Review of the Bank of Russia – IMF Workshop 'Recent Developments in Macroprudential Stress Testing'

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In September, the Bank of Russia held a joint workshop with the International Monetary Fund in Moscow on macroprudential stress testing. IMF experts, members of the research community, staff members of central banks, and regulators from 16 countries shared their approaches to and methodologies of macroprudential stress testing and systemic risk analysis.¹ This publication provides a brief review of the workshop and the key findings of the studies presented.

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1. Introduction

In the wake of the 2007 – 2009 global financial crisis, many central banks, in addition to their traditional objective of securing price stability, were given an official mandate to maintain financial stability. Unlike inflation targeting, which has been successfully implemented for several decades and the mechanism of which has been extensively explored in research studies, central banks' policies regarding the maintenance of financial stability is an area where a complex of universal approaches has yet to be developed and where very extensive studies are underway. Central banks' experience suggests that the goal of securing financial stability requires a system for identifying, monitoring and assessing

¹ Workshop program and presentations (in English) are available at http://www.cbr.ru/analytics/fin_stab/

systemic risks to be developed along with an array of macroprudential policy instruments.

One instrument that has started to be widely used after the global crisis for analysing risks – of individual banks and financial organisations as well as those of the financial system in general – is stress testing (Danilova and Markov, 2017). Stress testing helps assess financial organisations' stability, estimate the amount of capital required to cover losses should a crisis scenario materialise, compute the size of recapitalisation needed under such circumstances² and conduct quantitative estimation of individual risk types. Macroprudential Stress Testing (MST) is distinguished by its ability to factor in the effects of financial organizations' interconnection as well as the financial sector's effects on the real economy. MST is an area that is being extensively developed in leading central banks, and a single, generally accepted methodology has yet to be developed.

The Bank of Russia has been extensively developing an MST concept of its own since 2017. The concept was published for discussion and consultation in October 2017 (Bank of Russia, 2017).

The joint Bank of Russia – IMF workshop consisted of eight sessions, each covered in a separate section of this review: 1) development of MST methodology and assessment of its effectiveness; 2) macroeconomic scenarios for MST; 3) risk assessment using Big Data; 4) using stress testing to analyse nonfinancial companies' risks; 5) assessment of nonbanking financial organisations' risks as part of MST; 6) assessment of feedback effects between the financial sector and the real economy; 7) development of interconnection analysis in the financial sector; 8) policy issues: optimal disclosure of stress-test information and assessment of macroprudential policy effectiveness.

2. Development of MST methodology and assessment of its effectiveness

Four MST concepts were presented in this session: those of the European Central Bank (presenter – **Christoffer Kok**), the Bank of Japan (**Wataru Hirata**), the Bank of Russia (**Elizaveta Danilova**), and the National Bank of Poland (**Oskar Krzesicki** and **Marcin Borsuk**).

The European Central Bank (ECB) was one of the first regulators to start developing MST, for the benefit of, among others, the European Banking Administration (EBA) and the Single Supervisory Mechanism (SSM). The ECB's

² For example, the first stress testing exercise conducted by the Federal Reserve in 2009 became the central element of anti-crisis policy. This took place amid the market's severe lack of confidence in banks, as their investments in structured products, derivatives, and other risk assets were unknown. Instead of preventive infusion of government funds into the capital of all major banks, stress testing was conducted in order to recapitalise only fragile banks as necessary. Stress testing showed the actual situation at the major banks: a capital shortfall was identified, but its size proved to be smaller than the market expected; confidence was restored; and almost all banks were able to get hold of the required capital in the market without resorting to government support.

stress-test concept was published in February 2017 (Dees et al., 2017). The ECB only uses stress testing for banks. The ECB's methodology presented at the seminar by **Christoffer Kok**, includes the computation of credit and market risks, the estimation of net interest income and fee and commission income, the assessment of operating risk, and the forecast of banks' other income and losses. The aggregated stress testing results and data on the distribution of losses across banks are published on a regular basis in the ECB's financial stability review. MST results are compared with European banks' estimates calculated as part of supervisory stress testing by the bottom-up method.

The key macroprudential element of the ECB stress test is assessing feedback effects between the real economy and the financial sector. This methodology factors in banks' response to negative shocks, when a decline in capital in the stress environment brings about lending contraction, thereby further exacerbating recession, hitting companies' creditworthiness and entailing more problems for banks (see Section 7 for details). In addition, the ECB's MST takes into account the impact of macroprudential measures – in particular, the ratio of the countercyclical buffer size to banks' capital. Banks' behaviour as shocks are realised depends on their balance sheet structure and risk-return ratios. To assess banks' responses to shocks and their impact on lending, the ECB uses a variety of model-based approaches: regression analysis, empirical models for adjusting bank balance sheets, vector autoregression (VAR) models for individual banks' balance sheets, models of portfolio structure optimisation, modelling a relationship between the capital level and the cost of funds and agent-based models (ABM). Christoffer Kok pointed out the need to model not only banks' but also other economic agents' (nonfinancial companies, households) responses. To assess various banking risks and to forecast profits, losses, and balance sheets, a complex of satellite models is employed. Christoffer Kok believes that the effectiveness of the stress testing methodology needs to be verified via backtesting and via the analysis of case studies and the sensitivity of a model's key assumptions.

As **Wataru Hirata** showed in his presentation, the assessment of relationships between the financial system and the real economy also plays a central role in the Bank of Japan's stress testing concept. MST aims to assess not only the stability of the financial sector but also its efficiency in performing its financial intermediation function. Like the ECB, the Bank of Japan confines its stress testing to banks; but unlike the ECB, which only analyses the Eurozone's major banks, the Bank of Japan also provides estimates for smaller, including regional, banks (a total of 370 banks). The inclusion of smaller banks is essential, since, based on Japan's experience, it is above all the regional banks that suffer profitability problems and the most severe lending contraction in stress events.

The Bank of Japan's approach to MST provides for three components: an econometric macrofinancial model, a model for estimating long-run profitability (mainly for regional banks), and a joint modeling project with major banks.

