InSTA – integrated stress-testing approach at NBP.
The past, present and future perspectives

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Abstract

Stress testing is one of the fastest growing fields in the prudential world. It has recently gained importance as a tool for both microprudential and macroprudential purposes. In recent years Narodowy Bank Polski (NBP) has been developing an integrated stress-testing approach (InSTA), which captures the various sources of risk to solvency and liquidity as well as spillover effects that banks operating in Poland may face. The aim of this article it to present and discuss NBP's approach to conducting macro stress tests. We also point out the main areas where further analytical work should be focused on.

Keywords: stress-tests, financial stability, systemic risk, macroprudential policy
JEL classification: E47, E44, E58, G21

1. Introduction

The recent financial crisis highlighted the importance for economic activity of having fundamentally sound banks capable of withstanding unexpected and extreme shocks to their balance sheets and able to generate sufficient income even in times of distress. In fact, banks resilient to stress and able to act as stable and efficient financial intermediaries over the economic cycle are an essential condition for ensuring a smooth flow of credit to the real economy also in periods of economic instability. With the aim of ensuring a well-functioning financial system capable of supporting economic growth, macro stress-tests are often used to evaluate (in a forward-looking manner) the resilience of the banking sector to adverse macroeconomic and financial developments (ECB, 2017).

Stress testing is an important tool for analysing and evaluating risks to the financial system. The models employed to conduct these tests are constantly evolving in order to include more realistic features. The 2007-2009 global financial crisis (GFC) demonstrated that, in addition to solvency risk, market risk, liquidity risk and network spillover effects associated with interconnections among banks can generate losses for banks during times of stress. The most sophisticated variety of macroprudential stress tests (MaPST) try to capture all the significant risks in a simultaneous, integrated and interdependent manner (see Borio, 2012; McNeil et al., 2015; ECB 2017, ECB, 2019).

Stress testing capabilities have been subject to rapid evaluation across the global banking industry over the last several years. Both financial institutions and authorities have noted the need to continually improve capabilities, refine methodologies and deepen the use of stress tests in the financial stability assessment. Not surprisingly, in the recent years Narodowy Bank Polski (NBP) has been developing an integrated stress-testing approach (InSTA) which captures the various sources of risk that commercial banks operating in Poland face, as well as endogenous contagion through the so-called domino effect.

Despite its relatively fast pace of development, the current stress-testing framework is not without limitations and there are a number of areas across which further enhancements could improve its ability to assess the resilience of banks to negative shocks. Areas that need further improvement include testing banks against a wider range of interrelated resilience metrics (e.g. liquidity–solvency nexus), further exploring how shocks might be transmitted across the financial system (e.g. through contagion) and incorporating dynamic dimension (e.g. by introducing a dynamic balance sheet) as well as second-round effects that that take into account the two-way interaction between banks and the real economy.

This article has three main purposes. First, it describes the different methodologies employed by various authorities to stress-testing. Second, it describes the NBP approach to conducting macro stress tests of the Polish banking sector with particular emphasis on the scenario development framework and NBP satellite models. Third, it shows possible paths of development of current methodology.

The rest of the paper is structured as follows. In the second section we briefly review the existing stress testing approaches used by different authorities (the review includes both micro- and macroprudential stress tests). In the third section we present the main building blocks of NBP stress test methodology with the scenario development process and description of satellite models. In the last section we conclude and point out key areas for future development.

2. Literature review on existing stress testing approaches

Large banks have been running stress tests to understand how their balance sheet would behave in the face of a severe shock since the 1990s (Haben and Quagliariello, 2015). The philosophy behind this approach is borrowed from engineering. It is a legal requirement in chemical, nuclear or aerospace industries. The consequences of errors in stress testing in engineering are much more serious (often the life of people is at stake), but the variables are much more predictable as they include physical processes instead of human behaviour. However, both for finance and engineering the goals of stress testing remain the same: identify vulnerabilities and assess the resilience of the analysed system to the shock.

Stress tests can be conducted by three types of institutions: firms, supervisors and macroprudential authorities (Haben and Quagliariello, 2015). Firms conduct their own stress tests to analyse the risks included in their activities in order to measure, manage and control it. The goal of the supervisors is to gain bank-by-bank information on risk and vulnerabilities. As a result, supervisors may oblige particular banks to take necessary actions (raise capital, increase liquidity). The two mentioned perspectives are concentrated on the individual bank's level and do not take into account interactions within the financial system and feedback effects from the real economy. The macroprudential approach tries to test the resilience of the whole financial system to the negative events by taking into account not only individual firms' conditions but also the interdependencies between them and between the financial sector and the rest of the economy. Stress testing can be also helpful in evaluating the perspectives of the financial system and contribute to the calibration of macroprudential measures. Most of the tests that would be mentioned in this chapter are of a hybrid type, which means that they serve both microprudential supervisors and macroprudential authorities.

Stress tests can be also divided into crisis stress tests with predominant pass/fail thresholds and those aimed at assessing potential vulnerabilities (supervisory). Crisis stress tests are often used by authorities to regain market confidence in the banking system during financial turmoil and their results are often disclosed. In the US and in Europe there is a tendency to evolve from crisis stress testing (SCAP or EU-wide stress tests in 2010) to supervisory exercises (2018 EU-wide stress test).

