on the banking sector as a whole by measuring tail risk comovement based on the stock return of individual banks and the banking sector as a whole. Specifically, CoVaR is measured as follows:

$$CoVaR_{i,t} \equiv \beta_{i,t} \times VaR_{i,t}$$

$CoVaR_{i,t}$ is the stock return of the banking sector as a whole, given that the bottom 5 percent of the return on the stock of Bank *i*, denoted by $VaR_{i,t}$, is realized. That is, $CoVaR_{i,t}$ consists of the $VaR_{i,t}$ of the stock of Bank *i* and the parameter $\beta_{i,t}$, which indicates the degree of tail risk comovement between Bank *i* and the banking sector as a whole. In this box, we estimated CoVaR by replacing the stock return of the banking sector as a whole with the stock return of the real economy (the domestic non-financial sector) to examine the comovement between the financial sector and the real economy. A larger $\beta_{i,t}$, the parameter representing tail risk comovement between the two sectors, indicates that the fall in stock prices in the real economy would be larger when the stock price of Bank *i* falls, and that there is a high degree of comovement between the two sectors.

Chart B4-1: Finance-real economy CoVaR[1,2]



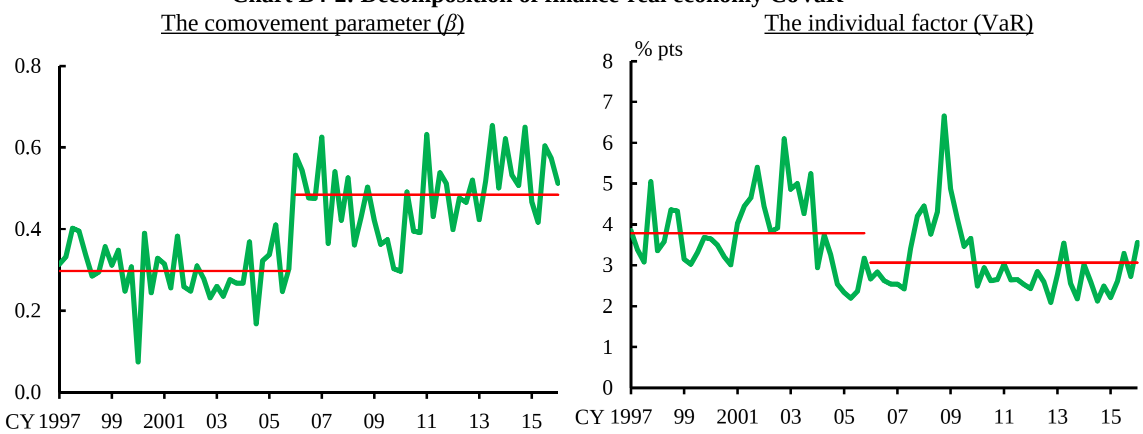
Notes: *1.* Latest data as at end-March 2016. CoVaR refers to the average value for the three major banks. Estimation period is from January 1996 to March 2016. The estimation uses 100-day rolling samples.
2. Horizontal lines indicate the average value of CoVaR from 1996 to 2005 and from 2006 to 2016, respectively.
Sources: Bloomberg; BOJ.

The results estimated using stock prices of three major banks confirm that the CoVaR between the financial sector and the real economy increased, starting from around the mid-2000s (Chart B4-1). To further investigate the cause of the increase, we decompose $CoVaR_{i,t}$ into $VaR_{i,t}$, the amount of risk of the stock of Bank i, and $\beta_{i,t}$, which

[16] For more details on CoVaR, see Tobias Adrian and Markus K. Brunnermeier, "CoVaR," American Economic Review, vol.106, no.7, July 2016.

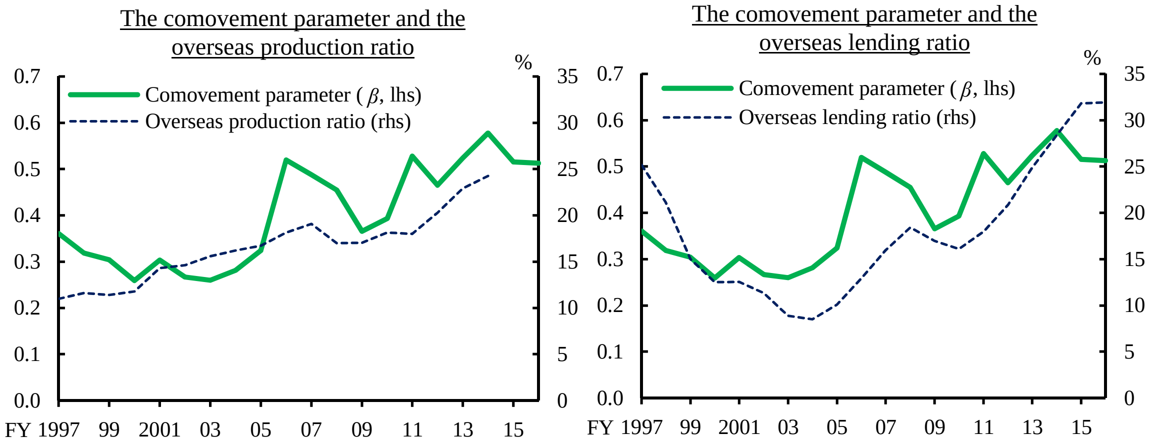
indicates the degree of tail risk comovement between the financial sector and the real economy. Although the former has decreased slightly, the latter has been increasing since around the mid-2000s (Chart B4-2). One of the factors behind the increase in $\beta_{i,t}$ is considered to be the increased common exposure to shocks originating from abroad for both the financial sector and the real economy, amid globalization among both firms and financial institutions. In fact, developments in the share of overseas lending and the share of overseas production are generally similar to the development of the comovement parameter (Chart B4-3).

Chart B4-2: Decomposition of finance-real economy CoVaR[1,2]



Notes: *1*. Latest data as at end-March 2016. β and VaR refer to the average value for the three major banks. Estimation period is from January 1996 to March 2016. The estimation uses 100-day rolling samples.
2. Horizontal lines indicate the average value of β and VaR from 1996 to 2005 and from 2006 to 2016.
Sources: Bloomberg; BOJ.

Chart B4-3: The comovement parameter, the overseas production ratio, and the overseas lending ratio[1]



Note: *1*. The comovement parameter and the overseas lending ratio refer to the average value for the three major banks. The overseas production ratio refers to the value for the entire manufacturing industry.
Sources: Bloomberg; Ministry of Economy, Trade and Industry, "Survey of overseas business activities"; Ministry of Finance, "Financial statements statistics of corporations by industry"; BOJ.

The increased comovement between the financial sector and the real economy suggests that modeling the interaction between the two sectors in macro stress testing is becoming increasingly important.