Aggregated results of the stress test are published twice a year in the Bank of Japan's Financial System Report. Stress testing uses one unlikely crisis scenario (comparable to the 2007 – 2009 crisis in terms of severity) and complementary scenarios reflecting current market risks (in 2016, for example, Japanese banks' resilience to an increase in the cost of dollar funding was checked; in 2017 their resilience to a crisis in the real estate market; in 2018, the model assumes an escalation of low-income borrowers' problems).

Jointly with major banks, the Bank of Japan experts analyse detailed bank data, and assess credit risks through constructing models that use different data aggregation levels (by industry, by individual borrower, by asset size, or broken down into production sector and nonproduction sectors). Analysis suggests that the total loss level is best predicted by a model in which loans are aggregated on the level "40 industries and two asset classes by size", whereas the levels of bad loans by industry are the most accurately identified by a model using data of individual borrowers. The Bank of Japan is currently implementing a joint stress testing project with banks to assess a potential impact of interest rate hikes on borrowers' creditworthiness and the banking sector's credit risks.

Elizaveta Danilova presented a MST concept implemented at the Bank of Russia. It aims to cover not only banks but also noncredit financial organisations (NFOs: insurance companies, nongovernment pension funds, and broker/dealer firms). The rationale for such a wide coverage (despite NFO's small share in the financial system's assets) is that, first, NFOs are extensively interconnected with the banking sector and, second, the Bank of Russia (unlike many other central banks) is a megaregulator responsible for, among other things, regulating and supervising the NFO sector. Stress testing applies to all companies belonging to financial groups owned by the same beneficiary, which allows for taking into account both financial support within the group, and contagion from other companies of the group. MST covers financial groups accounting for over 80% of the financial sector's assets. The most detailed data (from the credit registry, trade repository, and banks' reporting for securities investments) is used to analyse credit and market risks.

A two-stage approach is used to assess credit risk: the first stage evaluates the relationship between macroeconomic indicators and financial indicators of corporate borrowers; and in the second stage, the relationship between borrowers' financial position and a bank's provisions for individual loan types is examined. The Bank of Russia is currently fine-tuning its models. The construction of a default probability model is underway, based on information on defaults provided by major credit history bureaus.

The Bank of Russia uses MST not only for quantitative assessment of risks and their dynamics but also as a tool to implement financial stability measures. This policy can be regarded as addressing two goals: an anti-crisis one (measures to safeguard financial stability when risks are already realised) and a macroprudential one (regulatory measures to prevent the accumulation of systemic risks).

MST helps determine bank recapitalisation needs and plan anticrisis refinancing policy. Stress testing is performed on five time horizons (two days, one month, one quarter, one year, and two years) so as to identify the time when particular measures of support need to be stepped up.

Interconnection analysis is also conducted as part of stress testing along with assessment of the contagion effect (the amount of losses sustained by stress test participants as a result of their direct counterparties' default in the previous stage). Early prevention of contagion helps restrain further shock propagation. The high ratio of the contagion effect to capital deficit may point to a bank's high systemic importance.

Oskar Krzesicki and **Marcin Borsuk** dwell on the National Bank of Poland's approach to stress testing. Stress testing only involves banks (34 banks which account for over 80% of banking sector assets). Aggregated stress test results are published twice a year in the National Bank of Poland's financial stability review. The central bank is not a supervisory authority in Poland, but it has been interacting with a relevant authority since 2013, comparing the results of macroprudential stress tests and those conducted by the supervisory authority. An important element of a macroprudential stress test is a macro model which is used to identify a shock scenario. Economic growth slowdown in Poland's major trading partner countries (the EU and, accounted for separately, Germany and the UK, as well as the U.S.) and oil and gas price hikes are deemed to be the key stress factors. The National Bank of Poland uses historical shocks identified based on the Hodrick-Prescott filter, and takes into account analysts' macroeconomic forecasts and dispersion of forecast values reflecting the level of uncertainty of the macroeconomic situation. To assess credit risk and the interest margin, satellite models are employed. Separate regressions are constructed for the corporate loan portfolio, unsecured consumer loans, and mortgage loans. A regression for forecasting the interest margin is also constructed in which the net-interest-income-to-assets ratio is used as the explained variable. Explanatory factors in the equations are macroeconomic variables, lagged explained variables, and individual banks' variables.

Foreign currency loans account for a substantial 34-percent portion of the banking system's mortgage loan portfolio in Poland. Mortgage lending risks are assessed using credit history bureau microdata on borrowers' income and quality of loans. The test estimates to what extent a currency and interest rate shock changes the payment-to-borrower's-income ratio and the borrower's default likelihood.

Also, the National Bank of Poland assesses the impact of individual banks' risks on their balance sheets and profit and loss accounts. If the capital adequacy ratio falls below the statutory minimum, the bank is assumed to be in a situation of default on interbank loans. Krzesicki and Borsuk note, however, that banks' interconnection is low in Poland's interbank loan market, so no domino effect occurs: a bank's default does not result in a counterparty bank's insolvency.

3. Macroeconomic scenarios for a macroprudential stress test

Session 2 of the workshop dealt with developing macroeconomic scenarios for MST. The authors indicated key criteria which stress scenario parameters should meet and methods that can be used to analyse macroeconomic and financial relationships. They also discussed their experience and practices of developing stress scenarios for implementing MST.

Mindaugas Leika of the International Monetary Fund started his presentation with describing challenges for stress scenario designers. Stress scenarios should meet the requirements of plausibility and sufficient severity of losses, while the results of stress tests conducted based on these scenarios should lend themselves to formulating conclusions regarding further economic policy improvement. These requirements make it necessary to employ certain econometric tools. GaR (growth-at-risk) models based on (Adrian et al., 2018) help estimate the likelihood of a stress event and establish its relationship with macrofinancial risks. The severity of scenarios (which is equivalent to the amount of forecasted losses) can be estimated using the CaR (capital-at-risk) model. To estimate economic agents' operations aiming to reduce the overall risk level or to assess the effects of macroprudential policy, general equilibrium models (DSGE), structural vector autoregressions (SVAR), or ABM can be applied.

