Bank of Russia

ANALYSIS OF SYSTEMIC RISKS IN MACROPRUDENTIAL STRESS TESTING

Analytical note

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CONTENTS

The paper was prepared by the Financial Stability Department. Please provide your comments, proposals and remarks by 1 April 2021 (inclusive) to: sannikovkv@mail.cbr.ru.

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INTRODUCTION

In recent years, the development of central banks' function of ensuring financial stability has been accompanied by the improvement of analytical tools for risk assessment, with stress testing playing a key role. After the global financial crisis of 2008–2009, national regulators started employing macroprudential stress testing in assessing the sustainability of the financial sector to identify systemic risks by considering the structure of relationships between financial institutions, the transmission of risks within this structure, and their cyclical development over time.

An increase in external risks has become an important trend highlighting the importance of ensuring financial stability. The past five years have seen structural changes in the level of globalisation of the world economy, increased price volatility in the commodity market, and the greater role of international sanctions in the movement of foreign capital. All of this has been reflected in volatility in global markets, including the Russian financial market. In this environment, the Bank of Russia has made significant efforts to assess and improve the resilience of the financial sector to current shocks and their potential intensification in the future.

To achieve this objective, the Bank of Russia uses macroprudential stress testing in accordance with global best practices. In 2017, the Bank of Russia first published a conceptual framework for macroprudential stress testing for consultation. The macroprudential part of stress testing complements the traditional supervisory stress testing of financial institutions, making it possible to comprehend the macroeconomic implications of stress and develop necessary response measures.

In addition to the published conceptual framework for macroprudential stress testing, the Financial Stability Department has prepared this analytical note on the development of macroprudential stress testing. Section I provides a general description of current trends in the development of macroprudential stress testing models, both globally and in the Bank of Russia in particular. Section II shows approaches to risk assessment in markets with a central counterparty, and Section III – to assessing contagion effects. Section IV describes models for assessing the effects of the mutual influence of the real and financial sectors as well as anti-crisis measures aimed at supporting the financial sector.

The Financial Stability Department of the Bank of Russia kindly asks financial market participants and other stakeholders to provide feedback in the form of comments, remarks, and proposals regarding the content of this paper. The comments will be used for the further development of macroprudential stress testing in the Bank of Russia.

I. CURRENT TRENDS IN THE DEVELOPMENT OF MACROPRUDENTIAL STRESS TESTING

In recent years, regulators and the Bank of Russia have been paying more attention to macroprudential stress testing. Following the implementation of post-crisis innovations in international regulation, the banking sector has become significantly more resilient to potential risks, both in terms of structural vulnerabilities and overcoming the «too big to fail» problem and in terms of cyclical shocks. At the same time, funds and asset managers now take a significant share of the financial market, and the role of market financing has increased.

As these changes require improved approaches to monitoring and assessing systemic risks, as a result of which leading regulators and the Bank of Russia have been developing such approaches in several areas. The first of them deals with the significantly increased role of central counterparties in providing post-trading services to financial markets. In recent years, the vector of global financial regulation has been aimed at strengthening the role of central counterparties by transferring standardised financial instruments to centralised clearing. This has led to a new higher level of confidence in financial markets, contributed to an increase in the standardisation and liquidity of financial instruments, and created conditions for mitigating mutual risk faced by participants.

At the same time, the centralisation of trade in central counterparties means the concentration of systemic risks and enhanced requirements for central counterparties' risk management. From the point of view of financial stability, it is crucial to understand the consequences of the materialisation of macroeconomic shocks for the functioning of a central counterparty and its possible impact on the financial market as a whole. To solve this problem, we need to integrate a central counterparty stress testing model into the general system of macroprudential stress testing.

The development of macroprudential stress testing models for central counterparties is on the current agenda of foreign regulators. Stress testing for central counterparties is characterised by a shorter stress-testing horizon, more severe stress scenarios, a considerable perimeter of participants, an extended chain of contagion channels and the mutual influence of the liquidity and solvency risks of participants.

In this paper, the Bank of Russia presents approaches to assessing the risks of the largest Russian central counterparty, the National Clearing Centre (NCC) of the Moscow Exchange Group, as part of macroprudential stress testing. The stress scenario considers the consequences of margin calls for the liquidity of clearing members, defaults on insolvent participants' obligations to the NCC and spillover of the risks of discounting of the NCC's obligations to the entire financial sector. Thus, macroprudential stress testing enables assessment of the sustainability of the central counterparty in relation to emerging risks for market participants and the sector as a whole.

The second area in the development of macroprudential stress testing is associated with the global reform of the OTC money market and the derivatives market. After the crisis of 2008 – 2009, foreign regulators demand that market participants in local jurisdictions send information on OTC positions to trade repositories. In Russia, the requirement to provide information was introduced even earlier than in other countries, significantly increasing the transparency and completeness of data on the risks of the OTC market. The Bank of Russia aims to integrate the assessment of the systemic risk of the OTC market into macroprudential stress testing.

For these purposes, contagion models that can describe several mechanisms are being developed around the world. First, there is a direct contagion mechanism that assumes a deterioration in the financial position of an organisation due to the insolvency of its borrowers or creditors. Such models were implemented by leading central banks with varying degrees of coverage and detail. For example, the ECB and the Bank of Japan consider only interbank loans in their analysis, while the Bank of England and the Bank of Mexico also analyse positions in securities and derivatives, including for non-banks. This paper presents a direct contagion model for the Russian financial market that takes into account the most comprehensive network of mutual positions: in the money market, the securities market, and the derivatives market.

The second mechanism works through indirect contagion – that is, through the deterioration of the financial position of an organisation due to the negative revaluation of assets urgently sold by non-performing participants. Such models are used in the papers of the Bank of England, the ECB, the Bank of Japan and the Bank of Canada. At the same time, the coverage perimeter differs: the ECB considers the positions of asset managers in the financial markets in addition to banking positions. The Bank of Japan uses the indirect contagion model for cross-border transactions of Japanese banks, taking into account the non-linear nature of the impact of asset sales on their prices. In this paper, the Bank of Russia develops its indirect contagion model for banks and other financial market participants.

The third area in the development of macroprudential stress testing deals with the risks of the non-financial sector, which have become especially relevant during the coronavirus crisis. The non-financial nature of the shock affects the stress scenario and the course of its development, with the deterioration of the real sector and the growth of lending risks as the main sources of risk for the financial sector. This may result in restrained lending by banks and further deterioration of the position of borrowers. Thus, modelling of the second-round effects of the mutual influence of the real and financial sectors has started to play an important role in stress testing. Evaluation of anti-crisis policy measures aimed at mitigating the negative impact of such effects is becoming increasingly desirable.

In global practice, second-round effect models have not yet become widespread, unlike, for example, contagion models. Nevertheless, we see a number of central banks using such models. For example, the ECB is building a global VAR model taking into account cross-border links. The Reserve Bank of India also uses a VAR model, the Bank of Japan uses a macroeconometric model, and in Hong Kong second-round effects are assessed using the Monte Carlo method. It is significant that second-round effects lead to substantial additional losses. For example, in the ECB model, second-round effects make the drop in GDP under stress 1.5–2 times greater compared to estimates that do not take them into account.

This report presents an assessment of the mutual influence of the real and financial sectors, taking into account two second-round effect models. The first model is based on a sign-restricted VAR model, and the second one is based on a Bayesian vector autoregression (BVAR) model. Both models support the general assumption that the volume of losses from second-round effects is important for assessing systemic risks and overall financial stability.

Taken together, the described trends signify a need to develop macroprudential stress testing models for assessing the risks of financial infrastructure, contagion effects and secondary shock spillover. The following sections will detail approaches and models used for assessing systemic risks in macroprudential stress testing.

II. ANALYSIS OF SYSTEMIC RISKS IN MARKETS WITH A CENTRAL COUNTERPARTY

A current trend in the development of the Russian financial market is for participants to carry out a greater number of transactions through a central counterparty (CCP). Centralised clearing is one of the most effective methods for managing financial risks of participants. If clearing members fail to fulfil their obligations under concluded transactions, the CCP ensures the fulfilment of obligations under these transactions within the limits of the default waterfall provided for by the clearing rules. Thus, the CCP performs critical functions in the financial market and, in fact, concentrates the systemic risks of the financial market segments it serves on itself.

In Russia, non-bank credit institution NCC (JSC) (NCC), licensed as a non-bank credit institution – central counterparty, is the largest central counterparty and is of systemic importance for the Russian financial market. NCC is part of the Moscow Exchange Group and services the largest value and volume of transactions as compared to other central counterparties in the Russian market. For this reason and also because of its systemic importance, further description will relate to the largest Russian CCP.

The CCP is mainly exposed to risks of significant changes in the prices of financial assets and defaults on transactions by their participants. Such an event may have a number of negative consequences both for non-defaulting clearing participants and for the CCP itself. Apart from the possibility of suffering losses under concluded transactions, which will be reflected in the financial results of the institution, clearing participants may face, within a short period, a sharply increased need for liquid assets necessary for maintaining their current positions. In the exchange market, this situation may arise during the day due to the need to deposit additional collateral under concluded transactions.

As a result, the financial resilience of the CCP and clearing participants requires continuous monitoring to ensure financial stability. Important instruments of such monitoring include the assessment of CCP risks, stress testing of the adequacy of CCP default waterfall, identification of the interconnections and interdependencies of clearing participants, assessment of the financial market's exposure to systemic risk in the context of significant stressful events in the market and determination of the consequences of systemic risk spillover for financial market participants.

As noted above, to fulfil its obligations to non-defaulting clearing participants, the CCP forms default waterfall. Globally, the most common practice is the use of initial margin, aggregate prefunded participant default fund contributions and the CCP prefunded own resources (its so-called «skin in the game»).

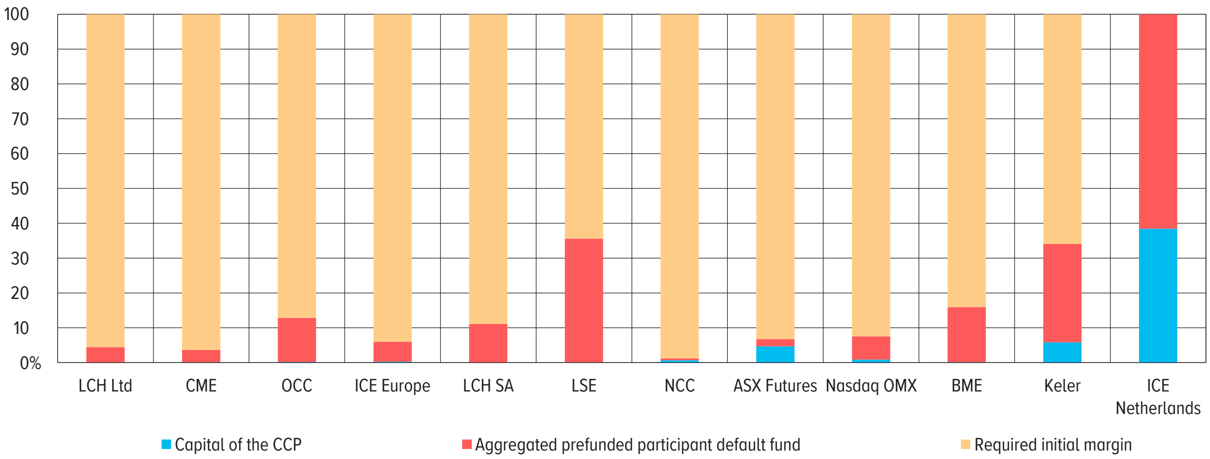
Initial margin is designed to compensate for the market risk arising due to the CCP's obligation to fulfil the obligations of defaulting clearing participants under partially secured transactions. Other levels of CCP default waterfall are used to cover risks if initial margin is insufficient. Aggregate prefunded participant default fund is formed from the contributions of clearing participants and is a tool for collective settlement of the obligations of defaulting clearing participants. The amount of such contributions is determined by the CCP's clearing rules.

The CCP's skin in the game[1] is a part of the CCP's capital to be used to settle the obligations of defaulting clearing participants in accordance with the clearing rules if other levels of CCP default waterfall prove insufficient.

Initial margin is the main element in securing the obligations of the CCP to non-defaulting participants, and in global practice it forms the bulk of all financial resources of CCPs. Foreign CCPs as well as the NCC form financial protection mainly through initial margin (1).

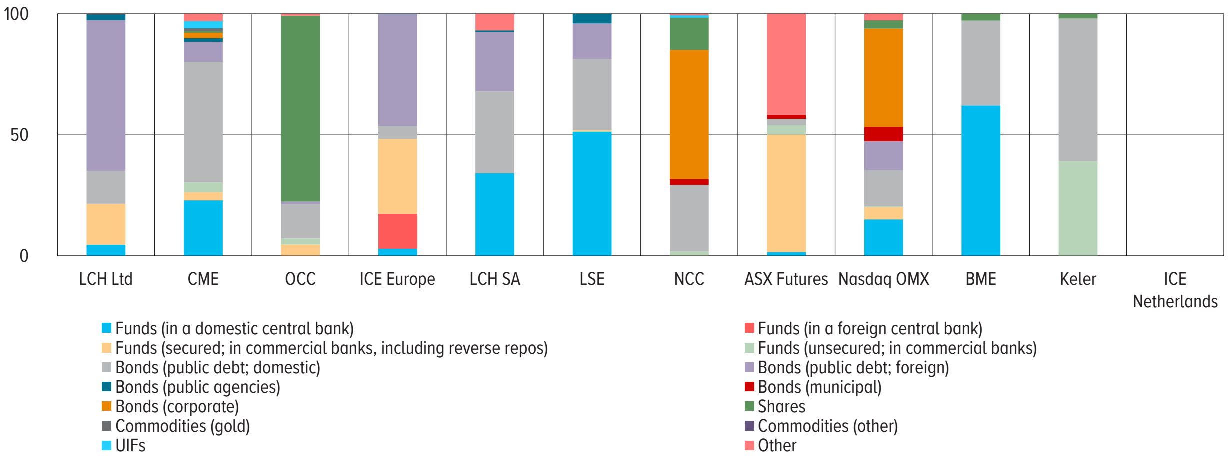
[1] *Must be at least 25% of the total capital of the CCP in accordance with the requirements of Article 35 of EMIR RTS 153/2013.*

STRUCTURE OF THE CCP'S FINANCIAL RESOURCES (2020 Q2) *Chart 1*
(%)



Source: Bank of Russia calculations.