There is also a more classical division (IMF, 2012): into top-down and bottom-up stress tests. In the bottom-up exercise the authority only defines scenarios and asks the financial intermediaries to use their own models to assess the impact on their balance sheets. The results are evaluated and usually compared against the benchmark. The top-down approach assumes

that authorities feed their own models with data provided by firms. Bottom-up tests were used to produce more accurate results as authorities lacked access to granular data. This is no longer the case and authorities in most advanced economies can use very detailed data to evaluate financial standing of banks. Still, intermediates seem to have a better knowledge of their internal situation, but on the other hand are tempted to manipulate the results.

Financial sector stress tests are conducted to gain information on the stability of financial infrastructure under exceptional but plausible economic conditions. Their results can also be used in the decision-making process of macroprudential policies that are designed to strengthen the system and make it less vulnerable. The value added of systemic stress testing derives from assessing not only the individual resilience of firms, but also the effect of interconnectivity within the sector and possible interactions and amplifications with the real economy. Therefore, financial system stress testing can be perceived as complementary to individual stress testing, providing a benchmark for their result.

The first international stress testing programme was introduced by the IMF in the form of the Financial Sector Assessment Program (FSAP). Stress testing is also one of the key elements of the Basel II and III framework, including in particular the IRB-cyclicality stress test and the Internal Capital Adequacy and Assessment Process (ICAAP). BCBS also published stress testing principles in May 2009, which were designed to address the key weaknesses in stress testing practices that were highlighted by the global financial crisis (BCBC, 2009). Given the rapid evolution of stress testing in recent years, the Committee undertook a detailed review of current supervisory and bank practices in 2017 (BCBC, 2017).

In recent years, there has been significant advancement and evolution in stress testing methodologies and infrastructure at both banks and authorities. Supervisory authorities and central banks continue to devote more resources to enhance the stress testing of regulated and unregulated institutions, with most supervisory stress testing exercises being carried out on at least an annual basis. This is resulting in significant progress in how the exercises are performed and how they are incorporated into the banking supervision process (BCBS, 2017).

At the moment, stress tests are increasingly used to calibrate macroprudential measures and supervisory policy changes. Other macroprudential uses are early warning exercises to identify potential weaknesses of the system and enhance crisis management plans (BCBS, 2017). Macroprudential stress tests are increasing in importance as a way of evaluating the financial resilience of banking systems, as they can allow for a more direct assessment of feedback loops, amplification mechanisms and spillovers. These important effects are most frequently assessed via top down approaches.

Although new models and frameworks are produced and there is no consensus on a universal set of rules that should be applied to all stress testing exercises, the majority of stress-tests are built on five interrelated stages: (i) development of severe but plausible economic scenario, (ii) translation of macroeconomic scenario into microeconomic consequences for financial institutions' balance sheets, (iii) assessing the behaviour of the financial institution under stress (including second-round and contagion effects), (iv) decision on financial resilience criteria, (v) communication of results. In this chapter we will briefly review three stress testing approaches employed by the European Banking Authority (EBA), European Central Bank (ECB) and Bank of England (BoE). The NBP approach is discussed in detail in chapter 3.

2.1.   EBA

In the EU the first bottom up stress tests undertaken in a coordinated fashion started in 2009 under the aegis of the Committee of European Banking Supervisors (CEBS) (Haben and Quagliariello, 2015). In 2011 they were replaced by the exercise coordinated by the newly established European Banking Authority. Before that stress tests were carried out on a national level. Taking into account that the European financial system consists of many multinational banking groups operating in the whole of the EU, one coordinated stress testing exercise can better capture the complexity and loss absorbing capacities of the system.

The preparation of a scenario always involves a trade-off between severity and consistency. It is hard to produce a severe enough scenario that would be at the same time internally consistent, especially in the area that consists of 28 different countries with different economic situations and regulatory frameworks. Finally, it was decided to accept a little loss in consistency by allowing a country specific idiosyncratic shock to appear. Currently, the scenario for the test is prepared by the ESRB with the help of the ECB.

The EU-wide stress test covers a wide range of banking groups. Since the main banks included have subsidiaries in EU countries, it was decided that these subsidiaries won't be included as their exposures are already covered at the consolidated level. EU-wide stress tests are solvency tests designed to capture credit, market and funding risk as well as conduct risk and other operational risk. It is not dealing with liquidity risk given its time horizon, the static

balance sheet assumption and the detailed disclosure of bank-by-bank results.[1] The lack of inclusion of liquidity risk and static balance sheet assumption are one of the most often cited weaknesses of the EU-wide stress tests (Bruno and Carletti, 2018). In comparison, the IMF, which also conducts stress tests to assess the resilience of the euro area banking system, employed a two-pronged approach involving both liquidity and solvency testing (IMF, 2018).

The EBA stress tests can be qualified as hybrid between top-down and bottom-up. They are called constrained bottom-up because they rely on banks' internal models, but banks' modelling solutions are constrained by methodology and a series of ceilings and floors for some variables. The balance sheet is assumed to be static, which means that banks are not allowed to take any action mitigating the stress arising from the adverse scenario. This may seem to result from lack of resources for the quality assurance and for assessing the credibility of the management actions. On the other hand, it can also be considered an intentional choice as it leads to greater comparability of results between banks. The goal of the exercise is to see what would happen if the shock hit at the cut-off date, holding everything else constant. It will not provide the best forecast of banking sector behaviour under certain circumstances, but rather project what would happen if, in today's state of affairs, the adverse macroeconomic scenario materialised.