Economic models used for MST purposes should meet the following requirements: they should be based on clear methodology; factor in structural features specific to national economies as the impact of exogenous shocks is modelled; take into account country-specific economic policy rules; enable data on a large number of objects to be included in analysis; and allow for the tracking of macrofinancial relationships in the economy.

The stress testing horizon is usually two to three years, while a longer horizon may result in an overestimation of losses at the time of a shock. The results of stress testing may show larger losses on a long horizon, as this implies keeping a bank portfolio unchanged. In reality, however, banks tend to adapt to the stress environment so as to minimise losses.

The GaR model constructs probability distribution of real GDP growth rates in relation to financial conditions. The degree of investor risk tolerance is an endogenous variable of the model (the volatility level of financial conditions and economic growth are interdependent). The GaR model, thus, links information contained in financial variables to the expected GDP performance based on tail risk.

The GaR model allows for the identification of the measures of financial conditions which have the strongest impact on future real GDP performance and shows the relative importance of these variables. The model shows a relationship between the financial sector and the real economy by constructing the probability distribution of aggregate output growth in relation to the severity of financial market conditions. The model allows for the assessment, among other things,

the severity of scenarios and comparing them with the current financial market conditions.

The GaR methodology explores a wide range of financial indicators, which can be roughly split into three groups: 1) the cost of risk (risk spreads, return on assets, price volatility, inflation); 2) lending measures (leverage – the debt-to-equity ratio, lending growth rate); 3) external conditions (global investors' risk appetite, commodity prices, exchange rates, regional growth rates).

The key findings reported by Leika based on the GaR model are as follows. Milder financial conditions help maintain higher economic growth rates and lower volatility levels in the short run (up to four quarters), but result in lower growth rates and high uncertainty in the medium term (more than one year). Mild financial market conditions heighten investor risk tolerance, jeopardising, however, economic growth in the medium term. Maintaining mild financial conditions at present is a drag on economic growth in the future.

Stress testing is especially important when developing recommendations for economic authorities. As part of this policy, the IMF, based on the results of stress testing, evaluates the effect of economic policy instruments on the GaR level. An analyst chooses the desired level of GDP growth at risk. Then the results of implementing microprudential and macroprudential instruments affecting the performance of explanatory variables in the GaR model (leverage, housing prices, lending growth rates) are estimated on a 12-month horizon. Comparing the implications of various economic policy measures, the analyst chooses the most efficient instrument – the one that secures GaR volatility reduction with the least decline of the mean output growth value.

To conduct structural economic analysis, the IMF relies on various versions of DSGE models, structural and global VAR and Flexible System of Global Models (FSGM) used for drawing up the World Economic Outlook. Models employed for MST purposes factor in an array of key variables characterising the condition of an economy and its financial system. Moreover, the model's tools enable macroprudential authorities' policy to be taken into account.

Iuri Lazier of the Central Bank of Brazil noted in his presentation that design of stress scenarios should proceed from the following assumptions: economic conditions are worsening, a negative impact of external conditions is observed or specific risks are realised.

The quantitative parameters of stress scenarios can be constructed based on market expectations, historical experience, expert estimates, statistical methods, or a combination of these. The Bank of Brazil studies four negative scenario types: baseline, worst-case, worse-than-worst-case (based on historical experience), and a structural scenario.

In conducting MST, the Bank of Brazil looks at the performance of major macroeconomic variables (GDP, interest rates, exchange rates, unemployment) and global factors (international interest rates, sovereign risk premia, and commodity prices).

The baseline, or the most likely, scenario is designed based on professional analysts' forecasts, with a number of parameters (commodity prices, unemployment, sovereign risk premia) assumed to remain unchanged. The level of interest rates in the international financial market is set in line with the U.S. Federal Reserve forecast.

The magnitude of a negative shock of a variable under observation in the worst-case scenario is set on the border of a 95% confidence interval. Commodity prices decline linearly at an annual rate of 5%. The unemployment rate soars to 80% within 6 quarters. The cost of borrowing in the international financial market is formed in line with a Federal Reserve forecast. The values of other variables are computed using the VAR model based on a conditional forecast.

The parameters of the worse-than-worst-case historical and structural scenarios are chosen based on historical observations (the largest variable deviations). Further performance of the model's variables is formed based on the proportions of relationships between the model's parameters. Under the worse-than-the-worst-case scenario, the scale of the shock is determined using data on the largest actually observed drop of the variable in history. To implement a structural scenario, a two-year period that saw the negative path of the variable under observation is selected, followed by a year of stabilisation. Proportions of the change in variables are carried over to the future stress testing horizon.

Stress scenario design and evaluation procedures at the Bank of Russia were reviewed by **Andrei Lipin**. In conducting stress testing, the Bank of Russia relies on a macrofinancial model consisting of a complex of modules which comprise a base semi-structural model of economy functioning and a set of auxiliary (satellite) models estimating individual macrofinancial indicators. The base semi-structural model is constructed in neo-Keynesian logic on a quarterly basis and features more flexible assumptions than the classical DSGE model, thus providing a more flexible forecasting tool in the stress environment. The model specification is based on a system of behavioural equations characterising a relationship between inflation, business activity, exchange rate movements, interest rates, terms of trade, and external sector variables (see Bank of Russia, 2017).

The strength of this model is that it includes the function of monetary policy response to stress as part of the Bank of Russia's inflation targeting mandate. Significant inflationary risks in the stress environment are therefore automatically alleviated in the model thanks to the Bank of Russia's proactive response.

The Bank of Russia's macroprudential stress test provides for stress scenarios on a horizon of up to two years. The scenario envisages a sharp drop in oil prices, and their staying at this level for two years. In addition to an oil price shock, the scenario assumes a deterioration of external conditions of the economy's functioning, including in global financial markets, which boosts net capital outflows from the Russian economy.

4. Risk assessment using Big Data

Modern banks extensively use machine learning and Big Data analysis to construct risk assessment models and to promote their products. The sophistication of reporting data collection happens in parallel; the most advanced countries move from supervisory forms to the data-centric model, where supervisory authorities have virtually continuous access to financial organisation accounts. Therefore, information of increasingly high granularity becomes available to central banks conducting macroprudential testing.

This session heard two presentations on using Big Data for assessing financial system risks.