THE STRUCTURE OF THE DEPOSITED INITIAL MARGIN (2020 Q2) *Chart 2*
(%)



** Initial margin not required.*
Source: Bank of Russia calculations.

As the main element in the structure of the CCP's financial resources, initial margin can include cash funds or highly liquid securities with minimal credit and market risks. The structure of the actually deposited initial margin (over the required initial margin) is different for each CCP and depends on a combination of factors (Chart 2). These include the level of development of the national financial market, financial instruments prevailing in the assets of participants, the extent of asset encumbrance of clearing participants, existing collateral management services and so on.

The NCC's initial margin structure has a relatively high share of corporate bonds due to the insufficiently large market for sovereign obligations in the context of low public debt in Russia as well as a significant presence of non-residents in the structure of its holders. Moreover, due to the Bank of Russia's policy of reducing the predominance of foreign currency and certain sanction restrictions, in recent years, large Russian companies have increased the issuance of ruble bonds, thereby contributing to the development of this segment of the Russian market.

In addition to individual clearing collateral, the NCC's default waterfall has several levels. In accordance with the requirements of Russian legislation, the NCC has created the following structure of default waterfall (Chart 3) as a protective mechanism to prevent systemic risk.

THE NCC'S DEFAULT WATERFALL *Chart 3*

Initial margin of the defaulting clearing participant

Aggregated prefunded Default fund contributions of the defaulting clearing participant

Skin in the game of the CCP

Additional skin in the game of the CCP (distributed across markets at the discretion of the NCC)

Aggregated prefunded Default fund contributions of non-defaulting clearing participants in relevant markets

Contribution of PJSC Moscow Exchange to Aggregated prefunded default fund

Additional capital of the NCC (at the discretion of the NCC)

Mechanism for limiting the CCP's liability (discounting the NCC's obligations to return funds to non-defaulting clearing participants (obligations to return funds that constitute the subject of transactions, collateral in cash and income from transactions))

Source: NCC.

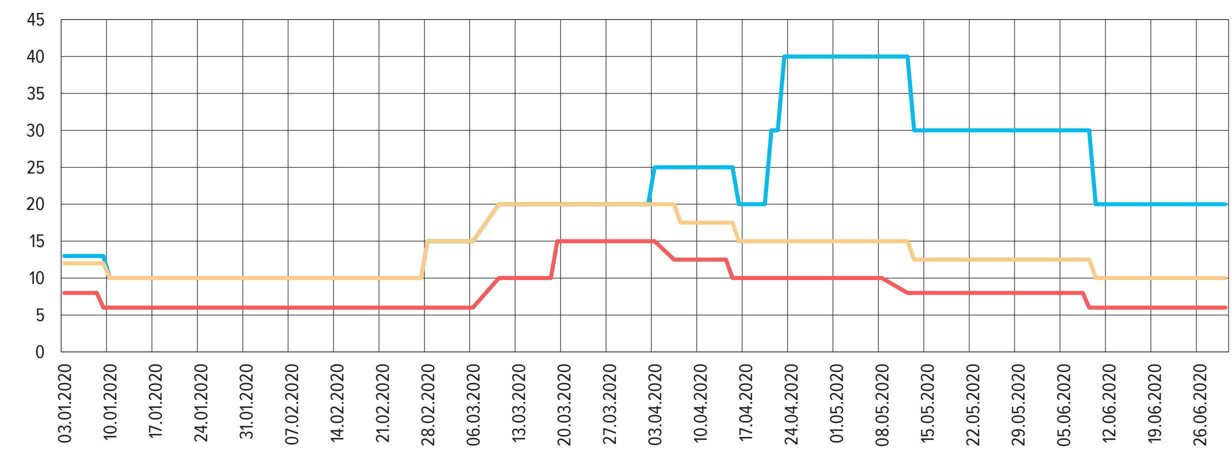
We note that initial margin of the NCC's clearing members includes an additional component, stress collateral. Its value is determined on the basis of mandatory stress testing periodically conducted by the NCC (at least once a month[2]), which, in particular, reveals fluctuations in the quotations of various financial instruments serviced by the CCP in conditions of high volatility. Accordingly, the NCC determines the total amount of initial margin required from clearing members, taking into account the value of stress collateral calculated for each of the markets serviced by the NCC.

From the point of view of risk emerging in the context of market shocks, a significant problem of initial margin rates is their procyclicality – that is, an effect where increasing volatility in the financial market of the CCP results in higher initial margin rates to compensate for the increasing market risk. During stress events, higher initial margin rates and corresponding requirements for clearing members to deposit additional collateral will put pressure on the liquidity of clearing members.

This exact situation was observed in all global markets in March 2020 at the beginning of the COVID-19 pandemic. The NCC's clearing members also faced higher initial margin requirements

INITIAL MARGIN RATESINITIAL MARGIN RATES FOR THE MOST LIQUID ASSETS IN THE MOSCOW EXCHANGE'S FUTURES AND CURRENCY MARKETS *Chart 4*

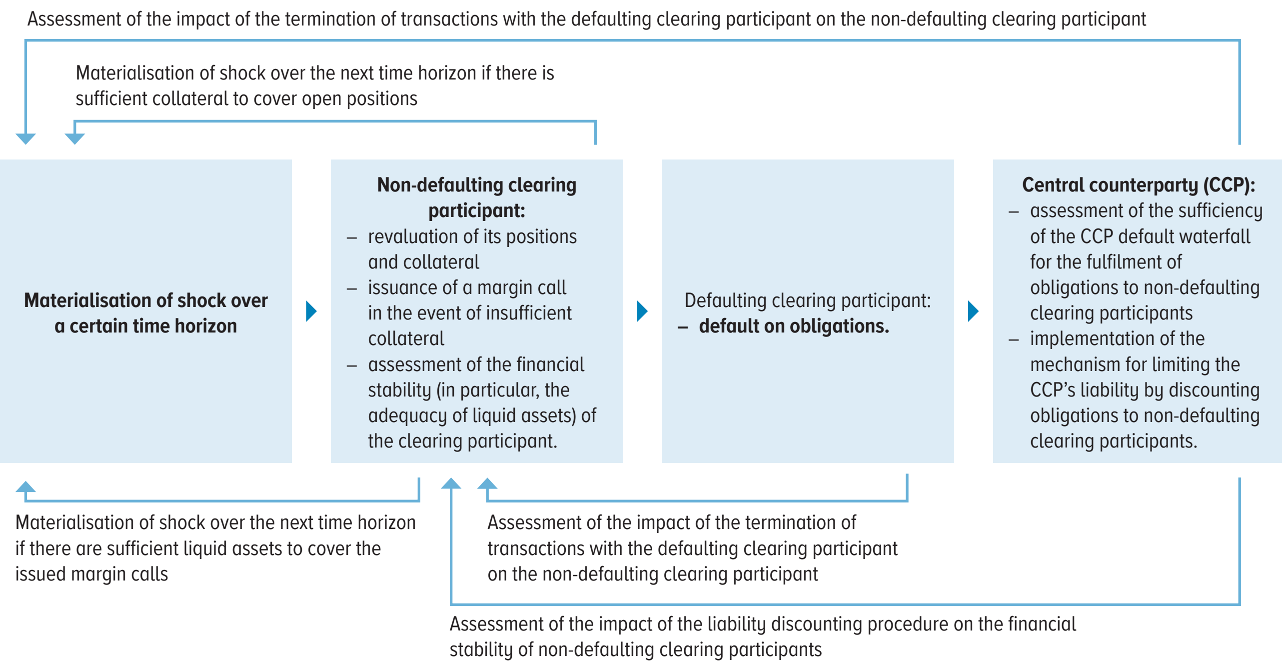
(%)



Sources: NCC, Bank of Russia calculations.

[2] *Clause 5.1 of Bank of Russia Regulation No. 576-P, dated 30 December 2016, 'On the Requirements for the Methodologies for Risk Stress-testing and Model Accuracy Assessment of the Central Counterparty, Risk Stress-testing and Model Accuracy Assessment of the Central Counterparty, and the Procedure and Timeframes for Providing Information on the Results of Risk Stress-testing of the Central Counterparty to Clearing Participants'.*

FLOWCHART OF MACROPRUDENTIAL STRESS TESTING WITH THE CCP *Chart 5*



Source: the Bank of Russia's approach.

amid growing market volatility and counterparty risks. To prevent the materialisation of the NCC's risks, the initial margin rates for serviced instruments in Moscow Exchange markets were increased, primarily for oil futures, MOEX Russia Index futures, and instruments in the foreign exchange market (Chart 4).

The increase in initial margin rates, including as a response to the high intraday volatility of instruments, led to higher margin requirements for clearing members of the NCC as part of standard risk management procedures. March 2020 saw significant growth in the value and volume of margin calls made to participants, while in April 2020 the value of this indicator returned to average levels. Margin calls were primarily made to resident credit institutions. To meet the margin calls, credit institutions mainly used their own liquidity, in some cases resorting to raising liquidity from the Bank of Russia.

The measures implemented by the NCC corresponded to the current adverse market events caused by the COVID-19 pandemic. Timely meeting of margin calls by clearing members and the absence of defaults in the financial market confirmed the limited procyclical impact of higher initial margin rates on the financial stability of clearing members.

At the same time, we note that the CCP has a number of countercyclical instruments available. For example, during quiet periods, the CCP can maintain higher initial margin rates, for example, by taking into account historical stress events in the financial market and using more conservative risk metrics (CVaR). In particular, the NCC applies the said risk metrics when calibrating margin rates. Also, as a countercyclical measure, the relevant regulations may allow the CCP to form special buffers from the collateral of participants.

In addition to the initial margin, the CCP forms a default fund out of clearing members' contributions. The contribution of the defaulting clearing participant to the aggregated prefunded default fund comes before the skin in the game and the aggregated prefunded default fund contributions of non-defaulting clearing members in the structure of the NCC's default waterfall. In addition to these standard levels, the structure of the NCC's default waterfall also provides for additional skin in the game and the contribution of the Moscow Exchange as a shareholder.

Moreover, to settle its obligations, the NCC can use its remaining capital (in addition to the skin in the game) as long as this allows the CCP to maintain its required ratios.[3]

The last level of protection is the haircutting of obligations to return funds to non-defaulting clearing participants. We note that the use of this liability limitation instrument is the least preferable since it will cause losses to non-defaulting clearing participants in proportion to the amount of the NCC's liabilities to them in cash. Despite the availability of this mechanism, the largest CCP in the Russian financial market has never had to resort to this liability limitation procedure.

As noted above, by performing critical functions in the financial market, CCPs concentrate the systemic risks of the financial market segments they service on themselves. A CCP's resilience determines the resilience of all its members. Chart 5 shows a flowchart of macroprudential stress testing with the CCP.

The starting point of macroprudential stress testing that takes the CCP into account is the materialisation of price shocks for the financial instruments it services over different time horizons (from several days to a calendar year). The values of positions and collateral of the CCP's clearing members and the CCP default waterfall are fixed as of a certain predetermined date. The total amount of collateral (both required and free) and the value of positions of the CCP's clearing members are revalued taking into account price shocks sequentially over different time horizons until one or more clearing members that will be subject to CCP margin calls to contribute additional collateral are identified.

After that, the liquid assets of such clearing members are assessed in respect of their adequacy for the timely meeting of such margin calls. If the clearing member's liquid assets are sufficient, its positions and collateral are revalued over the next time horizon. If not, it is assumed that the clearing member defaults and does not fulfil its obligations under transactions with the CCP.

At the next stage, we assess the CCP's ability to fulfil the obligations of such defaulting clearing member to the non-defaulting clearing participants and the sufficiency of the CCP default waterfall. This approach is reflected in international guidelines, in particular, in the Principles for Financial Market Infrastructures of the Committee on Payment and Settlement Systems and the Technical Committee of the International Organization of Securities Commissions, according to which a CCP should test its own default waterfall using a wide range of parameters and assumptions for possible market situations to assess the negative impact of stress market conditions on protection levels.

The analysis is carried out both in the context of the markets serviced by the CCP and for all markets. Based on the results of stress testing, the CCP default waterfall is evaluated as sufficient or insufficient in the event of a stress scenario involving a significant change in the value of financial instruments and defaults of clearing members on their obligations. If default waterfall of the CCP is sufficient, the positions and collateral of clearing members are revalued over the next time horizon. If not, the CCP applies the liability limitation mechanism by haircutting obligations to non-defaulting clearing participants.

Haircutting of obligations is a starting point in assessing systemic risk in CCP markets. At this stage, the negative spillover effect of this procedure for clearing members is modelled, and their financial stability is assessed. The criteria for assessing the financial stability of clearing members include the absence of capital shortage, availability of liquid assets, and compliance with regulatory requirements.

If the financial stability of clearing members is preserved after the procedure of haircutting liabilities, the positions and collateral of all clearing members are revalued over the next time horizon according to the algorithm described above. If not, the clearing members in respect of which obligations were discounted become defaulters. After that, we assess the sufficiency of collateral posted in connection with the amount of open transactions made by defaulting clearing members.

[3] *Established by Bank of Russia Instruction No. 175-I, dated 14 November 2016, «On Banking Operations of Non-bank Credit Institutions, Central Counterparties, on the Required Ratios of Non-bank Credit Institutions, Central Counterparties, and the Specifics of Exercising Supervision over Their Compliance by the Bank of Russia».*

If these transactions are unsecured due to the exhaustion of the default waterfall, the CCP re-implements the liability limitation mechanism according to the algorithm described above.

As already mentioned, the NCC has never had to actually resort to the procedure of «spreading» losses over non-defaulting participants, but this stress testing is necessary. Centralised clearing of transactions in the financial market is a relatively new area for global regulators, in which (for example, in comparison with banks) there are few examples of defaults and crisis events where the required amount of resources in the CCP's system of protection are empirically tested.[4] Consequently, we need to calculate the contagion effects under various negative scenarios to make sure that the system of protection is sufficient. Macroprudential stress testing takes into account the contagion effects that arise in the financial system.