In 2016, the EBA moved away from the capital thresholds (the pass/fail setting). Compared to the crisis of 2008-2009, this was a time when solvency ratios had improved and it was no longer deemed necessary to concentrate on whether or not banks needed immediate recapitalisation.

Instead, the EU-wide EBA stress test results contribute to the overall Supervisory Review and Evaluation Process (SREP)[2] and consist of a Pillar 2 Requirement (P2R) and Pillar 2 Guidance (P2G). At the same time, they still help market participants understand the sensitivity of banks to hypothetical adverse market developments and to gauge the possible depletion of capital under such scenarios.

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[1] Art. 100 CRDIV requires that competent authorities (CAs) conduct at least annual supervisory stress tests on the supervised institutions as an input to the SREP. EU-wide stress-tests are conducted biennially. In between, the ECB conducts stress tests focused on topical issues. For the first time, the ECB conducted the Sensitivity analysis of IRRBB in 2017. In 2019 it took the form of a sensitivity analysis of idiosyncratic liquidity risk (see: https://www.bankingsupervision.europa.eu/press/pr/date/2019/html/ssm.pr190206_presentation.en.pdf).

[2] The possible mitigating managerial actions are considered as part of the SREP.

In 2018 the stress test exercise inherited all the key aspects of the former exercise as well as the overall methodological framework, with a major update due to the revision of the accounting standards in Europe. The 2020 exercise will assess the resilience of EU banks to an adverse economic shock and inform the 2020 SREP. The methodology covers all risk areas and builds on the methodology prepared for the 2018 exercise, while improving some aspects based on the lessons learnt and banks' feedback (see Enria, 2018; ECA 2019).

While for 2020 EBA decided to stick to the traditional "constrained bottom-up" approach, it has also started an overall reflection on the need for potential fundamental changes to the EU-wide stress test framework. Two possible development paths have been outlined. One approach would be to stick with a current micro-prudential framework and to make it more relevant, comparable, transparent and less costly. The corner solutions would be moving to a fully top-down procedure conducted by the supervisor or allowing an unconstrained bank's bottom-up approach that would be quality assured by the supervisor. While all of the possible solutions have certain strengths and weaknesses, it should be recognised that the success criteria can be satisfied allowing for two components in the stress test: one under the supervisors' control, possibly leveraging on the current approach, and the other one allowing more flexibility for banks (see Campa, 2019).

2.2. ECB

In the euro area top-down solutions are also employed to measure the resilience of the entire financial system against severe yet plausible adverse scenarios (Henry and Kok, 2013). Here the focus is more on the macroprudential oversight and policies. These exercises are conducted entirely at the ECB without the participation of banks in the estimation processes and their main purpose is to provide a tool for regular systemic risk assessments as part of the regular macroprudential oversight process at the national and supranational dimension. The obvious drawback of this approach is the data access and data granularity, which cannot be as satisfactory as in bottom-up approaches. Top-down models can play an important role as a benchmark for bottom-up exercises described in the previous chapter. The top-down approach also allows for inclusion of spill-over within the banking sector and possible contagion effects between banks and other financial institutions. A renewed approach of the ECB to macroprudential stress testing (STAMPE) was presented in 2017 (ECB, 2017) and includes several new extensions with regard to the earlier framework (Henry and Kok, 2013).

The "first pillar" in the ECB stress testing framework is the macro-financial scenario design model. At the beginning the identification of systemic risk is derived from financial stability surveillance exercises, which are conducted regularly and contains systemic risk indicators and early warning models. Next, those risks are mapped to the macroeconomic scenarios. This process takes into account both the severity (need to hit banks hard enough) and probability of scenarios (should reflect a material risk). This probability is reflected in material terms. The design process includes various scenario building blocks. Each individual risk identified is used for calibration of an exogenous shock that is treated as input for models generating the scenario. Various types of models are used to cover different types of risk. The ECB does not rely on one particular model, but instead uses a specific model to capture specific risk. The initial shock can be calibrated ad-hoc, based on historical distributions (like VaR) or reflect residuals of simple dynamic models. The second approach is particularly useful for financial shocks. Financial variables are often strongly interrelated and many of them are required for scenario building models, therefore it is better to use non-parametric approaches like copulas.

To come up with macroeconomic shock, the so-called Stress Test Elasticity model is used (STE's). It combines national central banks forecasting models for MPC into an EU-wide simulation tool. The external environment scenarios are based on the NiGEM model, which is a large-scale multi-country macroeconomic model with global reach. To account for international spillover effects, an additional GVAR model is used. The output of the employed models are paths of macroeconomic and financial variables (contingent on the initial exogenous shocks imposed).

This output is further used by satellite top-down models to access its impact on various forms of risks on PD and LGD. The ECB typically employs the Bayesian Model Averaging technique to access PD, while LGD are either estimated using directly the value of collateral or calibrated using expert judgment. The methodology used for interest rates is similar to the credit one and includes a search for the best combination of models using the Bayesian Model Averaging approach (Gross and Población, 2015). The estimation of banks' fees and commissions depends on a dynamic panel approach (Kok et al., 2017). Some items are limited with caps and floors to ensure their consistency with baseline and adverse scenario.