The presentation of **Fabrizio Lopez Gallo Dey** from the Bank of Mexico dealt with using payment system data to assess bank risks for loans to nonfinancial organisations. It became evident after the 1994 – 1995 crisis that information available about the financial system was insufficient for monitoring individual sectors, markets, financial institutions, and transmission channels. Steps have therefore been taken to arrange information exchange among the country's regulatory authorities, with granular data collection on a daily basis currently being implemented.

The Bank of Mexico was one of the first central banks to use daily payment system data to analyse systemic risks. Based on this data, incoming and outgoing payments were evaluated for individual firms. The difference between incoming and outgoing payments was assumed to be indicative of a company's income. Expert estimates established the threshold of income decline below which a company was assumed to be in default, ceasing payments on its liabilities to other companies and banks. This identified the network effect which helped evaluate banks' sensitivity not only to corporate borrowers' defaults, but also to that of companies associated with borrowers.

In his presentation, **Evgeny Rumyantsev** of the Bank of Russia reviewed risk assessment in the mortgage lending segment relying on Big Data. He presented a technique for assessing the risks of a mortgage loan portfolio using the migration matrix. Unlike conventional approaches, under which the migration matrix depends on how long the loan has been in default, the likelihood of transition is, under the technique in question, described by such characteristics of the loan as LTV (the loan-to-value ratio), PTI (the payment-to-income ratio), and the number of a borrower's household members. Also, macroeconomic indicators such as unemployment, household income and inflation performance are used to model the likelihood of transition. All macroeconomic variables used are regional, enabling the specific features of the region where the loan was provided to be factored in.

Relationships between the probabilities of transition, loan parameters, and macroeconomic variables are identified using Dirichlet regression, which is widely employed for composite data. Regression coefficients are estimated by the Markov chain Monte Carlo method (Bayesian approach), which allows for

the computing of the joint distribution of model parameters rather than their pointwise estimation. This forecasting exercise provides data on the distribution of losses in the loan portfolio. The collection of a large number of loan portfolio parameters reveals differences in loan portfolio quality across banks, allowing for a more accurate risk assessment with the characteristics of borrowers and loans in the loan portfolio taken into account.

5. Using stress testing to assess nonfinancial companies' risks

Credit risk associated with lending to corporate borrowers is traditionally a key risk for various countries' banking sectors: loan claims on nonfinancial organisations account for the largest share of assets in banks' balance sheet structure (about 37% in Russia, for example). In a number of countries, nonfinancial companies not only borrow massively from the banking sector, but also raise a substantial amount of debt in financial markets, including from non-residents. In the event of a crisis, a large amount of companies' external debt may become a source of instability even if the situation in the banking sector is stable. This heightens the systemic importance of nonfinancial companies in a stress environment, making it necessary to regard them as a direct object of stress testing (rather than as an element of credit risk assessment for banks). A sizable external debt of nonfinancial companies is seen, in particular, in Turkey and Indonesia.

Pelin Sumer from the Central Bank of Turkey and **Linda Hakim** from the Bank of Indonesia presented similar approaches to assessing company credit risks. A company's financial stability is associated with the interest coverage ratio (ICR) calculated as the ratio of a company's earnings before interest and taxes (EBIT) to net financial expenses. A company's EBIT is calculated by multiplying the revenue of the previous period by the average EBIT profitability over the last three years. In modelling net financial expenses, potential interest rate hikes under a stress scenario and the movements of the national currency exchange rate are taken into account. Companies with the ICR value of less than 1.5 show an elevated default probability. To assess loan loss risks for such companies, a probability of default (PD) value of 15% is applied calculated by Moody's model on 1970 – 2012 data for companies with the ICR of less than 1.5. The level of losses upon a borrower's default (Loss Given Default, LGD) is computed using World Bank data for relevant regions and countries. The amount of expected loss is thus computed from the following formula:

$$EL = EAD * PD * LGD,$$

where *EAD* is the amount of loan claims on the borrower.

An increase in expected losses is reflected by changes in the capital adequacy ratio and helps assess the effect of losses on the financial stability of individual banks.

This approach helps assess the sensitivity of bank portfolios' credit quality to interest rate hikes and exchange rate fluctuations but can be complemented by companies' other financials. This approach can be successfully employed in countries where foreign currency-denominated or floating interest rate loans account for a substantial share of companies' debt. As regards other loan types, techniques for forecasting companies' revenues depending on a macroeconomic scenario still need to be developed. This will allow changes in the debt burden of companies in stress to be predicted. Also, given that the default probability of companies with similar financials may vary between countries due to national financial and business specifics, it would be worthwhile to replicate the Bank of France's approach and develop countries' own models of default probability forecasting based on their default statistics.

Because of this, the Central Bank of Turkey also uses an alternative approach to risk assessment for companies, assigning them scores calculated using Altman's models (Altman, 1968). Altman's model coefficients are calculated on Turkish companies' default data. After establishing a relationship between the assigned score and macro variables, an analysis of companies' financial resilience to macroeconomic shocks can be conducted.

6. Assessing risks of nonbanking financial organisations in a macroprudential stress test

Most central banks only cover credit institutions in conducting MST (in line, for example, with the Bank of Japan and ECB concepts described above). This stems from banks' domination of many countries' financial systems, and this is where systemic risks first emerge in the event of a crisis. On the other hand, long-term institutional investors (insurance companies and pension funds), which are not subject to the risks of short-term asset withdrawal, help absorb shocks.

The situation has been changing over the past decade: as the Financial Stability Board's review on the risks of the parallel (shadow) banking system suggests, nonbanking financial intermediaries' asset growth has steadily outperformed that of the banking sector. Financial reforms in the wake of the 2007 – 2009 financial crisis mainly consisted of toughening banking sector regulation. The 10-year period of low interest rates has brought down institutional investor returns. This situation has enhanced the role of asset management institutions, and recent years have increasingly seen initiatives to assess the systemic risks of nonbanking financial organisations (systemic stress initiative, Bank of England technique for risk assessment of investment funds, etc.). **Laurent Clerc** from the Bank of France, **Inro Lee** from the Bank of Korea, and **Alina Kuraeva** from the Bank of Russia presented their findings and insights regarding this issue.