[4] *As a unique example of the use of the funds of bona fide clearing participants, we can cite the default of a clearing member of a Swedish clearing house, NASDAQ OMX, in September 2018 when the losses from the default were covered by the funds of the clearing member, the skin in the game of the CCP and also in part by the guarantee fund of bona fide clearing participants.*

III. ANALYSIS OF CONTAGION RISKS IN THE FINANCIAL SECTOR

1. Global experience in modelling contagion risks

The topic of contagion risks and contagion effects attracted the attention of researchers during the 1997 Asian financial crisis and became even more relevant due to the global crisis of 2007 – 2009. Significant contributions to its study were made by Allen and Gale (2000, 2004),[1] Kyle and Xiong (2001),[2] Kodres and Pritsker (2002),[3] Kiyotaki and Moore (2002),[4] Kaminsky, Reinhart and Vegh (2003),[5] Brunnermeier and Pedersen (2005,[6] 2007[7]) and Longstaff (2010).[8]

According to the definition of Dornbusch, Park and Claessens (2000),[9] contagion effects are episodes of a significant increase in the interconnections between markets due to the occurrence of a shock event in one of them. IMF experts (Anderson et al (2018)[10]) came to the following conclusions about contagion effects:

1) there are direct (contractual obligations) and indirect channels for their materialisation;

2) the dynamics of these effects may vary depending on the time period and phase of the economic cycle;

3) to assess contagion effects, macroprudential stress testing should consider the financial system as a whole.

The authors emphasise that the modelling of contagion effects is largely determined by whether initial macroeconomic shocks are classified as exogenous (emerging outside the financial sector as a given for market participants) or endogenous factors. For example, Bartholomew and Whalen (1995)[11] adhere to the first option, seeing systemic risk as an event affecting not just individual companies but the financial sector as a whole. Furthermore, Kaufman (1995)[12] defines systemic risk as the probability of an event that triggers a chain of counterparty defaults (a «domino effect»). This approach treats shocks as mostly isolated phenomena.

On the other hand, systemic risk can be viewed as an endogenous factor that takes into account individual parameters and relationships as well as anti-crisis measures of market participants. For

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[1] *Allen, Franklin, and Douglas Gale, 2000, Financial Contagion, Journal of Political Economy, 108, 1 – 33.*
Allen, Franklin, and Douglas Gale, 2004, Financial Intermediaries and Markets, Econometrica, 72, 1023 – 1061.

[2] *Kyle, Albert S. and Wei Xiong, 2001, Contagion as a Wealth Effect, Journal of Finance 56, 1401 – 1440.*

[3] *Kodres, Laura and Matthew Pritsker, 2002, A Rational Expectations Model of Financial Contagion, Journal of Finance 57, 769 – 800.*

[4] *Kiyotaki, Nobuhiro, and John Moore, 2002, American Economic Review: Papers and Proceedings 85, 62 – 66.*

[5] *Kaminsky, Graciela, Carmen Reinhardt, and Carlos Vegh, 2003, The Unholy Trinity of Financial Contagion, Journal of Economic Perspectives 17, 51 – 74.*

[6] *Brunnermeier, Markus K. and Lasse H. Pedersen, 2005, Predatory Trading, Journal of Finance 60, 1825 – 1863.*

[7] *Brunnermeier, Markus K. and Lasse H. Pedersen, 2007, Market Liquidity and Funding Liquidity, Review of Financial Studies.*

[8] *Longstaff, Francis A. and Arvind Rajan, 2008, An Empirical Analysis of the Pricing of Collateralized Debt Obligations, Journal of Finance 63, 529 – 563.*

[9] *Dornbusch, Rudiger, Yung Chul Park, and Stijn Claessens, 2000, Contagion: Understanding How it Spreads, The World Bank Research Observer 15, 177 – 197.*

[10] *Ron Anderson, Jon Danielsson, Chikako Baba, Udaibir S. Das, Heedon Kang, and Miguel Segoviano, Macroprudential Stress Tests and Policies: Searching for Robust and Implementable Frameworks, IMF Working Paper 2018, p. 14 – 31.*

[11] *Bartholemew, P., and G. Whalen, 1995, Fundamentals of Systemic Risk. In Research in Financial Services: Banking, Financial Markets, and Systemic Risk. G. G. Kaufman, ed. Greenwich, CT: JAI, pp. 3 – 17.*

[12] *Kaufman, G. K., 1995, Comment on Systemic Risk. In Research in Financial Services: Banking, Financial Markets, and Systemic Risk. Greenwich, CT: JAI, pp. 47 – 52.*

example, Mishkin (1995)[13] linked systemic risk to the dynamics of the real economy and defined it as the probability of an unexpected event that disrupts information flows between financial markets. This makes capital allocation to the most productive investors less efficient. In turn, Adrian and Shin (2008)[14] paid special attention to network effects in the interbank market, which included, in addition to defaults on contractual obligations, drops in the value of assets due to hot sales and changes in the behaviour of market participants.

There are four main channels for the propagation of network effects. First, according to Kiyotaki and Moore (2002) and Kaminsky, Reinhart and Vegh (2003), information flow between markets with different levels of liquidity affects the value of collateral and cash flows. Second, Allen and Gale (2000) and Brunnermeier and Pedersen (2005) point out that losses in one market can limit refinancing opportunities in other markets. This leads to forced liquidation and depreciation of assets, or «flight to quality». Thus, network effects are materialised through liquidity risk. Third, Vayanos (2004),[15] Acharya and Pedersen (2005)[16] and Longstaff (2008, 2010)[17] interpret network effects as an increase in the risk premium (a decrease in asset prices) due to events in other markets. Some researchers also identify strategic complementarity as the fourth channel. According to Bebchuk and Goldstein (2011),[18] the similar reaction of many companies to a financial crisis leads to a slowdown in the activity of the interbank market and increase in the liquidity deficit.

Network models enable assessment of the systemic risks of the banking sector: interconnections between participants, potential losses due to defaults of counterparties and the feasibility of provision of financial support by the central bank. Network models imply an automated algorithm that performs sequential iterations of calculations. Market information and financial statements are used as input data: positions in the financial market, the structure of banking groups, the stock of liquid assets and capital and off-balance sheet claims and liabilities.

An example of an integrated approach to the accounting of network effects is the RAMSI model of the Bank of England (Risk assessment model for systemic institutions, Bank of England (2009)[19]), which has remained one of the most comprehensive models of network effects since 2009. Network effects are assessed based on detailed financial statements (400 asset classes and 250 liability classes) [Bank of England, 2009, p. 7].

Stress testing parameters are specified as spreads of random variables. The simulations make it possible to form sets of stress values of indicators, each representing a version of the initial macroeconomic shock. For each of these versions, iterations of calculations are used to exclude insolvent banks from the liabilities matrix, and their assets are distributed with a 10% discount to the rest of the participants, compensating for the lack of liquidity in the market. The iterations are repeated until the wave of bankruptcies breaks. Based on several hundred simulations, the probability distributions of financial indicators (credit losses, net interest income, net profit) are determined as a percentage of the 2007 values.

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[13] *Mishkin, F., 1995, Comment on Systemic Risk. In Research in Financial Services: Banking, Financial Markets, and Systemic Risk. Greenwich, CT: JAI, pp. 31–45.*

[14] *Adrian, T., and H. S. Shin, 2008, Liquidity and financial contagion. Banque de France Financial Stability Review: Special Issue on Liquidity 11, pp. 1–7.*

[15] *Vayanos, Dimitri, 2004, Flight to Quality, Flight to Liquidity, and the Pricing of Risk. Working paper, London School of Economics.*

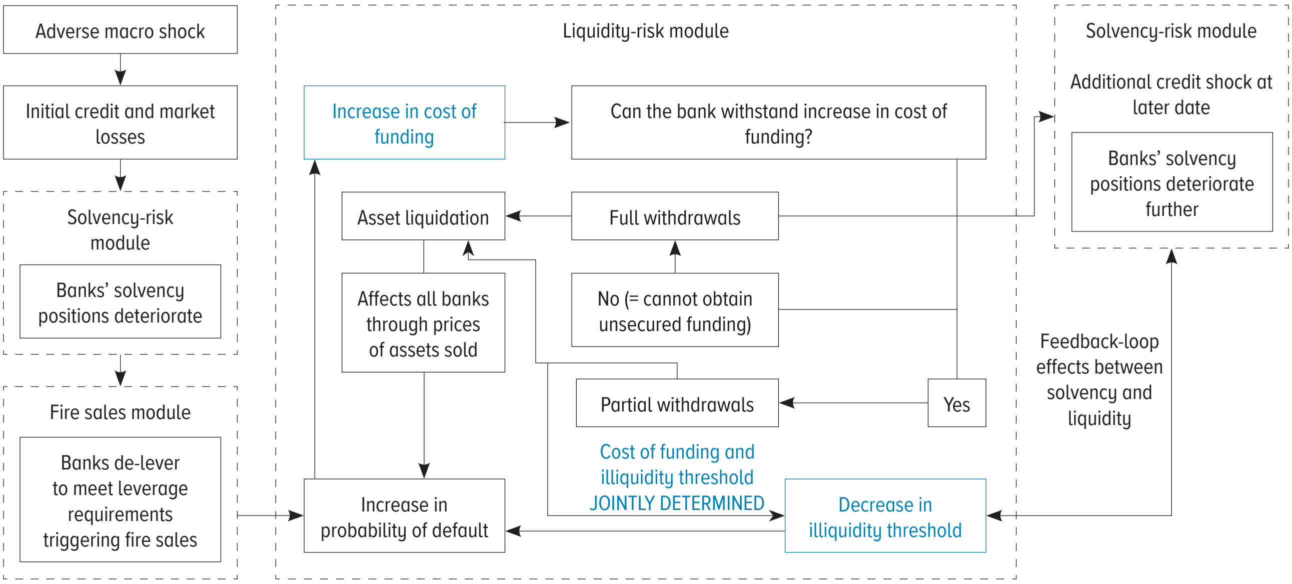
[16] *Acharya, Viral, and Lasse H. Pedersen, 2005, Asset Pricing with Liquidity Risk. Journal of Financial Economics 77, 375–410.*

[17] *Francis A. Longstaff, The subprime credit crisis and contagion in financial markets. Journal of Financial Economics 97 (2010) 436–450.*

[18] *Bebchuk, L., and I. Goldstein, 2011, Self-Fulfilling Credit Market Freezes. Review of Financial Studies, Volume 22 (11), pp. 3519–3555.*

[19] *Bank of England, 2009, David Aikman, Piergiorgio Alessandri, Bruno Eklund, Prasanna Gai, Sujit Kapadia, Elizabeth Martin, Nada Mora, Gabriel Sterne and Matthew Willison, Funding liquidity risk in a quantitative model of systemic stability, Working Paper № 372, Bank of England, June 2009.*

FLOWCHART OF THE BANK OF CANADA'S MFRAF (MACROFINANCIAL RISK ASSESSMENT FRAMEWORK) MODEL *Chart 6*



Source: Jose Fique, The MacroFinancial Risk Assessment Framework (MFRAF), Version 2.0, Technical Report N° 111, Bank of Canada, 2017, p. 18.

The Bank of Canada's MFRAF (MacroFinancial Risk Assessment Framework, Bank of Canada (2017)),[20] introduced in 2017, consists of several modules, including solvency assessment, crisis sales of assets, and liquidity risk. Network effects are assessed within the liquidity risk module based on the averaged parameters of the banking sector.

The inputs in this module are increased probability of default and cost of funding as a result of credit and market losses, decreased solvency and forced liquidation of assets in the previous modules. Depending on the bank's ability to cover the liquidity deficit, a full (default) or partial outflow of funds is assumed. It is covered by additional liquidation of assets, which in turn affects their quotations and the liquidity of counterparties. This creates an additional credit shock in the solvency assessment module. Like in the first iteration, this shock increases the probability of default and cost of funding. Thus, this algorithm is repeated until the banks with a liquidity deficit run out of reserves.

The MFRAF model uses elements of game theory. In addition to the liquidity position, risk appetite also acts as a factor of financial stability. When other market participants lend to a bank, it is interpreted by counterparties as a reduction in credit risk and results in increased willingness to provide refinancing (Fique, J., 2017, p. 23). Individual probability distributions of PD are based on PD0 provided by banks as part of the bottom-up approach. LD and EAD parameters are calibrated for scenarios and banks (Fique, J., 2017, p. 8).

Due to multiple risk factors, the need for detailed data and the automation of calculations, large-scale network models that take into account both interbank and inter-market interactions and interactions with other sectors (like the models of the Bank of England and the Bank of Canada) require significant technical and organisational resources. Despite the comprehensiveness of the models, the quality of the results is mixed.

[20] *Bank of Canada, 2017, Jose Fique, The MacroFinancial Risk Assessment Framework (MFRAF), Version 2.0, Technical Report No. 111/Rapport technique № 111.*
IMF, 2012, Christian Schmieder, Heiko Hesse, Benjamin, Neudorfer, Claus Puhr, Stefan W. Schmitz, Next Generation System-Wide Liquidity Stress-Testing, IMF Working Paper, International Monetary Fund, January 2012.

Therefore, most central banks use only elements of network analysis as a tool for decision support and stress testing in the interbank market.[21] For example, the ECB has developed a network model for the materialisation of insolvency risk in the interbank market, which forms a part of a more general system of macroprudential stress testing. This approach is used to analyse mutual short-term interbank positions and is conceptually based on the Espinosa-Vega model.

The Espinosa-Vega model estimates network effects based on a matrix of positions in the interbank market, participants' liquidity and capital, estimated price discounts, share of losses and other parameters (Espinosa-Vega, 2010). The degree of detail of the model is determined by the available data and can include both universal and individual calibration of indicators. The model treats the parallel materialisation of credit risk and liquidity (funding) risk as network effects.

The default of one of market participants serves as the input stage of the algorithm. If credit losses exceed the capital reserves of a counterparty, it also defaults, causing losses to second-priority counterparties. This triggers a chain reaction of defaults among market participants. At the same time, limitation of the refinancing of open positions is expected, which, as a consequence, leads to a liquidity deficit. If it is impossible to cover it through the sale of assets, the bank defaults on its obligations, starting a similar chain reaction. The algorithm terminates when a new iteration exhausts all reserves to cover the liquidity and capital deficit. The result of the calculation is a list of defaulted banks and the amount of liquidity and capital shortages resulting from the default of the original bank. This algorithm is used separately for each of market participants.

The following indicators are calculated based on the obtained data:

1. Index of contagion – the ratio of total losses of the banking sector to capital as a result of the default of each individual participant.
2. Index of vulnerability – the average ratio of losses to capital of each individual bank as a result of defaults of each of remaining market participants.
3. Number of induced failures – the number of defaults resulting from the default of each individual bank.
4. Hazard (Vulnerability level) – the number of times that each individual bank defaults as a result of defaults of each of remaining market participants.