Different econometric techniques are employed to estimate counterparty risk, credit valuation adjustment losses and market liquidity reserve losses, while held-for-trading losses are accessed using finance theory due to the lack of data. The market risk module captures the profit and loss impact of the investment portfolio of the participating institutions. Shocks

generated in the market-risk models are translated into performance of specific portfolios in the given horizon. Operational risk estimations are based on the loss distribution approach. Finally, other income components are added to the results of the previous modules. The impact of those other components is often derived using a simplified approach.

The next step is to calculate the individual bank's solvency position based on the result of satellite models and granular data on the bank's balance sheet. The simulation always starts with balance sheet levels at the stress test cut-off date. Over the stress testing horizon, exogenous paths resulting from the satellite models are applied. Solvency ratios are calculated at the end of the forecasting horizon using existing capital stock, earnings accumulated over the stress test period and risk-weighted assets.

As a result of stress, banks may decide to adjust their balance sheet, which may in turn affect the real economy and other banks. Failure of some banks, or even the deterioration of their financial situation under the stress scenario, may result in contagion effects that can spread thorough the financial system, either by direct links or indirectly through the confidence effect or deposit insurance system. Adjustment of the credit policy may affect the real economy and amplify the effects of the original adverse macroeconomic scenario. The ECB uses the Dynamic Stochastic General Equilibrium Model (DSGE) and Global VAR (GVAR) approach to account for that.

The ECB uses network analysis to account for financial contagion effects. It is assumed that banks that "failed" the stress test won't be able to fulfil their obligation on the interbank market, triggering a cascade of defaults in the system. Still, there are problems with obtaining a sufficient amount of data on banks' mutual obligations. STAMPE also includes a contagion with other banks module (including fire sales). Additionally, cross-sectional spillover via flow-of-funds are accounted for.

The results contribute to policy-related reports in a variety of ways. Capital shortfalls given a minimum threshold for the solvency ratio can be calculated to assess the capital needs of individual banks and the banking sector. Capital depletion under unfavourable external conditions can be compared across scenarios, which helps rank risks in terms of their potential impact. They can be aggregated across risks and reviewed over time to evaluate banks' resilience to the whole spectrum of prevailing risks. Stress-testing infrastructure can also be used to produce bank-level and banking sector projections which can help analyse, for example, the medium-term prospects for profitability and its drivers or policy moves that result in yield curve shift or prudential measures (Constâncio et al. 2019).

2.3.   BoE

The Bank of England (BoE) stress testing approach was developed as a result of the Financial Policy Committee (FPC) decision of March 2013 (BoE, 2015). It was developed to examine the potential impact of adverse shock to both the UK and global economy. BoE is currently running two types of stress-tests.

First, there is a concurrent stress that is run annually and is explicitly countercyclical, with the severity of the test varying systematically with the state of the financial cycle. This scenario may be most severe during a period when credit and assets prices are growing, and risk premia are compressed. The results of this scenario are used to set the countercyclical buffers by the FPC. The second type of stress test is run every second year and is based on a scenario that explores the wider range of risks that might threaten financial stability. This scenario will reflect emerging or latent threats to the financial stability. The banks for which the scenario may be less relevant may not be asked to participate.

For both scenarios, stress-test projections are prepared using a range of models and analysis. With respect to loss evaluation at a stress scenario, the BoE uses a dynamic balance sheet model. This means that bank reactions and asset repricing are taken into account in the modelling and evaluation of losses. This can be seen as an explicit account of second round effects of the stress scenario impact. The process of loss evaluation uses both bottom-up evaluations of banks as well as top down evaluations of banks and authorities. Specifically, in BoE's stress-testing exercise banks are asked to model the impact of stress scenarios themselves. The modelling performed by the BoE's staff acts as an important cross-check on banks' own projections. Currently BoE is working on the development of its capability to model system-wide dynamics, including amplification mechanisms and spillovers.

3. NBP stress testing framework

3.1.   Key aspects and assumptions

Macro stress tests are one of the elements of the analysis of the resilience of the banking sector conducted at NBP. Twice a year NBP conducts a macro stress test and publishes the results in its semi-annual financial stability reports. The exercise can be described as top-down balance-sheet based, forward looking assessment of the vulnerability of the domestic banking sector to unfavourable changes of external conditions.

The projected financial position of the banking sector is examined conditional on two scenarios which usually span over a three-year horizon: a reference scenario and a shock scenario. The central path of the NBP macroeconomic projection from the *Inflation Report*, prepared under the assumption of constant interest rates, serves as the reference scenario. The adverse scenario is designed on the basis of the main systemic risks to the banking sector identified as pertinent, at a specific juncture. This set of risks is mapped into exogenous shocks. The calibrated shock profiles are the input to dynamic macroeconometric models used to project macroeconomic and financial variables which constitute the scenario output.

The aim of the shock scenario is to quantify the effects of hypothetical shocks on domestic commercial banks. The NBP stress test is primarily focused on the assessment of the impact of credit risk on the solvency of banks. Notwithstanding this fact, it also covers other types of risks that are significant in the Polish banking sector, in particular market risk and liquidity risk.

In addition, depending on the needs, several sensitivity checks designed to evaluate the loss absorption capacity of banks against isolated credit and market risk events are run. In a nutshell, the analysis is performed as a four-stage exercise:

- In the first stage, the impact of the two macroeconomic scenarios (reference and shock) on the materialisation of credit risk and net interest income (NIM) in banks' balance sheets is examined,
- In the second stage, only in the case of the adverse scenario, the analysis of macroeconomic shock supplemented by an additional negative market shock on the capital positions of banks is performed,
- In the third stage, the impact of the market shock on the liquidity position of banks is analysed,

- In the fourth stage, the impact of a potential bankruptcy of a bank in the two macroeconomic scenarios on the standing of other banks is simulated (the so-called domino effect).