Laurent Clerc discussed the Bank of France's current study of insurance companies specialising in life insurance and asset management. The study became

relevant as legislation (Sapin II ³) was passed in December 2016 giving the Supreme Financial Stability Council (a collegiate authority for France's macroprudential policy) powers to apply macroprudential measures to these organisations (the right to impose a moratorium on early termination of life insurance contracts, and various measures to manage investment funds' liquidity). The Bank of France study assesses two channels whereby these financial organisations can generate systemic risk, i.e., a risk of mass financing withdrawal and that of 'fire sales', entailing direct or indirect contagion. Life insurance companies may encounter a surge of early contract terminations in the event of a crisis, when people seek to invest funds in risk-free assets (with those who terminate policy contracts earlier than others enjoying the greatest benefits). Investment funds also encounter this risk; moreover, they are heavily interconnected with other financial organisations via the funding channel (insurance companies and pension funds take the lead, followed by banks, with households in third place).

The study analysed a sample of France's major funds and insurance companies accounting for over 50% of total assets under management. The partial equilibrium model (Greenwood et al., 2015; Cetorelli et al., 2016) was employed to examine funds' behaviour in the event of interest rate rises, which the model regards as an initial shock. The concept of an investor's risk budget was used, showing the possible amount of losses an investor is prepared to tolerate. Heterogeneity is ensured by adding an individual stop loss limit (a minimum price triggering the sale of an asset). After the shock has happened, the investor's risk budget dwindles, hence investors want to sell a part of their portfolios. The sales are assumed to start with the most liquid assets, followed by less liquid ones, which are sold at a larger discount. Further negative repricing also hurts other investors (an indirect effect). With assumed risk budget of 34%, asset selloffs stand at about 13% of assets under management, while the second-tier effects are limited. Contagion may, however, arise in the event of a substantial yield curve shift (more than 300 bps).

As **Inro Lee** reported, the Bank of Korea is currently working on integrating the model of the macroprudential stress test for the banking sector developed in 2012 with the model of stress testing nonbanking organisations completed in June 2018. Korea's key nonbanking financial organisations include insurance and credit card companies. Inro Lee pointed out the increasing share of these institutions in the financial system and the significant degree of interconnectedness of this sector, with its regulation remaining relatively loose.

The Bank of Korea's model of stress testing nonbanking financial organisations is made up of several modules: a module for calculating operating income/loss, modules for estimating losses from credit and market risks, modules for estimating net interesting income and capital adequacy, and a risk transmission module. An individual model is constructed for each nonbanking organisation

³ Sapin II Law (Law No. 2016-1691) is the bill on transparency, the fight against corruption and the modernisation of the economy.

type, while business income (fees and commissions, insurance premiums, etc.) is estimated using regressions with macroeconomic and financial variables. Risk transmission is estimated based on the mutual positions of stress test participants (via liquidity, credit, and market risks).

Alina Kuraeva presented a scheme for assessing nonfinancial organisations' risk as illustrated by insurance companies. Insurance companies' market risk is assessed based on the z-spread approach for securities and real property repricing under a single scenario. Counterparty risk is assessed using the LGD methodology allowing for changes in ratings. Insurance risk is determined as a scenario-based worsening of an insurance business's operating results using standard Solvency II formula with simplifications.⁴ The sum of an insurance company's risk is set against its available equity, the results are included in an overall assessment of the financial group's stability; the insurance company's stability is, among other things, assessed with support from its parent financial group factored in.

As the presenter noted, the parameters of this methodology are subject to calibration as the risk-oriented approach to regulation (Solvency II principles) for Russian insurance companies is introduced and quantitative studies of the Russian insurance market are conducted.

7. Assessing feedback effects between the financial sector and the real economy

The conventional approach to stress testing provides for assessing the immediate effect of a stress scenario on the indicators of financial sector stability. For microprudential stress testing, a stress scenario implies shocks to the real economy, such as negative GDP growth and a rise in unemployment; while for commodity countries shocks are represented by a drop in commodity prices, a fall in export revenues, and weakening of national currencies. The implications for the real economy of a bank's potential problems revealed by a stress test are of course not assessed.

MST, by contrast, implies that a stress test assesses not only banks' stability but also their ability to perform their key function of lending to the economy and transforming household savings into investment. Economic growth and the pace of the economy's recovery after an initial shock in turn depend on lending and investment performance.

If the financial system is unstable, banks have to undertake deleverage – curtailing lending and restructuring bad loans, – which means they are unable to provide loans to efficient businesses and thus to help the economy's recovery. One vivid example of the impact of financial stress on economic development is provided by Japan, where the burden of restructured loans weighed down on bank

⁴ Solvency II (QIS5 Technical specification), <https://eiopa.europa.eu/publications/qis/insurance/insurance-quantitative-impact-study-5/technical-specifications>.

lending, resulting in the ‘lost decade’ of the 1990s (Danilova and Markov, 2017). Therefore, after obtaining the results of stress testing on the macro level, a second estimation should be launched to find out how the economy’s further weakening would affect the financial sector.

Assessment of feedback effects between the financial sector and the real economy was discussed in the Session 6 of the IMF – Bank of Russia workshop. In their presentation, **Stefan Schmitz** from the National Bank of Austria and **Mindaugas Leika** from the IMF noted that ignoring feedback effects could result in a substantial underestimation of systemic risk, as stress not only brings about the financial system’s direct losses (direct effect) but also produces indirect negative effects. They are divided into so called front-book and post-book effects.

The impact of financial stress on the economy materialises through front-book effects under which the worsening conditions of the financial sector’s functioning make intermediaries curtail financial services or provide them at a higher price. The post-book effects act in the opposite direction: an economic activity decline stemming from a financial intermediation squeeze worsens economic agents’ solvency, which in turn causes an additional financial sector stress.

The issue of feedback between the financial sector and the real economy is closely related to financial intermediaries’ behaviour mode and their response to stress. After the emergence of stress, financial intermediaries have to decide on their countermeasures under the given financial and regulatory constraints. The extent to which the worsening of financial sector conditions affects the real economy, and the other way round, largely depends on how most financial intermediaries deal with the problem.