In general, global practices show that models of network analysis of contagion effects are a generally accepted element of systemic risk modelling in macroprudential stress testing.

2. Assessment of contagion effects in the Russian market

As part of macroprudential stress testing, the Financial Stability Department of the Bank of Russia assesses contagion risks in financial markets in three sequential stages. At the first stage, the methods of network analysis are used to analyse the structure of connections between financial market participants, with the results taken into account, among other things, when determining the perimeter of macroprudential stress testing. At the second stage, we assess the consequences of materialisation of shocks through direct contagion channels. At the third stage, we assess the consequences of materialisation of shocks through indirect contagion channels.

2.1. Network analysis

Network analysis makes it possible to assess the configuration of the network of mutual positions, determine the significant network participants, and the number and composition of clusters (homogeneous groups of participants), and form the perimeter of stress testing.

Networks can be divided into two main classes depending on the distribution of the number of links between their nodes. The first type of networks is a fairly homogeneous (centralised) network

[21] *Ron Anderson, Jon Danielsson, Chikako Baba, Udaibir S. Das, Heedon, Kang, and Miguel Segoviano, Macroprudential Stress Tests and Policies: Searching for Robust and Implementable Frameworks, IMF Working Paper 2018, p. 68, table 2.*

where each node has approximately the same average number of edges and only a few nodes have a significantly smaller or larger number of edges. In highly interconnected financial networks, links serve as shock absorbers in a certain range of materialisation of shock events, but outside this range such links contribute to the spread of financial consequences throughout the system and make the network unstable.

The degree of financial contagion demonstrates a phase transition: when the magnitude of negative shocks is below a certain threshold, a more diversified structure of links means a more stable financial system. However, as the magnitude or number of negative shocks exceed certain thresholds, close links serve as a mechanism for shock spillover, leading to a loss of financial system stability.

The second type of networks is heterogeneous, where most of the nodes have a small number of edges, while a few of them have many edges. This network structure indicates that some nodes are part of a tightly connected core and others belong to a loosely connected periphery. The central nodes are well connected to the peripheral nodes, while the peripheral nodes have no direct links to each other. Networks of this type are more stable, as even if several nodes are affected, the network will retain its integrity. However, the resilience of such networks to shocks is due to the stability of certain of the most interconnected nodes.

The structure of such a network is determined by links of the «core-periphery» type and is visually identified in the form of a star graph; it is centralised and has the following features:

1. The centre of the network consists of several major financial institutions that act as the main intermediaries for transactions/contracts for all other members of the network. In this case, the major financial institutions are usually the largest non-dedicated financial institutions classified as systemically important credit institutions and development institutions.
2. The periphery of the network usually consists of medium-sized and small financial institutions as well as large institutions with a narrower scope of activities and a significantly smaller variety of transactions.
3. There are extensive links between the major financial institutions.
4. The links between the major financial institutions and other financial institutions are not material.

Centrality is used as a measure of the importance (degree of influence) of individual participants in a network. Centrality generally defines the most important vertices of the graph using various construction methodologies. Generally, the centrality of a graph is inversely related to the interdependence of the participants: the greater the interdependence, the less the centrality – that is, the graph is closer to complete when each vertex is connected to each vertex. Star graphs are the opposite: interdependence is minimal, but there is a problem of large «intermediaries», or key graph nodes.

The structure of a network of financial counterparties in macroprudential stress testing is analysed in the context of all major markets for financial instruments where financial companies perform bilateral transactions. As an example, we consider the links between participants in the main segments of the financial market (repos, swaps, unsecured loans). To identify the structure of links in each of the segments, this paper considers them in isolation; in macroprudential stress testing, they are analysed on a consolidated basis.

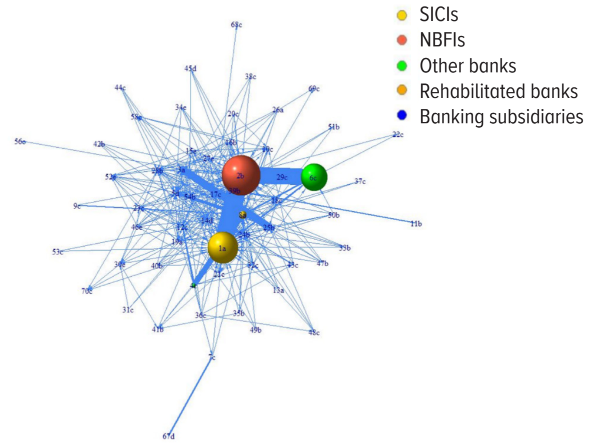
The growth of volatility in the Russian market in spring 2020 could potentially act as a trigger for changes in the architecture of market ties. At the same time, structural changes in the market depend on the initial architecture of the network and specific features of the financial instruments and financial institutions that operate in the market.

In the Russian repo market, the first five most significant macroprudential stress testing participants retained their dynamics throughout 2020 (as of 1 January, 1 April and 1 July), with slightly changing positions, indicating a constant core of major participants; subgroups (clusters) of participants remained the same for all dates. It is worth noting that central participants include not only large credit institutions but also non-bank financial institutions and development institutions (Chart 7). Consequently, in systemic risk assessment, it is imperative to include financial institutions outside the banking sector in the stress testing perimeter.

In the swap market, the most significant participants (top 10) are less constant in their dynamics in 2020, and changes in the importance of individual participants over time are relatively material. With a spike in volatility, as in March – April 2020, the structure of the network may change, and the centrality of individual participants and the centralisation of the network may increase, potentially resulting in higher insolvency risks.

The centralisation of the network along its vectors makes it possible to assess how closely the network elements are interconnected – that is, whether it is characterised by a large number of links and lesser importance of individual participants (the degree of centralisation will approach zero). A low degree of centralisation means that the network is more complete – that is, each node is connected by an edge to every other node, and the weights of the edges are approximately the same.

REPO MARKET GRAPH BASED ON OPEN POSITIONS AS OF 1 JANUARY 2020 *Chart 7*

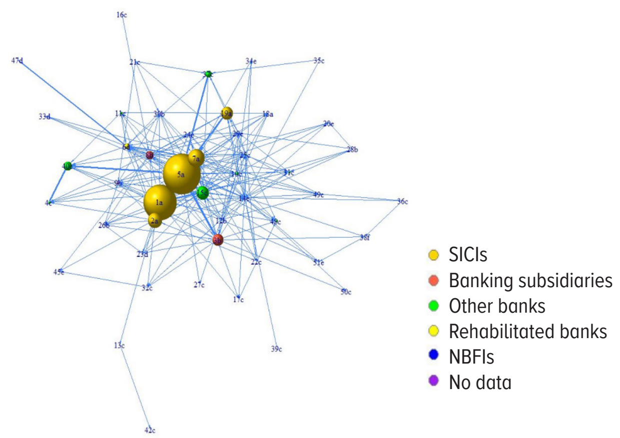


Note: The size of the sphere reflects the importance of participants; the width of the line reflects the size of open positions.
Source: Moscow Exchange.

For the swap market, it should be noted that during the period of volatility in spring of 2020 the centralisation of the network grew, increasing the importance of central participants for the stability of the market. Therefore, when analysing contagion risks, such participants should be seen as potential sources of shock spillover.

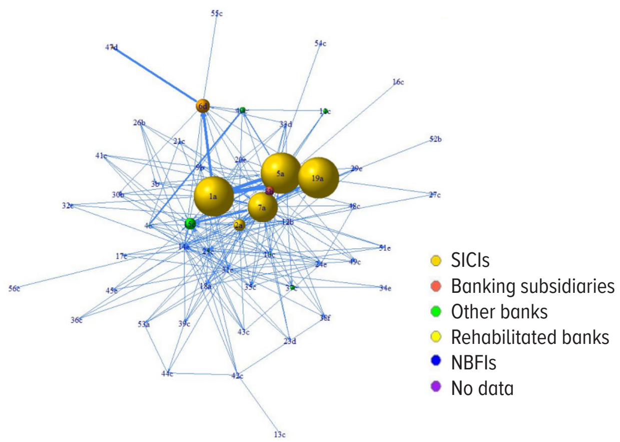
For unsecured loans[22] in the money market, the volatility period of 2020 was also characterised by increased network centralisation. This happened because during the period of shocks, some institutions reduced lending limits, and the market shifted toward central participants. This means that in periods of increased volatility for these markets, the stability of major participants is an important factor in reducing risk spillover in the system. The repo market shows the opposite situation: a decrease in the importance of individual participants for the network as a whole indicates a more even distribution of open positions in the network.

SWAP MARKET GRAPH BASED ON OPEN POSITIONS AS OF 1 JANUARY 2020 *Chart 8*



Note: The size of the sphere reflects the importance of participants; the width of the line reflects the size of open positions.
Source: Moscow Exchange.

SWAP MARKET GRAPH BASED ON OPEN POSITIONS AS OF 1 APRIL 2020 *Chart 9*



Note: The size of the sphere reflects the importance of participants; the width of the line reflects the size of open positions.
Source: Moscow Exchange.

[22] *This market included operations with loans, deposits, bonds and funds in current accounts.*

2.2. Assessment of contagion effects through direct channels

This subsection presents the approach used by the Bank of Russia when conducting macroprudential stress testing as part of assessing contagion risks as a result of the hypothetical default of Russian financial institutions. The approach is based on the Espinosa-Vega model (see Section 3.1 Global experience in modelling contagion effects) with the expansion of the scope of its application to all major financial institutions operating in the Russian financial market. This approach makes it possible to study the mechanism of the formation and spread of systemic risk arising from specific features of the network, the heterogeneity of institutions, sources of risk, and their interaction.

As a starting point for assessing the effects of stress, we consider the state of the financial sector as of the date of calculations. Accordingly, all risk parameters of business models of financial institutions are assessed on the basis of their positions (open positions in transactions) as of the initial date. This stage of macroprudential stress testing involves the assessment of risk divided by the objects of stress testing. Risks for the participants included in the macroprudential stress testing perimeter at each stress testing horizon are assessed from the moment the stress testing begins with an assessment of the impact of the values of stress factors typical for each time horizon.

We assess the ability of a banking (financial) group of a financial institution to meet the criteria for the absence of liquidity deficit and capital shortage. If the implementation of anti-crisis measures at the level of the financial group has made it possible to eliminate the capital shortage, the participant continues to be the object of stress testing for subsequent horizons of analysis.

If the macroprudential stress testing participant is not a part of any banking (financial) group, or the implementation of these measures failed to eliminate the capital shortage, the participant is deemed to be insolvent, and all its liabilities are deemed to be defaulted at the subsequent stages and horizons of stress testing. At the same time, the positions of other participants are reassessed taking into account its default on obligations using the contagion model.

If one market participant (banking group) defaults on its obligations to other market participants, a corresponding adjustment of the amount of capital (group capital) and recalculation of their financial stability criteria are carried out in each iteration. The financial stability criteria are recalculated for the direct borrowers of the bank, their creditors in case of their default, creditors of their creditors, etc. The calculation ends if no participants default on obligations in a new iteration.

Expected loss on claims of counterparties is equal to:

$$Expected\ loss = EAD * PD * (1 - Recovery\ rate\ ),$$

where EAD means value at risk in the event of a default;

PD means probability of default;

Recovery rate means the rate of recovery after default;

LGD = (1 - *Recovery rate*) means losses given default.

In the event of default on obligations of a financial institution, expected loss is estimated based on the following values of the indicators in the equation:

PD = 1, since the financial institution is recognised as insolvent in the stress scenario;

Recovery rate = 0, since based on the conservative approach it is assumed that there is no recovery on obligations;

LGD=100%, since it is assumed that the losses are realised in full.

The overall assessment of contagion effects and contagion risks is as follows (based on the example of a credit institution's balance sheet).

The credit institution's balance sheet is represented by the following components:

$$\sum_j \sum_k x_{ij}^k + a_i = c_i + d_i + b_i + \sum_j x_{ji},$$

where x_{ij}^k means claims of bank *i* of type *k* on the financial institution;

j, a_i mean other assets;

c_i means capital;

d_i means deposits of customers;

b_i means major financing (except for mutual obligations of macroprudential stress testing participants);

x_{ji} means the total obligations of bank i to financial institution j or, conversely, claims of financial institution j on bank i (links between macroprudential stress testing participants).

Z means the complete set of all financial institutions in the network (macroprudential stress testing participants). Default on obligations resulting from the materialisation of shock during macroprudential stress testing is displayed as follows. The bank incurs losses in terms of its claims on defaulting financial institutions in accordance with the subset of financial institutions $\mathcal{Y} \subset Z$. The losses of bank i are summed up for all financial institutions $j \in \mathcal{Y}$ and types of claims: x_{ij}^k and are absorbed by capital; the assets of bank i are adjusted by a comparable amount:

$$\sum_{j \in Z \setminus \mathcal{Y}} \sum_k x_{ij}^k + a_i = \left[c_i - \sum_{j \in \mathcal{Y}} x_{ij}^k\right] + d_i + b_i + \sum_j x_{ji},$$

As a result, the balance sheet of bank i is reduced, and its capital decreases by the amount of incurred losses: $\sum_{j \in \mathcal{Y}} x_{ij}^k$. After that, we test the capital adequacy of the credit institution:

$$\frac{c_i'}{rwa_i'} \geq c_n,$$

where c_i' means the amount of capital of bank i, taking into account the losses incurred by the default of counterparties participating in macroprudential stress testing;

rwa_i' means risk-weighted assets, taking into account incurred losses;

c_n means the regulatory capital requirement.

If the capital adequacy requirement for bank i is not met, and group support is not possible, the bank becomes insolvent and defaults on its obligations to other macroprudential stress testing participants – $\sum_j x_{ji}$.

Thus, the contagion is assessed for each financial institution included in the macroprudential stress testing perimeter.

Upon completion of the calculation for all macroprudential stress testing time horizons and all iterations of the contagion assessment over each of the horizons for market participants with a capital deficit resulting from contagion, we calculate the total capital deficit. We also estimate the total number of participants recognised as defaulting on obligations. The result of this stage of stress testing is the revaluation of losses incurred by all participants and the financial sector as a whole following the materialisation of network effects and contagion risks.