The sample of banks that is being stressed consists of all the commercial banks operating on the market covering approx. 85% of the banking sector in Poland. Stress tests are run at individual levels. Data on standalone entities (unconsolidated) is mostly acquired from FINREP and COREP reporting templates. NBP stress tests do not cover cooperative banks, which account for about 10% of total assets of the banking sector. However, two association leader banks are included in the sample due to their systemic importance for more than 500 local cooperative banks operating in Poland. Thus, the coverage of the stress-testing exercise captures a representable sample of the Polish banking sector, while keeping the number of participants involved at a level that allows further bank-by-bank analysis.

The composition of the balance sheet of the banks is assumed quasi-static during the stress test. This means that the composition of the balance sheet of the banks does not change throughout the whole 3-year horizon. Assets and liabilities that mature within the time horizon of the exercise are replaced with assets with similar features. However, there are some exceptions from the static balance sheet approach. Firstly, it is assumed that banks that comply with the required capital ratios and the combined capital buffer requirement would increase their loans, securities portfolios and other assets at a rate not higher than the quarterly growth of the nominal GDP (if positive). Additionally, growth rates for individual banks are dependent on the level of capital surplus above capital adequacy thresholds. Banks with only a slight surplus over Pillar I and II requirements have to restrict their lending activities. Secondly, in the adverse scenario, the market shock in the form of zloty depreciation and the increase of government bond yields impact the value of FX loans and government bonds, respectively.

The RWA weights are kept fixed during the stress horizon. This simplification results from the fact that most of the commercial banks in Poland use the standardised approach for credit risk (STA) that is rather insensitive to the changing risk profile of assets. At the end of December 2018, only 4 banks in Poland used the internal ratings-based approach (IRB) to determine the risk-weighted assets for certain classes of exposures.

Banks are permitted to distribute dividends to their shareholders from profits earned over the projection horizon. However, the dividend rate depends on the banks' compliance with

the guidelines on the dividend policy of banks set by the Polish Financial Supervision Authority (PFSA).[3]

Capital requirements in the NBP stress tests are defined under the assumptions that all analysed banks must maintain regulatory capital at a level compliant with the minimum capital adequacy ratios. Subsequently, amounts of capital necessary to fulfil the combined buffer requirement are presented (Figure 1).[4] The second threshold is motivated by the fact that compliance with minimum standards does not provide the bank with continued access to market funding at a reasonable cost. The GFC clearly showed that during a severe economic downturn the market can cut off the sources of funding if it believes that a bank does not have sufficient own capital to withstand losses.

Figure 1. NBP capital thresholds in NBP macro stress tests
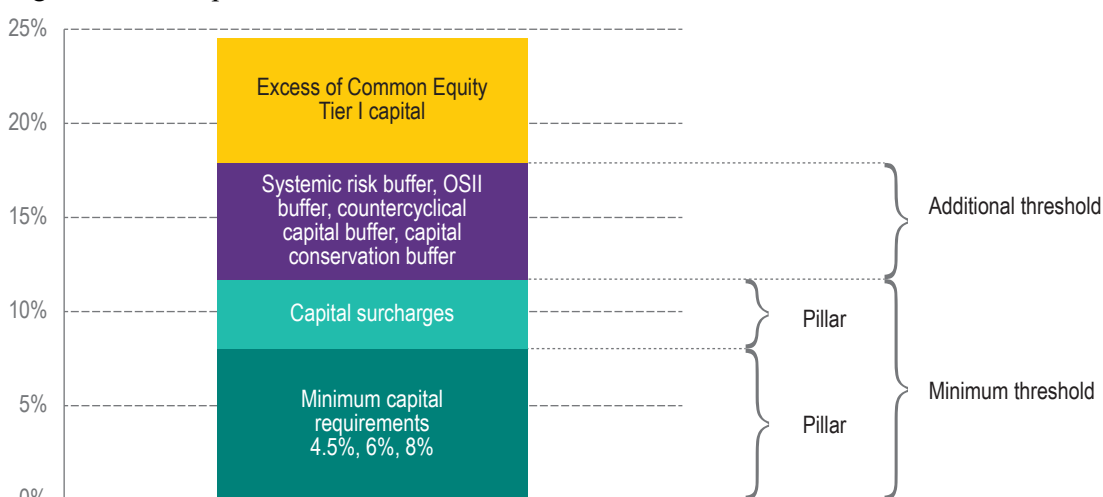
Source: NBP.

Thus, the outcome of the exercise is a list of identified banks with a probable capital shortfall in relation to pre-determined hurdle rates. In addition, the decomposition of the decline in the capital adequacy ratio enables to distinguish, measure and evaluate different factors affecting changes in the capital ratios over the simulation as a percentage of risk-weighted assets. This contributes to a better understanding of the various determinants of risk for banks and the channels through which shocks would propagate.