One of important triggers of banks’ response to stress is changes in the cost of funding. Schmitz and Leika pointed out in their presentation that the increasing cost of funding is an essential factor of business activity revision and provided examples of how much major banks’ cost of funding rose after the 2007 – 2009 global financial crisis. The estimation from a simultaneous equations system illustrated feedback between the cost of funding and capital adequacy. As the cost of funding increases, a bank’s stability declines on the back of rising interest expenses, but the opposite relationship is also significant: a decline in financial stability sends the cost of funding higher (Basel Committee on Banking Supervision, 2015).

In choosing assumptions for the construction of optimisation models, it is important to identify financial intermediaries’ business priorities in a stress environment. The recovery of financial stability may be driven by deleverage, changes in asset risk profile, and bank recapitalisation (or a combination of the three). A Basel Committee on Banking Supervision survey has shown that, following stress testing results, most banks prefer to improve their financial

stability primarily through recapitalisation.⁵ Similar conclusions are found in the ECB reports regarding plans for restoring European banks' financial stability.⁶ That said, one should bear in mind that this option of financial stability improvement is best used under relatively favourable market conditions.

In a stress environment, the main channel of financial intermediaries' adaptation to a shock is deleverage. In the models presented, deleverage is achieved by revising lending prices and selling a part of (primarily non-core) assets. In revising banking product prices, it is important to take into account the level of pass-through of funding costs to deposit and loan rates (Harimohan et al., 2016). This largely depends on the nature of a shock (idiosyncratic or systemic), an intermediary's market power, and also its objective function in balance sheet optimisation.

Therefore, in an environment of stress and rising funding costs, financial intermediaries are to address the optimisation problem. On the one hand, a rise in expenses needs to be restrained (sources of finance need to be optimised), while on the other hand, the asset portfolio needs to be rebalanced. Several portfolio optimisation models were presented at the workshop. Meanwhile, the issue of choosing optimisation criteria remains open to discussion. In particular, models with various optimisation criteria, including Risk-adjusted Return on Capital (RAROC) and the multi-period optimisation based on Economic Value of Equity (EVE), have been developed.

One example of the deleverage optimisation model allowing for feedback effects between the financial sector and the real economy was provided by **Laura Valderrama** of the IMF. The model seeks to identify an inter-sector equilibrium under which various types of financial intermediaries interact, factoring in with their effect on macroeconomic performance. The model covers banks, with banking and trading books analysed separately, as well as nonbanking organisations – comprised in one part by borrowers receiving bank loans, and in the other part by bank traders and shareholders.

The key model components in the banking sector block include the current profit maximisation function, a balance sheet equation, and regulatory restrictions. The nonbanking sector block of the model defines a borrower's default probability functions, which rise monotonically in proportion to lending growth but decline monotonically with economic growth. The securities market appears to be in equilibrium resulting from the operations of traders, who can buy securities from banks at low prices during fire sales. Investors play the role of additional capital suppliers and buy banks' shares in proportion to their increase in return.

In addition to the financial sector, the model contains a macroeconomic block represented by the IS curve, the extended Phillips curve, the Taylor rule,

⁵ Basel Committee on Banking Supervision, 2018.

⁶ EU banks have to submit restructuring plans to authorities; the documents contain a detailed list of bank reactions to both idiosyncratic and macro-economic shocks (European Central Bank, 2018).

and interest rate parity. An illustrative numerical example shows that feedback effects are economically significant, thus aggravating the depth and length of a recession. Therefore, the incorporation of feedback effects in the model improves its accuracy and enhances its relevance to MST.

The importance of the feedback effects in estimating banking sector stability was pointed out by the Bank of Japan's **Wataru Hirata**. As mentioned above, banking sector problems resulted in a 'lost decade' for Japan, hence this aspect acquires a special importance for Japan's system of MST.

To assess the implications for economic growth of the weakening of banking sector financial stability, the Bank of Japan uses an econometric equation linking nominal GDP growth to a change in the real economy's bank debt, which also depends on the banking sector's profitability and capital adequacy. The incorporation of the feedback effect in the equation doubles the deviation of GDP growth rate from the baseline scenario. In modelling the deleverage process, banks' profitability heterogeneity needs to be factored in, as banks with low or negative profitability are the most prone to lending contraction.

8. Development of financial sector contagion analysis

The 2007 – 2009 global financial crisis revealed structural imbalances in the global financial system and lack of information about interconnection among the financial sector's participants. In this context, studies examining contagion risk, the channels of its occurrence, and implementation of measures to contain financial panic and restrain shock propagation acquire special relevance. Session 7 of the workshop was devoted to these issues.

The presentation of **Fabrizio Lopez Gallo Dey** from the Bank of Mexico examined the contagion mechanisms, their modelling methods and examples of regulatory practices. It also dwelt on solvency issues, constraints on funding sources and the role of payment systems in a stress environment.

The author noted a lack of consensus among economists regarding the concept of contagion, which King and Wadhwani (1990) regard as an increase in correlation among markets, while Kodres and Pritsker (2002) regard it as a price change in one segment in response to a situation in another segment, Hartmann et al. (2004) regard it as a rise in an overall default probability. Various contagion criteria are indicated: declaration of default (Allen and Gale, 2001; Eisenberg and Noe, 2001), a fall in profitability (Battiston et al., 2012; Tasca and Battiston, 2016), an asset price drop (Kiyotaki and Moore, 2002; Caballero and Simsek, 2013), and constraints on funding sources (Fourel et al., 2013; Acharya et Merrouche, 2013).

Fabrizio Lopez Gallo Dey presented the results of several contagion models which cover: 1) the financial sector with external shocks introduced (banks, insurance companies and brokerages, pension and investment funds); 2) the domestic market as a closed system; and 3) the banking sector. The variables

of the models included deposit and securities portfolio changes, money market operations, derivatives and repo transactions. In addition to individual losses, contagion effect modeling assumes the realisation of a macroeconomic shock with the following parameters: interest rates, exchange rates, GDP, inflation rate, and stock indexes.