2.3. Assessment of contagion effects through indirect channels

Financial system participants may face the consequences of materialisation of an exogenous shock even in the absence of direct interaction with its source or affected market participants, receiving contagion through indirect risk transmission channels. The best-known example of such a channel is concentration of investments in financial market instruments of a limited group of participants. Financial system participants' susceptibility to contagion depends on the following factors:

- sensitivity of market prices to emergency asset sales by individual participants;
- investment structure and market concentration of assets in the portfolios of participants (for example, the total share of ownership of an asset attributable to one, two and five of its top owners);
- behaviour of participants which may be procyclical and increase market risk for individual securities present in the portfolios of other participants.

Cases of companies' participation in common investment projects, overlapping of activities in the same region, industry affiliation, changes in the preferences of end users (caused by reasons not related to the companies and/or not directly affecting their activities), and other situations where risks are transmitted through a chain of relationships and not directly related to the activities of the companies and their shareholders can also be considered indirect channels.

Sensitivity of market prices to emergency sales

The assessment of indirect contagion effects is based on the identification of securities that are most sensitive to emergency sales. Such assessment can be difficult both in very highly-liquid markets (the effect is short-term and causes little volatility) and in low-liquid and illiquid markets (any relatively large sale usually leads to a serious price decrease, moreover, it may not be a «hot» sale).

Recognising the problem of identifying and evaluating hot sales, the International Monetary Fund (IMF) recommends that central banks conduct additional research on how to identify and evaluate these measures. The main mechanism of their realisation is the emergency sale of a large volume of issued instruments by an individual participant that significantly affects its market price.

Macroprudential stress testing uses two models to assess the impact of sales on asset prices:

1. The Markov Regime-Switching Model.[23] It involves dividing banks' assets into classes and then assessing the cumulative impact of hot sales for stress and non-stress regimes of each class, averaging the price changes of individual assets of the class.

$$LIQ_t = \beta_0^S + \varepsilon_t^S + \sum AR \ ,$$

where LIQ_t – means aggregated assessment of impact on the price for all instruments of the selected class;

β_0^S – means a constant whose value depends on the selected stress regime S (non-stress regime with high liquidity and stress regime with low liquidity);

ε_t^S means estimation of the variance of residuals, which also depends on the chosen stress regime;

$\sum AR$ – means the autocorrelation element.

2. A simplified analytical model of the potential impact on a price downturn of a hot sale effect for Russian stocks.

Formula for individual stocks:

$$R^i_{fire(\text{EST})} = C + \left(1 + \frac{V_{ud}}{V_{flow}}\right)\left(\alpha_i * \frac{|\Delta(Pclose - Popen)|}{V_{av.flow}} + \beta_i * \frac{Phigh - Plow}{Paver}\right) + \varepsilon_i \ ,$$

where V_{ud} means the volume of a participant's position;

C is a constant;

V_{flow} means daily market volume;

$V_{av.flow}$ means average daily market volume;

$Pclose, Popen, Phigh, Plow, Paver$ means a closing, opening, highest, lowest and average price;

ε_i means a residual member satisfying the Gauss – Markov conditions.

Investment structure by issuer

The second element of modelling contagion risks through indirect channels relates to the assessment of participants' vulnerability to market shocks. As part of macroprudential stress testing, risks are assessed through the bonds of Russian issuers (including government securities). The list of potential sources of indirect channels for banks includes 15 issuers whose total volume of bond issues is mostly represented in credit institutions.

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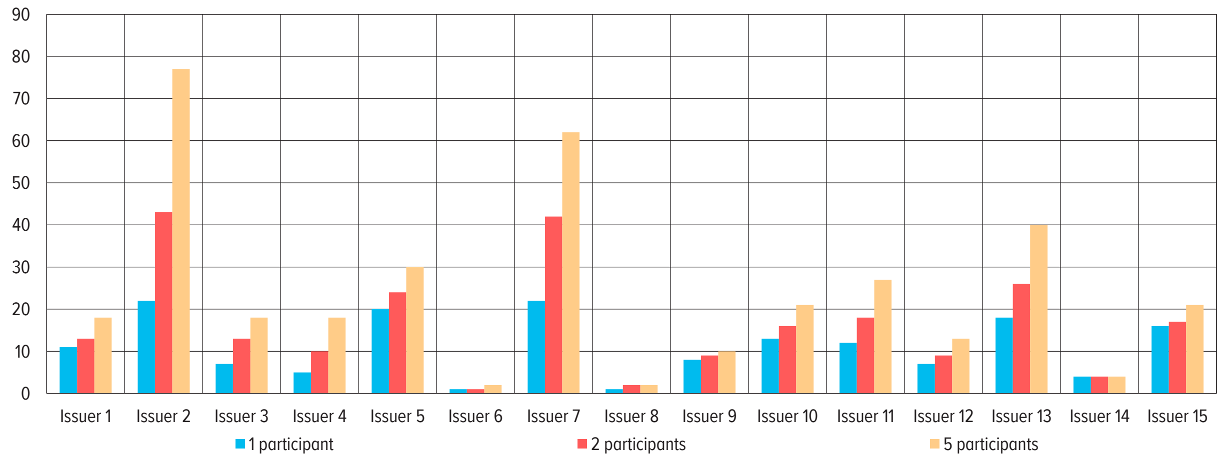
[23] *This model was also used by the IMF in its market analysis. The experience of its application by the IMF is provided in a number of works and presentations by Mindaugas Leika.*

CONCENTRATION BY A BANK'S OWNERSHIP SHARE IN THE ISSUER'S BONDS IN CIRCULATION *Chart 10*
(%)



Source: reporting form 0409711.

Identification of channels by issuer was based on assessing the concentration of the financial asset with one, two and five top owners (credit institutions); in this way the perimeter of potential indirect contagion of banks for each of the issuers was determined (Chart 10).

At the next stage, we selected institutions with a high share of ownership in the market and, at the same time, high capital involvement (large investments in relation to capital); essentially, we identified indirect contagion channels for credit institutions sensitive to fluctuations in the value and size of investments in issuers' securities.

As shown in Chart 10, a number of banks are potentially vulnerable to fluctuations in the market value of the securities of issuers №2, №7 and №13. For the rest of the bonds, the concentration even for five credit institutions did not exceed 30% of the issue in circulation. The concentration indicates a degree of possible contagion through indirect channels and not the probability of the specified vulnerability.

To analyse the risks of contagion through indirect channels, in addition to assessing the vulnerability of banks to the market risks of individual issuers, we have to consider the behaviour of participants in the markets of the respective securities. Indirect contagion occurs in the event of an emergency sale of securities by one or more participants and materialisation of market risk losses for other participants. Such procyclical behaviour exacerbates market shocks related to individual securities, leading to shock spillover to other participants.

Procyclical behaviour of certain market participants

During the period of increased volatility in the spring of 2020, certain participants demonstrated procyclical behaviour by selling corporate bonds (Table 1). The resulting downward pressure on market prices had a stimulating effect on other participants that demonstrated countercyclical

MAJOR PROCYCLICAL AND COUNTERCYCLICAL PARTICIPANTS IN THE BOND MARKET (EXCLUDING OFZS) FOR THE PERIOD OF 20 FEBRUARY 2020 – 18 MARCH 2020, ₽ BILLION *Table 1*

Procyclical participants	Net sales of bonds	Countercyclical participants	Net purchases of bonds
NBFI 1	-10.6	SICI 4	6.9
NBFI 2	-10.3	Bank 1	8.9
SICI 1	-8.3	SICI 5	13.2
NBFI 3	-6.7		
SICI 2	-5.4		

Source: Moscow Exchange.

behaviour. Examples of such categories of participants and corresponding volumes of purchases and sales are shown in Table 1.

In March and April, the public debt market saw procyclical behaviour of NBFIs (mostly in April) and non-residents (mainly in March). In turn, the largest banks played a countercyclical role, which made it possible to limit volatility and ensure the stability of price dynamics.

Analysis of the procyclical transactions of participants showed that they did not constitute hot sales and were not carried out in order to restore the financial stability of individual participants. Their volumes were negligible relative to the portfolios of participants with significant investments in the corresponding securities. In addition, participants with countercyclical behaviour supported the price of the issues being sold, reinforced by the measures of the Bank of Russia.

In particular, to support financial institutions in acquiring assets in the financial market, the Bank of Russia has allowed banks and other financial institutions that maintain accounting records under Bank of Russia regulations to recognise equity and debt securities purchased before 1 March 2020 at fair value as of 1 March 2020 and debt securities purchased between 1 March and 30 September 2020 at fair value as of the acquisition date. This measure will remain in force until 1 January 2021.

According to the Bank of Russia's data as of 1 October 2020, the majority of systemically important credit institutions did not use this rule; only three out of 11 banks announced the use of the provided concessions. Out of other banks, 80 credit institutions implemented this measure.

IV. EFFECTS OF MUTUAL INFLUENCE OF THE FINANCIAL AND REAL SECTORS OF THE ECONOMY

1. Global experience in modelling second-round effects

The increasing complexity of the structure of global financial markets results in the strengthening of relationships between individual participants of the financial market. In this context, an increasingly important role is assigned to the secondary effects of various processes, which lead to an increase in the total economic consequences for the financial system. Secondary effects can occur both in individual segments of the financial market (interbank contagion, cross-sector spillovers) and at the level of the economy as a whole (macroeconomic feedback). However, the implementation of models for assessing secondary effects in the system of macroprudential stress testing is still a relatively new area of research. According to the Bank for International Settlements, less than half of the surveyed regulators require commercial banks to assess models of secondary effects in the process of stress testing.

Currently, macroeconomic feedback effects («second round effects», SRE) are assessed in the system of macroprudential stress testing of the Bank of Japan and the European Central Bank (ECB).

Traditionally, macroprudential stress testing involves an assessment of the «first round» effects – that is, the impact of an initial negative macroeconomic shock on the state of the real and financial sectors of the economy. However, the bi-directional relationship between economic phenomena leads to the emergence of second-round effects – that is, the impact of the deterioration of the financial sector on economic activity, which aggravates the overall negative consequences for the economy.

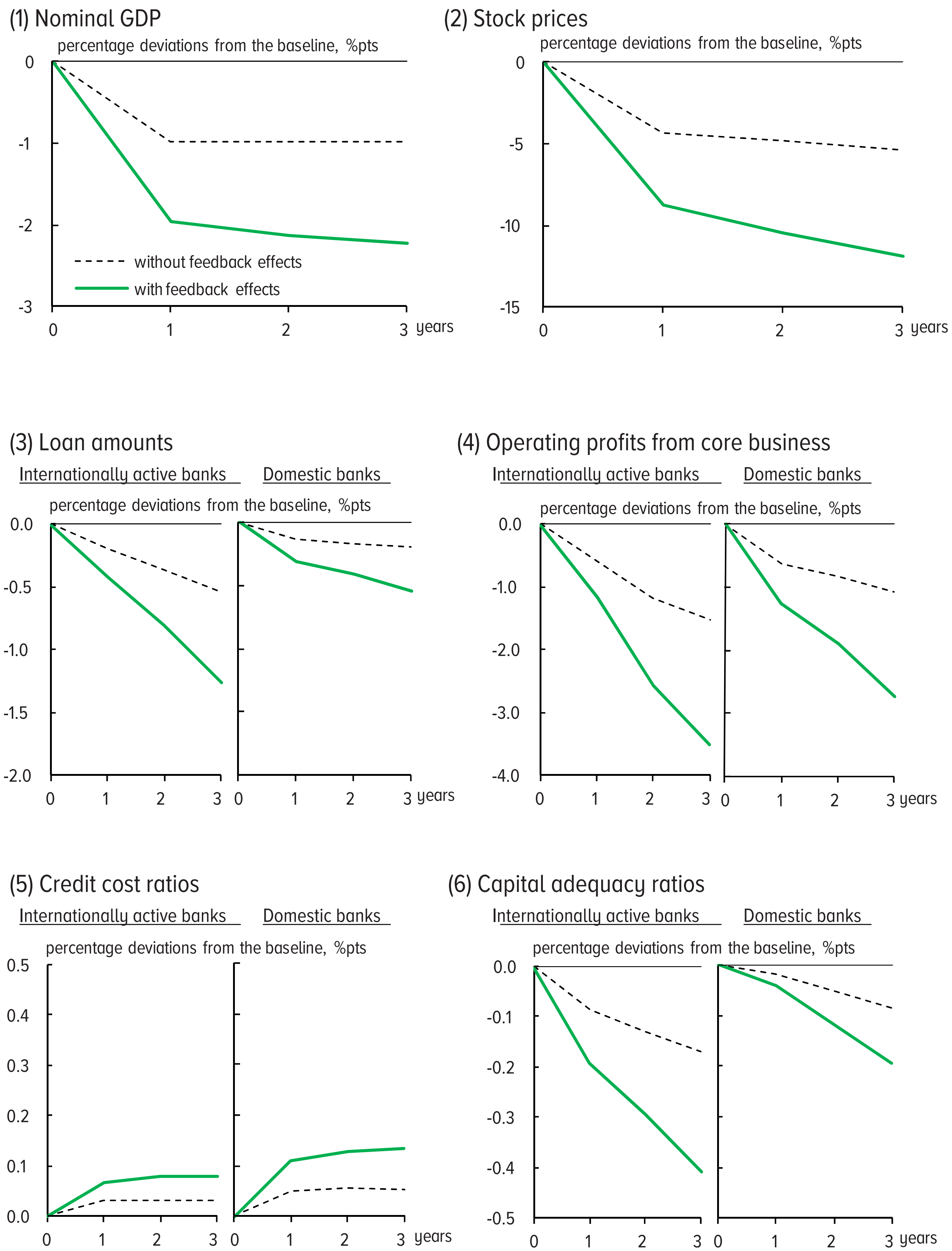
The conceptual framework of macroprudential stress testing of the **Bank of Japan**[1] presents a methodology for assessing the second-round effects in macroprudential stress testing, the results of which are published in the Financial System Report of the Bank of Japan. For the purposes of macroprudential stress testing, the Bank of Japan has developed a middle-dimensionality structural macroeconomic model with the financial sector included (FMM, Financial Macro Model).

When assessing first-round effects, the authors show that a negative macroeconomic shock leads to a decrease in the capital reserves of banks and an increase in risk weighted assets (RWA), which results in a lower capital adequacy ratio (CAR) of financial institutions under stress. Next, second-round effects are assessed: the impact of the lower CAR on bank lending and economic activity in the real sector. The reduction in the capital adequacy ratio of financial institutions forces banks to cut the supply of loans, which is reflected in a reduction in equilibrium lending due to the tightening of monetary conditions. The tightening of lending conditions causes a drop in the expenditures of economic agents and a further decrease in total output (in addition to the decrease resulting from the initial negative shock). Thus, due to close links between the parameters of the real and financial sectors, second-round effects lead to an increase in losses in total output, which exceed the drop in GDP resulting from first-round effects.