The results of stress tests can be used in a number of ways. In general, all stress tests are tools for measuring and managing the risks banks face on a forward-looking basis. The results,

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[3] See: "KNF position of 14 March 2018 on the dividend policy of banks in a medium-term perspective".
[4] More about capital thresholds used in the NBP stress test may be read in Box 4 of "Financial Stability Report. June 2017".

on the one hand, give a quantitative assessment of the scale of risks faced by banks and on the other hand, are an input to the policy decisions. From a microprudential standpoint, how banks' capital positions evolve under stress relative to specified hurdle rates is one important yardstick to judge whether individual banks are adequately capitalised, and how they might adjust their capital plans. From a macroprudential perspective, the results should inform policy-makers about the evolution of the system as a whole, including, for example, credit dynamics, and the strength of the potential contagion effects. The results can also be used to help macroprudential authorities judge the possible and appropriate macroprudential measures, such as the level of system-wide bank capital buffers (BoE, 2016).

3.2.   Adverse scenario development

Scenario design is a critical aspect of supervisory stress tests, reflected in the considerable attention paid to the scenarios and their severity when authorities publish their stress testing results. According to BCBS (2017), the number of scenarios included in supervisory stress testing exercises varies considerably across jurisdictions. The scenario narrative is seen as a useful device through which authorities can communicate the risks that they are exploring through the scenario and help banks to generate additional variables that are not specified in the scenario. The typical time horizon used by supervisors for a stress test scenario is two to three years. A small minority use a four to five-year test horizon. For supervisor-run stress tests, the majority of authorities use data at the portfolio level, drawing on the supervisory reporting system.

Stress test scenarios are typically produced using three kinds of approaches: i) structural econometric model, ii) vector autoregressive methods and iii) pure statistical approaches (Foglia, 2009). Some central banks employ structural econometric models, using a set of initial shocks on exogenous variables to produce coherent macroeconomic scenario that includes a wide range of macroeconomic variables. The main concern about this approach is the inability of linear models to capture the non-linear relationships between macroeconomic variables that may arise at times of stress. The second possibly is vector autoregression (VAR) or vector error correction models (VECM). The main advantages of this approach are flexibility and simplicity, but it is very limited in the scope of variables it can produce. Autoregressive models are used in the United Kingdom (BoE), Japan (BoJ), Spain (BoS), the Netherlands (DNB) and at the ECB. The pure statistical model, without economic assumptions, can also be used to produce an adverse economic scenario. The Oesteriechische

Nationalbank (OeNB) models macroeconomic and financial variables through a multivariate t-copula. (Foglia, 2009). The most obvious advantage of the last approach is that the co-dependence between micro-financial variables may display tail dependence, which would be very hard to capture using structural or autoregressive models. It is especially important as correlations between macro-financial variables seem to explode at times of stress.

In the case of NBP, in order to produce a coherent scenario, with wide enough selection of macro-financial variables a structural model NECMOD is employed (Budnik et al. 2009). Ideally the stress test scenario should reflect the balance between severity and plausibility. In our framework this is achieved using a trigger that is based on historical experience and calibrated according to the composition of the forecast pool and expert knowledge. This trigger is used afterwards as an input to the macroeconomic model NECMOD, which produces the coherent economic adverse scenario. The scenario development framework is presented in Figure 2.

First, we are trying to find the worst historical outcome for all the "external world" exogenous variables that NECMOD is using. The quarter with the biggest downside deviation from the trend is identified using a HP filter. This shock is assumed to repeat in the future with arbitrary distribution among future quarters. The asymmetry of the forecasts pool taken from Reuters is used to correct the growth paths for too pessimistic or too optimistic outliers. Finally, NECMOD is fed with stressed variables in order to generate adverse scenario for all important domestic variables.

Figure 2. Scenario development framework at NBP
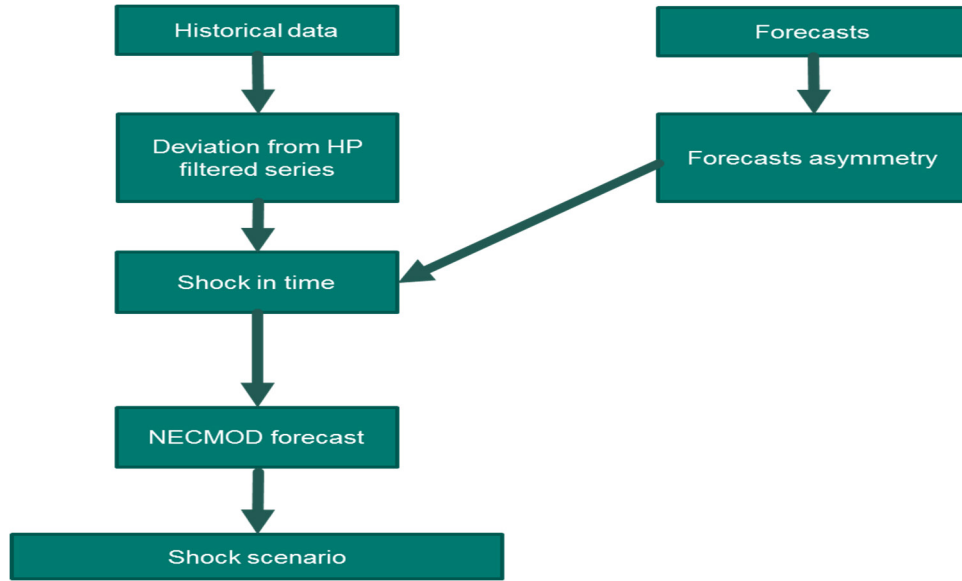
Source: NBP.