To finance the liquidity deficit in a situation of limited access to the funding market, a bank may operate under the following four scenarios. A bank withdraws its short-term funds 1) from all positions in the money market on a pro rata basis (Hard, 2016), or 2) according to a certain structure of preferences with regard to counterparties. Possible alternatives include 3) withdrawing all funds from the interbank market and covering the balance through selling liquid assets, and 4) first selling liquid assets, then withdrawing funds from the interbank market.

It was emphasised that contagion effects are dangerous because they can amplify the initial shock manifold, triggering a number of further defaults. The presenter noted that confining analysis to just one round was inadequate, resulting in an underestimation of financial risks. The Bank of Mexico takes account of stress test results in developing its regulatory framework. Specifically, contagion risks in Mexico's financial system have been reduced by imposing restrictions on transactions within a group.

Lopez Gallo Dey regards clustering analysis as a promising area of research, as world practices lack an optimal algorithm of splitting a cluster into homogenous subgroups that would serve as an intermediary link between an individual bank and the banking sector. The most popular model, presented in Craig and von Peter (2014), has limited applicability. The key issue to be addressed is the criteria and assessment of the extent of interconnection, which affects the propagation of contagion in the financial sector. One of interconnection determinants is regularity and volume of cash movement between market participants via payment systems.

Cluster elements need to be grouped to forecast contagion dynamics. It is highly inhomogeneous: seizing an individual bank, contagion is to a certain extent localised within its subgroup, acquiring a cumulative nature in the event of default. The closeness centrality indicator, the betweenness centrality indicator, and the eigenvector centrality indicator are used as additional analysis instruments.

Xiaobei He from China's Tsinghua National Institute of Financial Research focused on the price channel of contagion and presented the relevant model. The price channel of contagion risks makes itself felt through the effect of asset price decline in response to asset selloffs by one or several major participants encountering liquidity risk. The asset price decline in turn affects the participants owning these assets (or assets highly price-correlated with them) in their portfolios and marking these assets to market, which produces a negative financial result and a negative effect on capital.

Modeling the impact of 'fire sales' on the market value of assets is conducted using the Cont and Schaanning (2017) model, which estimates elasticity of

an asset for sale price in relation to the market depth. According to estimates provided in the presentation, China's securities market depth is more than 130 times lower than that in the U.S. for government bonds and more than 216 times lower for corporate bonds. Due to the low liquidity of secondary markets, the model presented showed high sensitivity of asset prices even with a relatively low volume of sales. Therefore, the price channel of contagion is, based on Xiaobei He's estimate, of major significance.

Given the low liquidity of the national securities market, the model assumes successive asset sales, with the riskiest assets being the first, and the least risky ones the last, to be sold; and also selling first the most liquid and then the least liquid assets. The deleverage strategy for the trading portfolio was therefore modelled based on its impact on a bank's financial position. Fire sales start with the most liquid commercial papers, then corporate bonds are sold, and the last to be sold are the least liquid government securities. This sequence allows the fastest sale of securities at the lowest discount and with a maximum positive impact on capital adequacy.

The initial shock assumed in the model is a twofold rise in the level of non-performing construction sector loans (NPL), because it is in this sector where banks' highest credit risks are concentrated. The model's NPL level doubles from 1.04% to 2.08%, bringing about a shortfall in a minor bank's capital. In the next stage, the model estimates contagion triggered by this bank selling a part of its assets so as to recover its capital adequacy. The first round of contagion produces a capital shortfall at three banks. It is, thus, shown that even small banks can give rise to significant systemic effects that need to be taken into account in macroprudential stress testing.

The European Central Bank's **Christoffer Kok** provided a review of contagion models and the use of network analysis for macroprudential regulation purposes at the ECB. Worth noting are, among other things, models based on accounting data, those analysing direct credit exposure and allowing for the structure of investment portfolios, as well as static and dynamic models, depending on the assumed nature of network effects. Contagion models may assume fire sales, retention of liquidity by banks, and overall macroeconomic and individual shocks.

Christoffer Kok made special mention of changes in central banks' approaches to safeguarding financial stability under the influence of the global financial crisis. Prior to the crisis, regulation proceeded from the assumption that the market was self-sufficient and hence it was reasonable to limit government intervention. The key risks were attributed to fundamental factors, such as the profitability level, competitive positions, and an individual bank's capital adequacy, whereas bank runs and liquidity shortages were regarded as possible consequences rather than root causes of these. On top of that, the scale and depth of potential network effects were underestimated. The financial market, with its ongoing sophistication of the structure of instruments, had therefore largely outpaced legislation and regulation development, paving the way for the crisis.

The global financial crisis has revealed the need to develop network analysis methodologies and early response systems to localise potential risk. The assessment of the degree of interconnection among market participants and ensuring efficient intermediation have come to be treated as macroprudential policy priorities. Banking sector stress testing, taking into account contagion effects, has gained wide acceptance (Henry and Kok, 2013; European Central Bank, 2016; Dees et al., 2017). It seeks to estimate the banking sector's aggregate losses under the adverse scenarios of risk contagion among the participants. Meanwhile, methodologies currently employed across countries are, as Christoffer Kok pointed out, still in their early stage of development, and their effectiveness has yet to be explicitly evidenced in practice.

The degree of interconnection among banks varies across market segments. The absence of direct credit exposure does not mean that banks are isolated from the perspective of contagion. It is banks, insurance companies, brokerages and other firms that can act as intermediaries. An individual organisation's position in a counterparty network – i.e., the number and volume of transactions, the number of businesses in a banking group, the degree of business diversification and its geography – plays an important role. This provides a basis for identifying a group of systemically important financial institutions whose default would have serious implications for the entire market. Therefore, these institutions are subject to especially close supervision by regulatory authorities.

Analysis of financial sector structure uses, among other approaches, the theory of graphs, which enables interaction among market participants to be reflected in a standardised form. This standardisation substantially widens the array of analytical instruments available, including the measures of centrality. These instruments are used to forecast potential implications of particular regulatory measures. The findings of Halaj and Kok (2013) suggest that a reduction of the limit of interbank loan exposure from 25% to 10% of a lending bank's Tier 1 capital (Basel III) has proved highly effective in limiting contagion risk for major banks.