The authors demonstrate the effectiveness of accounting for second-round effects in macroprudential stress testing. In the model specification without SREs, during the first year after stress, the growth rate of nominal GDP deviates downward from the baseline path by 1 pp, while the slowdown in economic growth rates with SREs taken into account amounts to 2 pp compared to the baseline path. Thus, second-round effects double the loss of aggregate output. Secondary effects also lead to an almost twofold decrease in other financial variables (value of shares, lending,

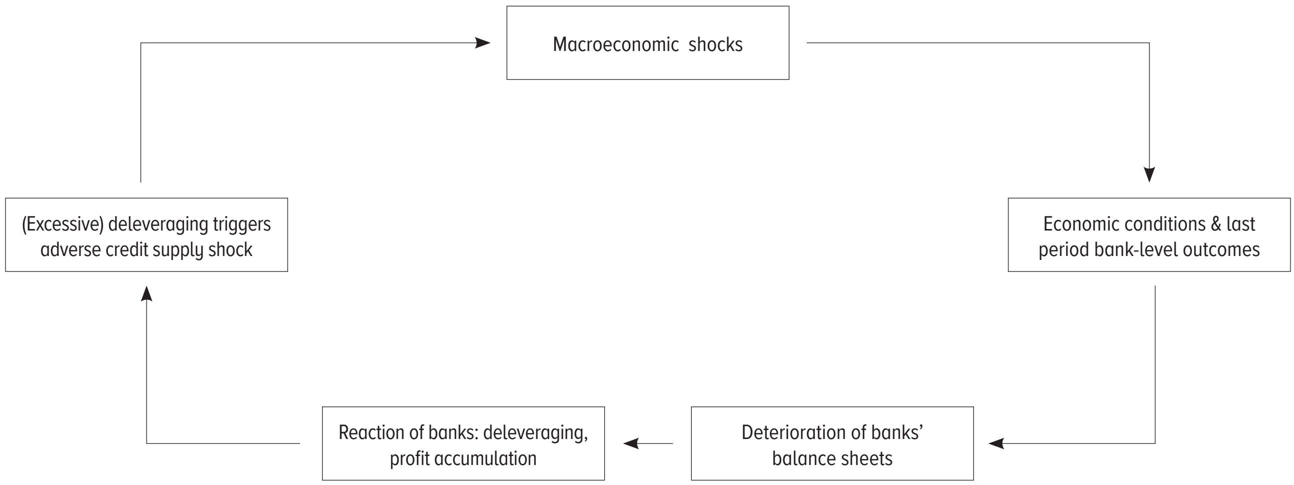
[1] *Kitamura et al. (2014). Macro stress testing at the Bank of Japan.*

FEEDBACK EFFECTS BETWEEN THE FINANCIAL SECTOR AND THE MACROECONOMIC SECTOR *Chart 11*



Assumption: Nominal GDP growth rates deviate by one percentage point from the baseline for the first year.
Source: Kitamura et al. (2014).

SCHEMATIC ILLUSTRATION OF THE FEEDBACK LOOP BETWEEN BANKS AND THE REAL ECONOMY *Chart 12*



Source: Budanik et al (2019).

operating profit, credit costs, capital adequacy ratios of banks) compared to the change in the corresponding indicators resulting from first-round effects (Chart 11).

The paper of the **European Central Bank (ECB)**[2] notes the importance of the dynamics of the loan supply in unwinding the spiral of spillovers. According to the authors, in a normal macroeconomic environment when making decisions on the level of lending and lending rates banks are guided by the aggregate demand for credit resources. However, in the face of increased volatility in the credit market, the supply-side effects gain priority as in these conditions banks will seek to restore capital reserves reduced under the influence of the initial shock. Thus, the main reason for second-round effects is the materialisation of an adverse shock to the supply of loans by banks.

Reduced profitability and capital reserves of financial institutions under stress will stimulate banks to adjust their lending. The more negative the initial macroeconomic scenario is, the more significant the reduction in capitalisation will be relative to the threshold level, and the more significant the credit contraction (or even credit crunch) will be. The adverse credit supply shock will translate into a subsequent structural shock, triggering second-round effects (Chart 12).

The methodological basis of the ECB paper is structural panel vector autoregression (SPVAR) on data from 19 euro area countries. During the modelling process, 10 structural shocks are identified, including credit supply shock, by imposing sign and temporary (zero) restrictions on the structure of shocks. According to the authors, credit supply shock plays a key role in triggering secondary effects in the financial market; its identification is based on the approaches presented by Hristov et al (2012)[3], Barnett and Thomas (2014)[4] and Duchi and Elbourne (2016)[5].

Hristov et al (2012) showed that to identify credit supply shocks we need to impose the following restrictions on the reaction of model variables: changes in the volume of issued loans and lending rates as well as lending and short-term money market rates should occur in opposite directions. This is due to the fact that under the influence of adverse macroeconomic shocks the financial position of banks is deteriorating, forcing them to increase the cost of credit resources and reduce the volume of lending. At the same time, a worsening economic situation and a concomitant decline

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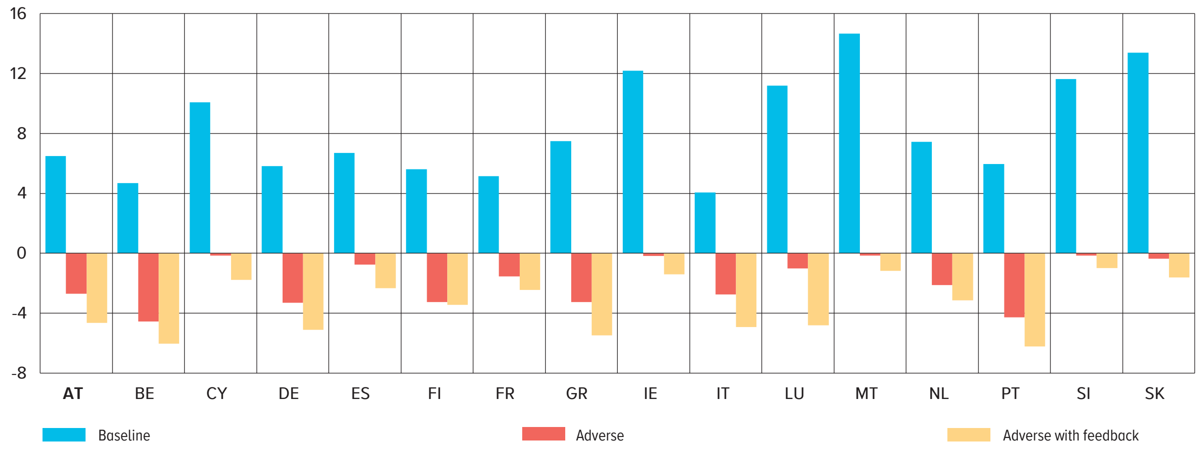
[2] Budanik et al (2019). Macroprudential stress testing of the euro area banking system.

[3] *Hristov et al. (2012). Loan supply shocks during the financial crisis: Evidence for the Euro area. Journal of International Money and Finance, vol. 31, pp. 569-592. DOI: 10.1016/j.jimonfin.2011.10.007.*

[4] *Barnett A., Thomas R. (2014). Has weak lending and activity in the UK been driven by credit supply shock? The Manchester School, Supplement 2014, pp. 60-89. DOI: 10.1111/manc.12071.*

[5] *Duchi F., Elbourne A. (2016). Credit supply shocks in the Netherlands. Journal of Macroeconomics, vol. 50, pp. 51-71. DOI: 10.1016/j.jmacro.2016.09.001.*

GDP IN A SCENARIO WITH FEEDBACK *Chart 13*



Source: Budanik et al (2019).

in inflation (materialisation of adverse aggregate demand shocks) will make central banks switch to an accommodative monetary policy, leading to a decrease in short-term interest rates. This will result in a simultaneous decline in short-term interest rates and in lending volumes along with the growth of loan rates. Barnett and Thomas (2014) and Duchi and Elbourne (2016) likewise accept the assumption of multi-directional dynamics of credit spreads and lending growth rates, while no restrictions are imposed on the dynamics of the base rate of the monetary authorities.

In their study on the aggregated data of the euro area, the authors conclude that taking feedback effects into account in an adverse scenario leads to a 1.6 pp drop in GDP growth rates. The study also notes that the significance of secondary effects and their adverse impact on total output is higher in countries with weaker structural parameters of the banking sector (lower initial capital reserves) (Chart 13).

Thus, secondary effects can amplify possible adverse consequences for the economy and the financial system in response to a shock. To improve the quality of the macroprudential stress testing system, an assessment of the second-round effects is necessary.

2. Assessment of feedback effects on Russian data

2.1. Estimation of a sign-restricted VAR model

First, based on the ECB's experience and the methodology of Hristov et al (2012), Barnett and Thomas (2014) and Duchi and Elbourne (2016), we will assess the relationship between changes in lending growth rates and economic activity in the real sector of the economy using a sign-restricted vector autoregression model.[6]

The scheme of restrictions imposed on the structure of shocks in the model is given in Table 2. We use two specifications of the model depending on the proxy variable reflecting the change in monetary conditions in Russia: the first model includes the exchange rate variable, and the second one includes the short-term money market rate.[7] The identification scheme indicates an inverse relationship between changes in the volume of loans and lending rates and between the dynamics

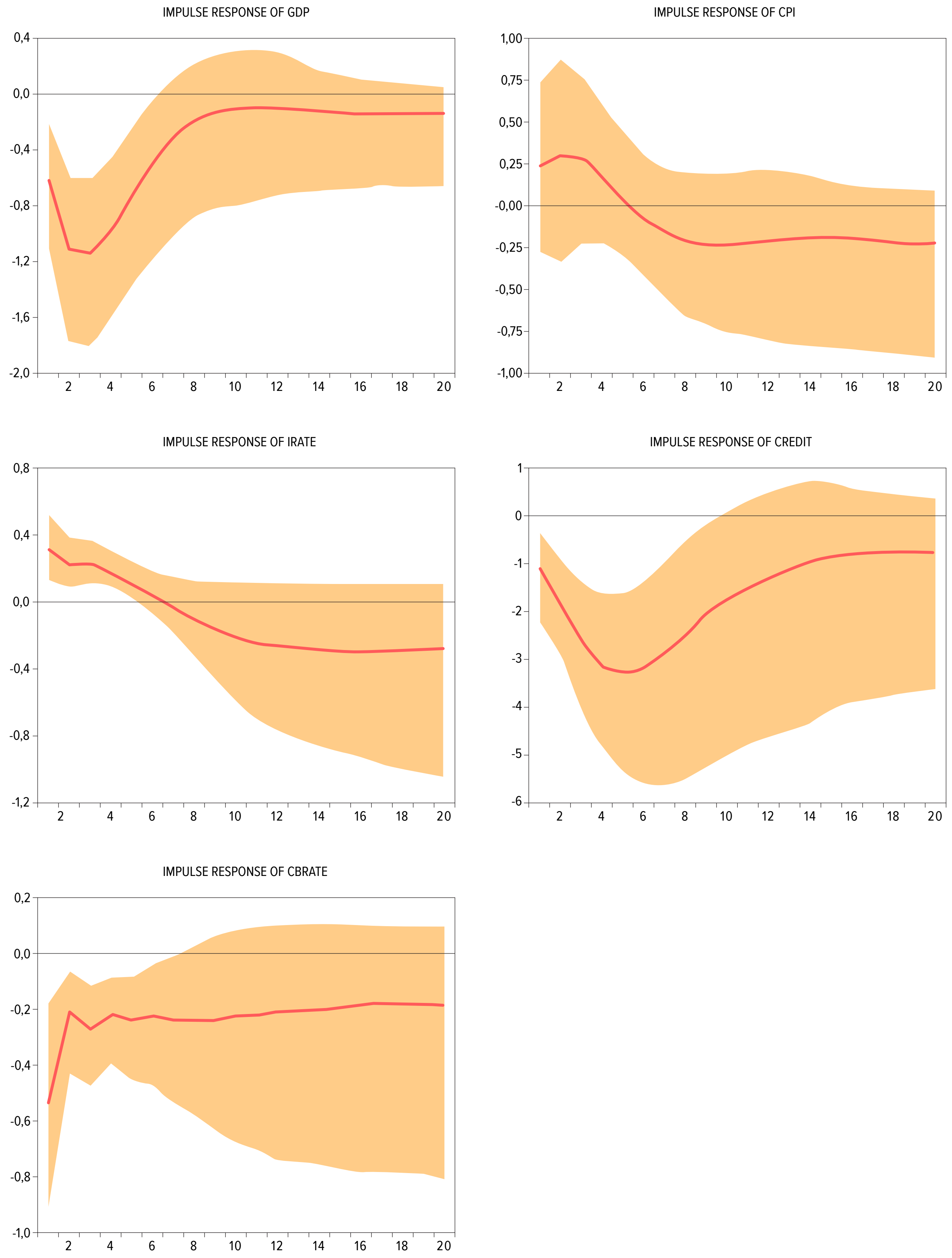
[6] *Uhlig H. (2005). What are the effects of monetary policy on output? Results from an agnostic identification procedure // Journal of Monetary Economics, vol. 52, issue 2, pp. 381–419. DOI: https://doi.org/10.1016/j.jmoneco.2004.05.007.*

[7] *Over the considered horizon of 2005–2020, the monetary policy stance of the Bank of Russia changed; therefore, the exchange rate and short-term interest rate are used as key variables characterising the monetary situation. Simultaneous inclusion of both variables in the model is not possible due to the restrictions on the dimensionality of VAR models.*

IMPULSE RESPONSE FUNCTIONS OF SIGN-RESTRICTED MODEL SPECIFICATION 1 *Chart 14*

Sources: Rosstat, Bloomberg, Bank of Russia calculations.

IMPULSE RESPONSE FUNCTIONS OF SIGN-RESTRICTED MODEL SPECIFICATION 2 *Chart 15*



Sources: Rosstat, Bloomberg, Bank of Russia calculations.