Historical shock

According to Henry and Kok (2013), the first step in creating a scenario is mapping identified risk to financial institutions into adverse macroeconomic scenarios. We assumed that those risks in the Polish case are rapid deterioration of macroeconomic conditions, exchange rate depreciation and credit premium increase. As Poland has a rather small and open economy its growth fluctuations are strongly correlated with the behaviour of its main trade partners. The shock is therefore supposed to come from global slowdown in economic activity.

The deterioration of growth of four major Polish trade partners: Germany, EU (except Germany), the UK and the US is assumed. Prices of most important commodities (oil and gas) also form part of the shock scenario. To capture the size of the most severe depression in the post-war period, GDP of those countries and commodities prices were filtered using a HP filter in line with the equation below (Hodrick and Prescott, 2007):

$$\min_{\tau} \left(\sum_{t=1}^{T}(y_t - \tau_t)^2 + \lambda \sum_{t=2}^{T-1}[(\tau_{t+1} - \tau_t) - (\tau_t - \tau_{t-1})]^2 \right) \quad (1)$$

where $\lambda = 1600$.

The use of a HP filter allows to capture the deviations of economic activity from its long-term trend (Skrzypczyński, 2010). We are interested in finding the biggest depression in the analysed period. To do that we find the biggest deviation from trend on the downside for each time series in relative terms, assuming that it captures all kinds of cycles in economic activity. These deviations will be further used to determine the size of the shock in comparison to basic forecasts. We assume that the strongest historical slowdown will happen in the first quarters of the stress period. The results are presented in Figure 3. Figure 3 shows that the biggest slowdown in the period taken into account happened for all analysed time series round 2008-2009, which is the time of the global economic crisis. This seems to reflect economic intuition.

Figure 3. The most severe economic slowdown for selected series
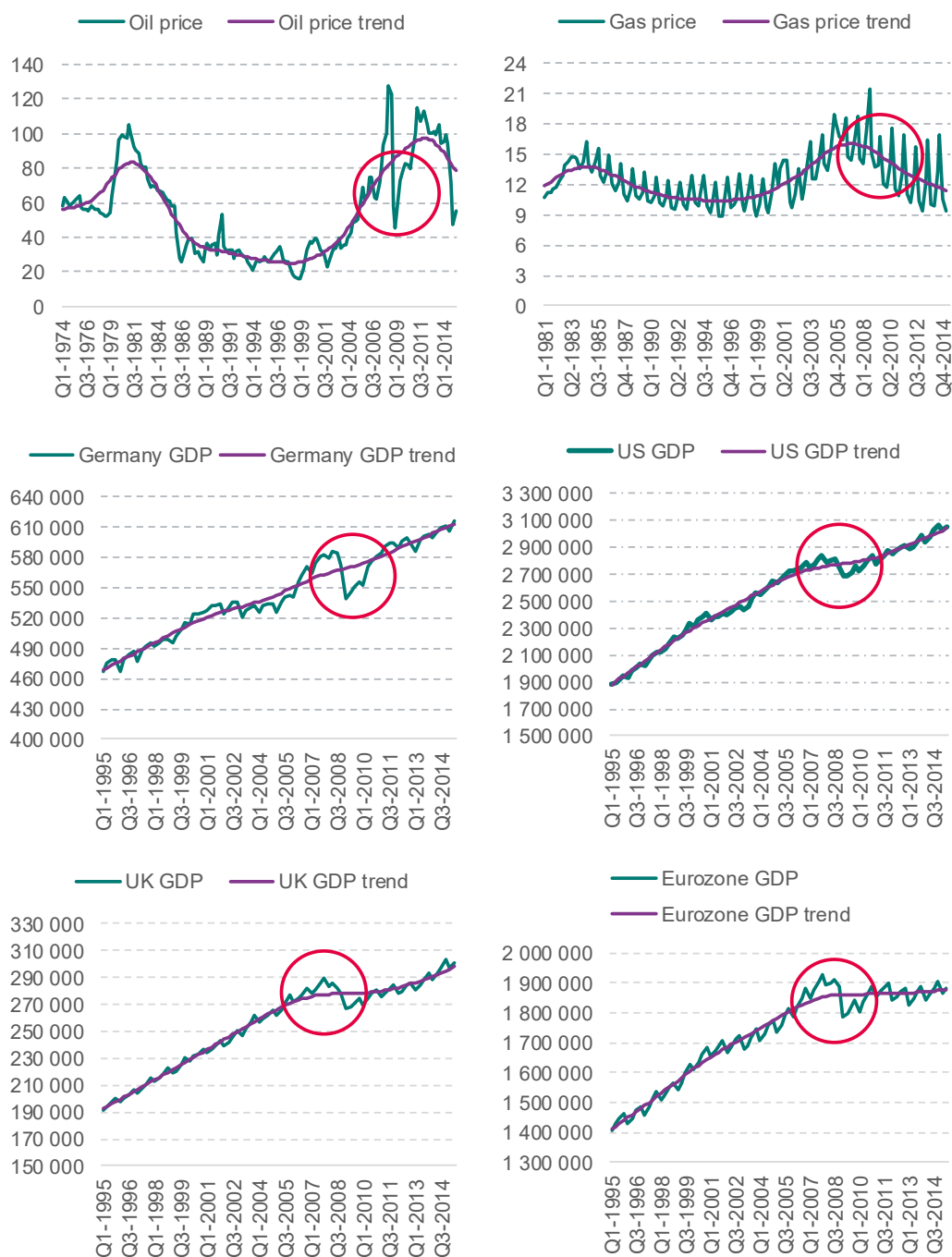
Source: OECD, NBP calculations.