In Christoffer Kok's view, a major problem in analysing network effects is limited access to data and low potential for its processing. A large number of contagion channels and their interconnection call for a large variety of statistical data, ranging from general market information to financial accounting access to which is limited. On the one hand, the network analysis of the banking sector requires unified standards for the comparability of results to be ensured, while on the other hand, the specifics of individual organisations need to be taken into account. Given these requirements, banks are themselves asked to take part in stress testing and provide expert evaluation of default probabilities to the regulator.

The inconsistency of network data presents an additional difficulty. One example is provided by Covi et al. (2018), which analysed the causes of discrepancy between the Page Rank indicators, centrality with regard to its own vector and

degree. These measures provide inconsistent assessment of the interconnection structure, and researchers lack consensus on what the optimum version is.

Kok also pointed out the ambiguity of regulation aiming to limit banks' susceptibility to risk. On the one hand, a rise in credit exposure, the amount of transactions within one group, and the number of counterparties amplify contagion risk, but on the other hand, this brings about a positive synergy. Therefore, the toughening of regulatory requirements regarding, for example, the share of a maximum loan in a bank's capital may produce negative effects. The need for a balanced approach which would both secure financial stability and create conditions for economic growth is emphasised.

9. Policy issues: optimal stress test disclosure and use for assessment and evaluation of macroprudential policy

Central banks conducting macroprudential stress tests, as a rule, disclose their results in an aggregated form. Detailed information disclosure may give rise to a market panic if the test results prove to be negative. At the same time, in some countries (in the U.S. for example) this instrument is extensively used as part of supervision, and, if the stress test results are negative, banks are required to recapitalise.⁷

Dmitry Orlov from the University of Rochester presented the key findings of his paper (Orlov et al., 2018), which discusses optimal approaches to information disclosure regarding stress test results.

The disclosure of stress test results is clearly positive from the perspective of market discipline and provision of the right incentives to banks *ex ante*, also enhancing the credibility of central bank policy. If a stress test produced positive results, their disclosure is certainly worthwhile. If, however, the stress test results were negative, this may trigger a market panic and bank runs.

The author's analysis suggests that gradual information disclosure may make sense. If a bank has failed a stress test, it would be best not to release the results at first but to require the bank to recapitalise. After the bank has recapitalised, information can be disclosed.

Marco Gross from the IMF discussed the Eurace 2.0 ABM model, which the IMF constructed to look into endogenous causes of a phase change in a business cycle and to assess macroprudential policy potential to reduce the economy's output volatility. The model incorporates households, firms, banks, a central bank, and government responsible for implementing fiscal policy. The model describes markets for real property, including rental property, mortgage loans, corporate loans, and investment and final consumption goods.

The impact on the banking sector of a central bank's macroprudential policy, regarding, for example, the tightening of capital requirements, is modelled via

⁷ This is mostly relevant to supervisory rather than MST.

an increase in banks' funding costs. The model also factors in the possibility of a regulator imposing lending restrictions, for example, on loans with a small down payment. Numerical experiments show that countercyclical macroprudential policy oriented to tightening capital requirements reduces the economy's output volatility. That said, measures based on borrowers' characteristics (the debt ratio, the size of down payment) directly affect the cycle and are more effective in reducing the amplitude of business cycle fluctuations.

Also, banks' assessment of risks at a point in time, based, for example, on the current loss level, was found to be ineffective, since it fails to allow for a possible worsening of the borrower's financial position should negative macroeconomic shocks occur. This problem can be partially addressed by assessing risks under the IFRS 9, where a borrower's default probability is estimated based on a macroeconomic forecast.

10. Key takeaways from the workshop

The key findings of the workshop, including key recommendations for conducting stress testing, are as follows:

- Effective MST requires ensuring high-quality input data, sample completeness, and the use of the most relevant models. It is therefore best to choose granular data, to cover, among other things, small banks and nonbanking organisations, and to conduct backtesting of the models used. It is of major importance to work closely with financial organisations so as to test the adequacy of assumptions and results and to share experiences and practices of using risk assessment models.
- As stress scenarios are designed, they should be tested for plausibility, severity, and suggestiveness. The GaR model is an innovative method of stress scenario evaluation helping explicit assessment of these properties. In addition to modelling on historical data, stress scenarios should be designed with market expectations, expert estimates and statistical estimates taken into account. The regulator's response as part of the monetary policy rule should also be borne in mind.
- Banks have made Big Data analysis an integral part of their operations, with many of them already relying on machine learning approaches. Central banks are also beginning to use these tools in MST. At the same time, such models should be used with caution in designing macroprudential policy measures, because models on which decision-making is supposed to be based should allow both the regulator and the banking community their clear and unambiguous interpretation.
- Techniques of nonfinancial organisations' credit risk assessment continue to grow in sophistication. Most central banks are currently using simplified models, often based on just one measure of debt burden. Their further

development may move both towards a more complex analysis of bank borrowers' financial operations and towards the sophistication of models identifying corporate borrowers' default probability.

- The assessment of feedback effects between the financial sector and the real economy has become part and parcel of MST. Ignoring the feedback effects may result in a significant underestimation of systemic risk. The workshop discussed a number of approaches to feedback modelling, including the model of post-stress business optimisation. The choice of optimisation criteria, however, remains open to discussion. In particular, models have been developed using the risk-adjusted current return-on-capital (RAROC) and economic value of equity (EVE) measures as optimisation criteria.
- Modelling contagion effects is a relatively new area of systemic risk assessment. It requires highly granular data, which is often hard to obtain, and facilities for their processing. Contagion is dangerous in that it can amplify the initial shock manifold, triggering systemic risk. The difficulty of contagion analysis stems from the variety of channels through which it is realised: the channel of access to liquidity, those of asset prices and counteragent default, etc. Contagion effects are not always assessed as part of stress testing, special models are used to assess them, including network analysis methods.
- The disclosure of MST results requires a cautious and balanced approach. The transparency of results improves risk assessment by the participants and market discipline, but may trigger further market volatility. It is best to ration information disclosure (in terms of content and time) so as to prevent stigma effects and other negative implications of disclosing stress testing results.

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