SIGN-RESTRICTED IMPULSE RESPONSE FUNCTIONS FOR VAR MODEL VARIABLES *Table 2*

	GDP (gdp)	CPI (cpi)	Lending rate (lrate)	Lending (credit)	FX rate (usdrub)	Interest rate (cbrate)
Model 1	-1	0	+1	-1	0	X
Model 2	-1	0	+1	-1	X	-1

Note: X means that the variable is excluded from the model specification; 0 means no restrictions; +1/-1 means a restriction on the growth/decline of the variable in response to a shock.
Source: Bank of Russia calculations.

of lending rates and the base rate of the central bank, which is necessary for the purposes of macroprudential stress testing (under the influence of initial adverse macroeconomic shocks, banks reduce credit supply and increase the cost of credit resources; simultaneously, monetary authorities ease their policy in response to the deteriorating macroeconomic situation).

We used the following quarterly statistics (2005 Q1-2020 Q2, with a lag of two quarters):

- YoY real GDP growth rate (%);
- YoY consumer price index (CPI) growth rate (%);
- interest rate on corporate loans (%);
- YoY growth rate of corporate lending in national and foreign currencies (net of exchange rate effect) (%);
- logarithm of the nominal exchange rate of the US dollar against the ruble or the actual MIACR on one-week ruble loans (%).

The graphs of the impulse response functions of the sign-restricted VAR models shown in Charts 14 and 15 indicate the following results.

This identification scheme helps show that the deterioration of the macroeconomic situation expressed as a reduction in the real GDP growth rates leads to a decrease in lending activity.[8] According to the results of both model specifications, a 1 pp drop in the real GDP growth rate one quarter after the initial adverse macroeconomic shock leads to losses of 2.2–2.6 pp in lending growth rates one year later.

2.2. Development of conditional forecasts based on VAR (2)

Conditional forecasting uses a vector autoregression model with two factors (VAR (2)) based on the methodology of the Bank of England.[9] The methodology implies the development of a scenario of independent variable dynamics over a horizon of three quarters and the construction of a forecast for the change in another variable in this scenario.

We used data on real GDP and total corporate lending growth rates (in national and foreign currencies, taking into account exchange rate revaluation) for 2005 Q1-2020 Q2. We assessed conditional forecast values of the GDP and lending dynamics.

If the dynamics of real GDP growth rates for 2020 Q3-2021 Q1 correspond to the following vector (% YoY): [-5, 0, 1][10] (return of the indicator to the pre-crisis level three quarters after the pandemic), the YoY lending growth rates for the same period will amount to 3.6%, 1.6% and 1.3%[11] respectively. Thus, the return of lending growth rates to the pre-crisis level after the fall in 2020 Q2 occurs later than the adjustment of GDP (due to the delayed effect of GDP dynamics on lending) (Charts 16, 17).

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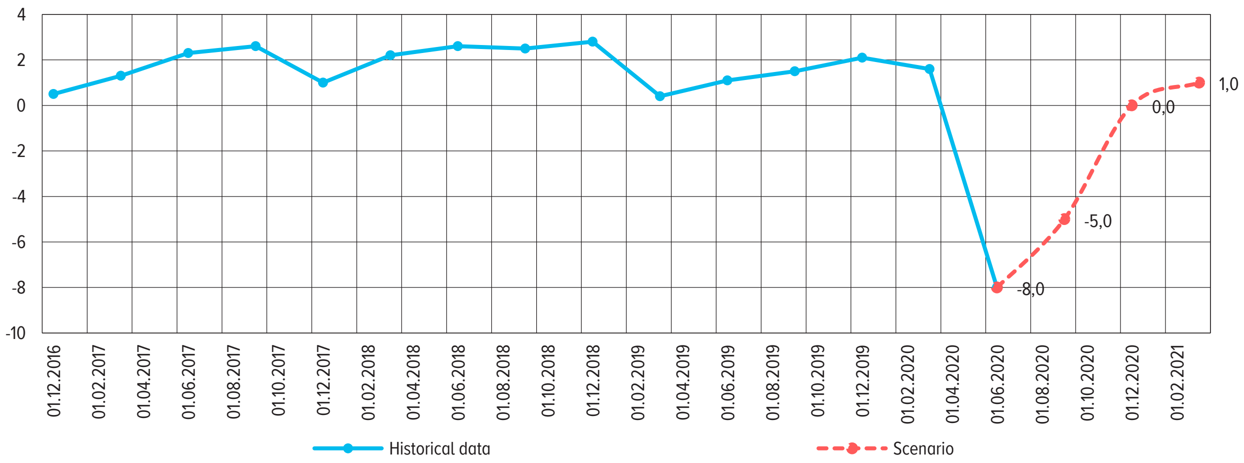
[8] *The opposite (a slowdown in lending activity leads to a decrease in economic activity in the real sector of the economy) is also true, taking into account the bi-directional relationship between indicators assessed in the VAR models.*

[9] *Blake A., Mumtaz H. (2017). Applied Bayesian Econometrics for central bankers. Centre for Central Banking Studies.*

[10] *In this part of the paper, all the statistical data presented are used only to assess the mutual influence of lending growth rates and real GDP and should not be treated as an official forecast of the Bank of Russia.*

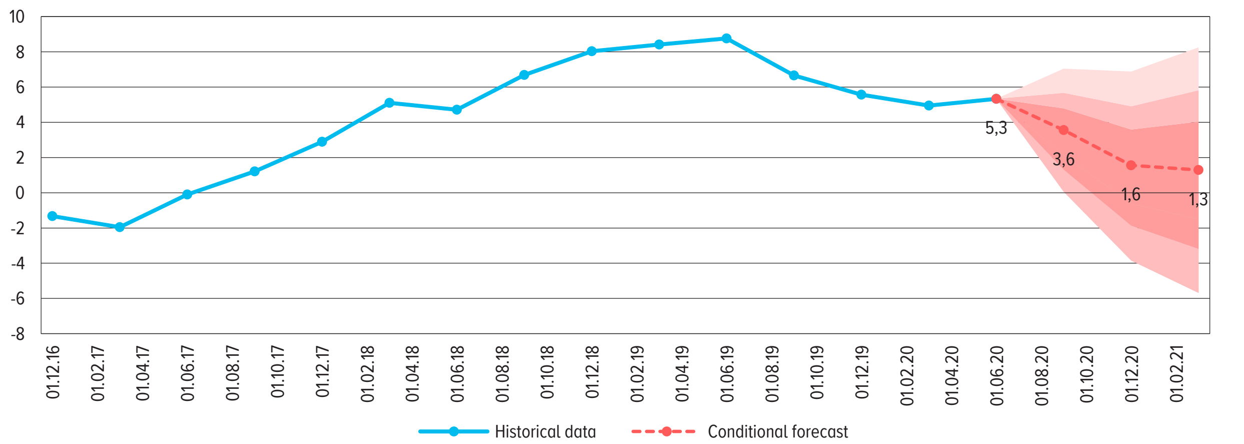
[11] *The data result from an assessment of the cyclical relationship between changes in lending growth rates and do not take into account the measures of the Bank of Russia to support lending activity during the pandemic.*

SCENARIO OF GDP GROWTH RATE DYNAMICS *Chart 16*



Sources: Bank of Russia calculations, Bloomberg, Bank of Russia.

FORECAST OF CHANGES IN LENDING GROWTH RATES UNDER THE GIVEN SCENARIO FOR GDP DYNAMICS *Chart 17*



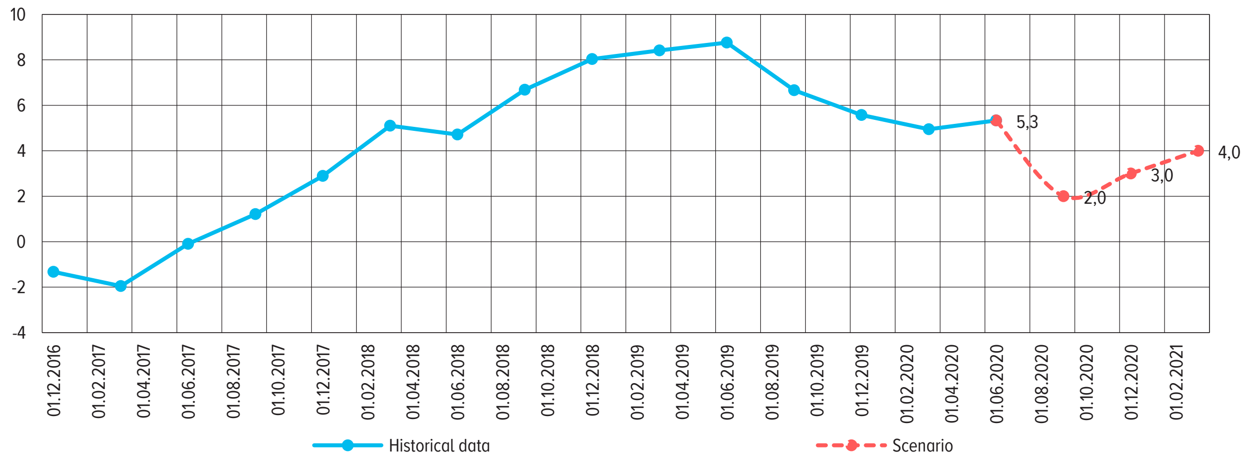
Sources: Bank of Russia calculations, Bloomberg, Bank of Russia.

If the dynamics of lending growth rates for 2020 Q3-2021 Q1 correspond to the following vector (% YoY): [2, 3, 4][12] (return of the indicator to the pre-crisis level three quarters after the pandemic), the YoY GDP growth rates for the same period will amount to 8.1%, – 4% and 1.2% respectively (Charts 18, 19).

Thus, the results of the calculations confirm the interdependence between the GDP and lending growth dynamics; therefore, it is important to take this mutual influence into account to improve the quality of assessments of macroprudential stress testing results.

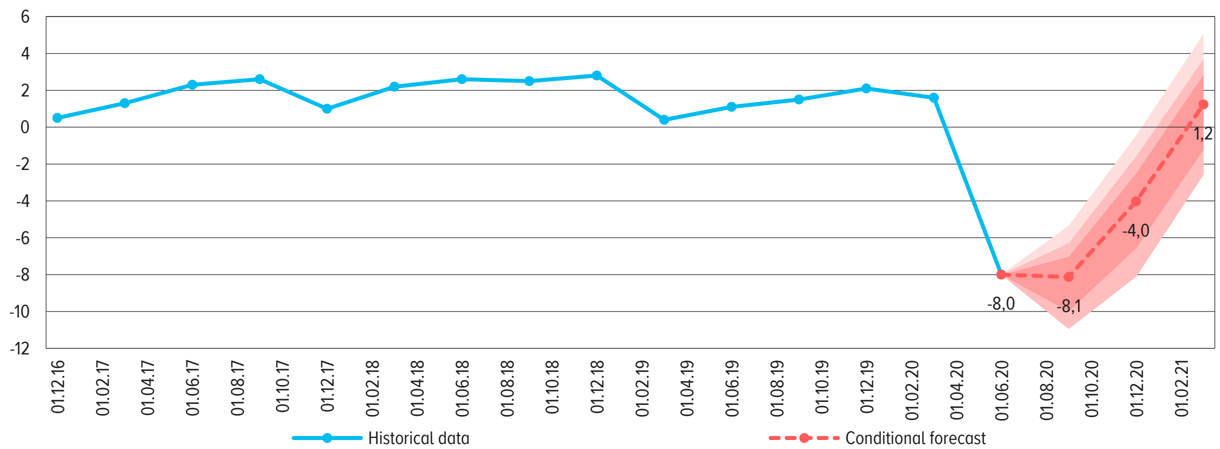
[12] *In this part of the paper, all the statistical data presented are used only to assess the mutual influence of lending growth rates and real GDP and should not be treated as an official forecast of the Bank of Russia.*

SCENARIO OF LENDING GROWTH RATE DYNAMICS *Chart 18*



Sources: Bank of Russia calculations, Bloomberg, Bank of Russia.

FORECAST OF CHANGES IN GDP GROWTH RATES UNDER THE GIVEN SCENARIO FOR LENDING DYNAMICS *Chart 19*



Sources: Bank of Russia calculations, Bloomberg, Bank of Russia.

2.3. Assessment of feedback effects based on a BVAR model

To assess the scale of secondary effects, we used a Bayesian vector autoregression (BVAR) model.[13] For structural identification of the model, we used recursive variable ranking. The length of the time series is 2005 Q1-2020 Q2. The model includes the following main variables: exogenous factors (logarithms of the VIX implied volatility index and the price of Brent crude oil), YoY growth rates of real GDP and the consumer price index (%), the average rate on corporate loans (%), YoY growth rates of corporate lending in national and foreign currencies (net of foreign currency revaluation) and the logarithm of the nominal exchange rate of the US dollar against the ruble.

The modelling results confirm the bi-directional relationship between changes in GDP and lending growth rates: a decrease in total output leads to a slowdown in lending growth rates, while a downturn in lending dynamics also has an adverse effect on the economy due to a reduction in investment (Charts 20, 21). A 1 pp decrease in the real GDP growth rate leads to lending growth rate losses of 1.9 pp, which, in turn, becomes a factor for a subsequent downturn in economic growth of 0.3 pp. As a result, the total loss of economic growth rates is 1.3 pp (instead of the initial 1 pp).

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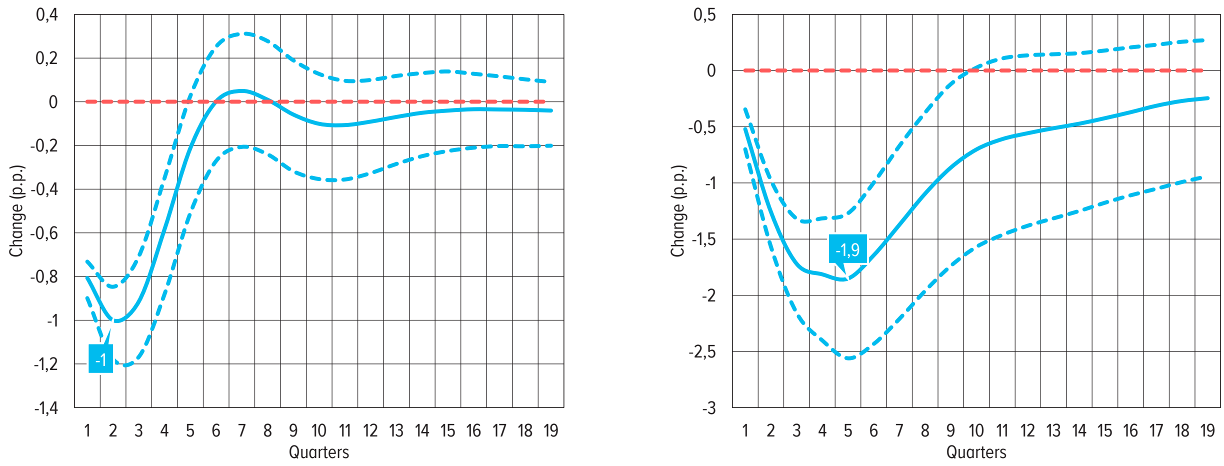
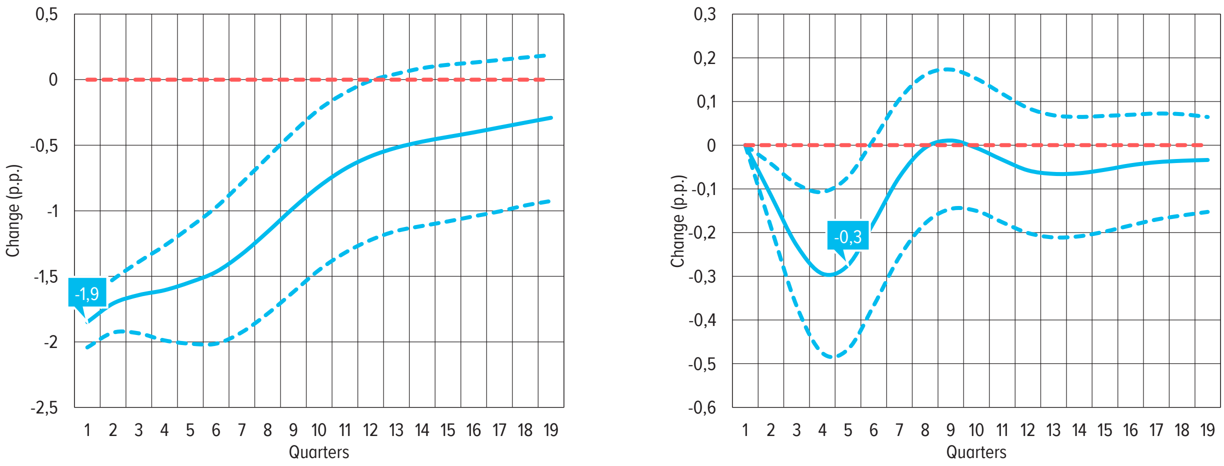
[13] Blake A., Mumtaz H. (2017). Applied Bayesian Econometrics for central bankers. Centre for Central Banking Studies.

REDUCED LENDING GROWTH RATES RESULTING FROM A LOWER GDP GROWTH RATE *Chart 20*



Sources: Rosstat, Bank of Russia, Bloomberg.

REDUCED GDP GROWTH RATE RESULTING FROM LOWER LENDING GROWTH RATES *Chart 21*



Sources: Rosstat, Bank of Russia, Bloomberg.

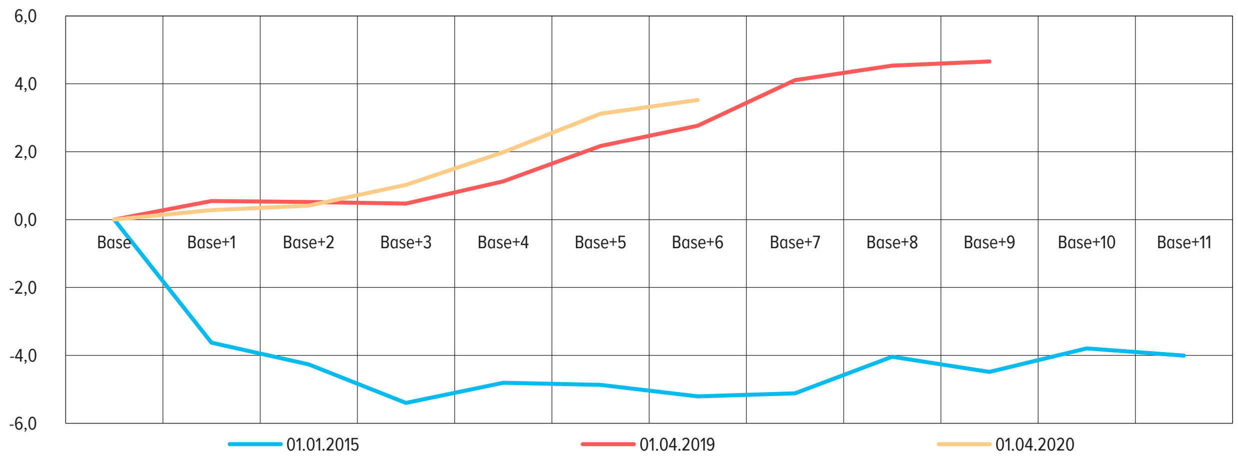
Losses of the economy due to second-round effects amount to 0.3 pp in terms of the real GDP growth rate for every 1 pp of initial contraction under the influence of an adverse macroeconomic shock. Consequently, the secondary effects increase macroeconomic losses by 30%.[14]

3. Evaluation of the effectiveness of government support measures

In 2020, the coronavirus pandemic triggered an unprecedented decline in global economic activity. Since the dynamics of lending activity are the basis of investment activity as a key factor of economic growth, in 2020 global regulators used a wide range of instruments to support lending. This helped contain the spread of a chain of adverse secondary effects similar to the 2008 global financial crisis. The measures of the Bank of Russia and the Government aimed at supporting lending also ensured an increase in lending activity in the context of the pandemic in comparison with previous crises.

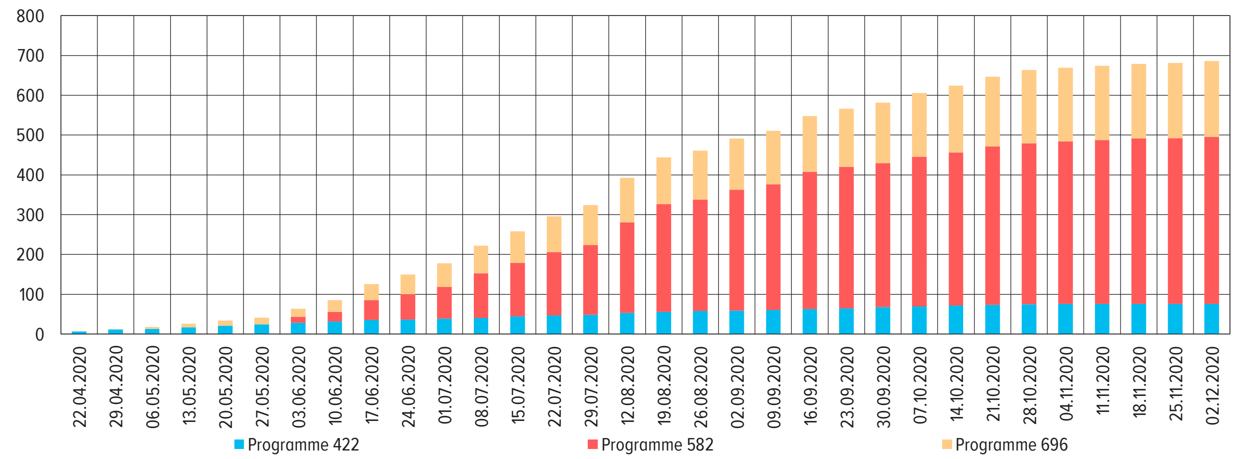
[14] *The assessment of the scale of secondary effects is dynamic and can change as new historical data are included in the initial sample and the structure of the relationship between GDP and lending dynamics changes under the influence of macroeconomic factors or Bank of Russia policy.*

REAL INDEX OF CORPORATE DEBT GROWTH NET OF THE FOREIGN CURRENCY REVALUATION FACTOR
(% AGAINST THE BASELINE DATE) *Chart 22*



Sources: reporting form 0409101, Rosstat.

AMOUNTS OF ACTUALLY GRANTED LOANS UNDER STATE SUPPORT PROGRAMMES (CUMULATIVE TOTAL)
(BILLION RUBLES) *Chart 23*



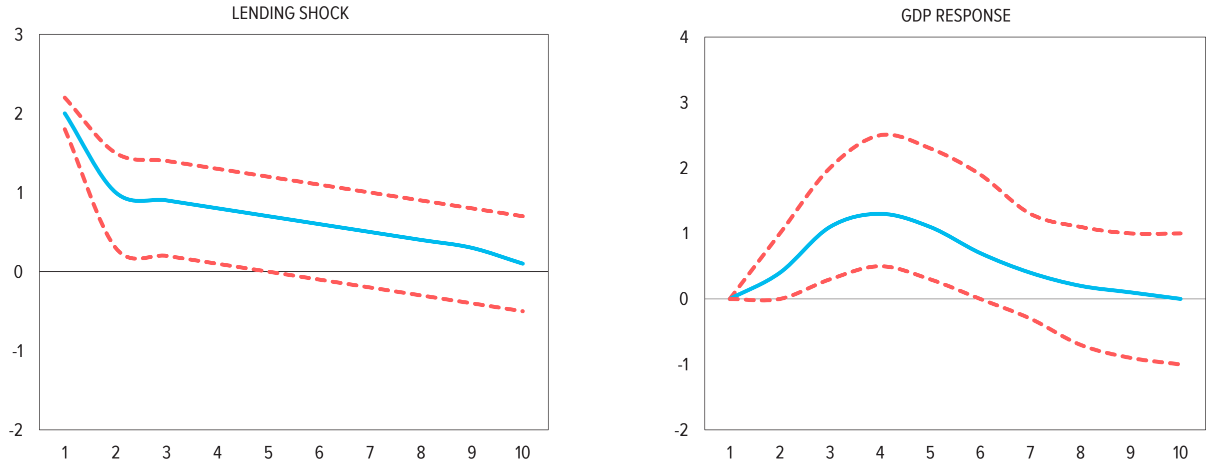
Source: Bank of Russia survey of credit institutions.

An important role in maintaining employment, economic and lending activity in the context of the pandemic was played by state programmes to support lending promptly launched during the period of restrictive measures and aimed at mitigating their negative impact on the economy. They included programmes for the provision of subsidies from the federal budget for loans provided to strategic organisations (hereinafter, Programme 582) and to legal entities and individual entrepreneurs to enable them to support and maintain employment (hereinafter, Programme 422) and to resume activities (hereinafter, Programme 696).

To assess the effectiveness of state lending support programmes in the context of the COVID-19 pandemic, we used a specification of the VAR model (Chapter III, Clause 2.1), with the MoM growth rate of new ruble corporate loans chosen as the lending variable. The calculation showed that a change of 1 pp in the lending growth rate triggers a change of 0.8 pp in the GDP growth rate (Chart 24).

The volume of all state lending support programmes in April – June 2020 amounted to ₽177 billion (33% of new corporate loans in national currency), and in July – September, to ₽404 billion (81%). An analysis of the sensitivity of GDP growth rates to changes in lending growth rates taking into account the share of state programmes relative to the increase in the size of the loan portfolio

CHANGE IN GDP GROWTH RATE IN RESPONSE TO CHANGES IN THE GROWTH RATE OF NEW LOANS *Chart 24*



Sources: Rosstat, Bank of Russia, Bloomberg.

CHANGE IN GDP GROWTH RATE IN RESPONSE TO CHANGES IN THE GROWTH RATE OF NEW LOANS *Table 3*

Date	**Corporate loans**	**Lending growth rate per quarter**	**State programmes**	**State programmes growth rate per quarter**	**GDP growth rate (incl. state programmes)**	**GDP growth rate (excl. state programmes)**
	billion rubles		**billion rubles**			
1 April 2020	26 176					
1 May 2020	26 695		11.9			
1 June 2020	26 661		33.2			
1 July 2020	26 714	538	132.3	177	-8.0	-8.5
1 August 2020	26 973		146.3			
1 September 2020	27 235		167.5			
1 October 2020	27 213	499	90.1	404	-3.6	-4.8

Sources: Rosstat, Bank of Russia, Bloomberg.

showed that the effect of state support for the economy through the channel of lending activity amounted to 0.5 pp in 2020 Q2 and 1.2 pp in 2020 Q3 (Table 3). The more significant macroeconomic effect from the state support programmes in 2020 Q3 is due to the high contribution of these programmes to the increase in loan disbursements over this period.

Thus, the implementation of state lending support programmes in 2020 Q2 – Q3 made a significant contribution to reducing negative economic growth rates in Russia in the context of the pandemic.

CONCLUSION

The process of macroprudential stress testing primarily deals with the analysis of systemic effects and their impact on the stability of the financial sector. The most relevant trends in the development of macroprudential stress testing are the growth of markets with centralised clearing, the growing importance of contagion risks due to the expansion of activities of non-bank financial intermediaries (asset managers and development institutions) and the mutual influence of the financial and non-financial sectors due to feedback effects.

This analytical note provides an overview of international experience and Russian practices in the analysis of systemic risks in the specified areas within the framework of macroprudential stress testing. The main conclusions of the analysis are as follows.

- Central counterparties that provide centralised clearing services for transactions in a significant part of the financial market should be inherently subject to macroprudential stress testing. Not only do they concentrate significant volumes of positions on themselves, but they also have a limited capacity for loss absorption, thereby introducing potential risks for financial system participants in the event of large-scale shocks. An important element in assessing systemic risks is the central counterparty's default waterfall mechanism as well as the procedure for its use under stress.
- Non-bank financial intermediaries are becoming a significant source of systemic risk, as confirmed by network analysis of the architecture of the main segments of the Russian market. A number of non-bank financial institutions and development institutions have acquired a high degree of centrality in the network, forming the basis for their inclusion in the perimeter of stress testing. They can act as a source of systemic risk through direct and indirect channels. The procyclical pattern of behaviour of non-bank financial institutions among local market participants must be taken into account when assessing the stability of the financial market in periods of increased volatility.
- During the coronavirus pandemic, the non-financial sector has become a source of risk for the financial sector, which, in turn, has a significant impact on the non-financial sector through the credit channel. As shown by the results of our study, the scale of the feedback effects between the financial and non-financial sectors is material for modelling crisis dynamics in macroprudential stress testing. Our estimates show that state lending support measures have made a significant contribution to curbing the downturn in economic dynamics.

In general, the above-mentioned areas of systemic risk analysis form a part of macroprudential stress testing since they enable us to go beyond assessing the risks of individual financial institutions and to estimate systemic effects at the macroeconomic level. In turn, the results of this analysis can serve as a basis for the development of proposals for anti-crisis measures and macroprudential policy measures.