Asymmetry

The paths of external GDP and commodities prices are put into NECMOD three times a year to produce a forecast for the MPC. As the result is produced using a pool of external economy forecasts, it reflects the central tendency of market forecasts, which can be influenced by overoptimistic or overpessimistic forecasters. As this basic path is afterwards used to produce the shocked path of external variables, we need to correct for the asymmetry of forecasts. The other reason is that significant asymmetry in forecasts may reflect growing uncertainty among forecasters and that needs to be reflected in the shock size. The asymmetry of forecast is calculated in line with the equation below:

$$A = \frac{n}{(n-1)(n-2)} \Sigma \left(\frac{x_i - \bar{x}}{s}\right)^3 \quad (2)$$

As *A* may be infinitely big and we would like to limit the scope of its influence on the final shock, it is further converted into:

$$\beta = arctg(A) \cdot \frac{2}{\pi} \cdot 0,2 + 1 \quad (3)$$

That leads to the correction factor *β*, which varies between 0.8 and 1.2. Its values are between 0.8 and 1 when there are more forecasts above the average and between 1 and 1.2 otherwise. It will be later used as a multiplier that corrects the shock size if the current basic path is influenced by relatively few negative forecasts (*β* from 0.8 to 1) or positive ones (*β* from 1 to 1.2).

Final shock

Finally, the assumptions for an adverse scenario for every quarter of stress testing exercise is derived using:

$$S_t = X \cdot \beta_t \cdot \gamma_t \quad (4)$$

Where S_t is a deviation from basic path, X is shock obtained from historical data (constant in t) and β_t is an asymmetry correction factor from 1.2. and γ_t is a shock distribution factor.

The last element of the equation is set arbitrarily, taking into account the time distributions of historical slowdowns and expert knowledge. The recent distribution of γ_t is as follows:

Table 1. Shock distribution factor

T+	1	2	3	4	5	6	7	8	9	10
γ_t	0.6	0.65	0.7	0.65	0.6	0.55	0.5	0.45	0.4	0.35

S_t is multiplied by the basic path creating shocks that are put into the NECMOD model to produce an adverse scenario for the Polish economy. Figure 4 illustrates the result.

Figure 4. Stressed GDP and CPI compared to fancharts
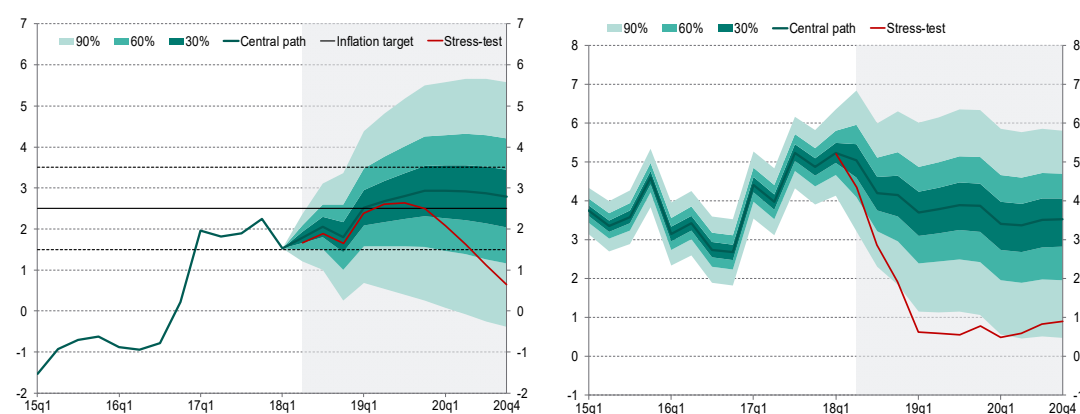
Source: NBP.

In line with intuition, we could observe downturn deviations from the central path for both inflation and growth. The growth path exceeds the 90% probability range while the inflation path enters it at the end of the forecasting horizon. That confirms that we came up with a severe but plausible economic scenario.

Further work should be done to include in the stress scenario the effects of materialisation of risks that come from within the domestic economy as opposed to risks that are purely exogenous. Another challenge is to broaden the scope of variables for which baseline and stress test paths are generated. Under the current methodology this set of variables is limited to the ones included in the NECMOD model. An alternative method for the construction of the adverse scenario, which would circumvent some limitations of NECMOD, could be based on historical crisis episodes in a chosen group of countries. Another alternative would be to exploit statistical relationships between variables of interest and generate observations from

the tails of multivariate distributions. Both approaches would have to be based on the experience of other countries. This is due to the fact that Polish history is scarce in crisis events and those that took place were related to the transition from the centrally planned to the market economy and as such are not a good basis for the calibration of the magnitude of possible shocks.

3.3.   Simulation process

Once a set of scenarios and risk channels has been identified and described, the next step is to estimate the impact of the shock on selected elements of the profit and loss account and balance sheet items. Historically, the level of write-offs for bad loans and net interest income had the main impact on the profitability of the Polish banks. Unsurprisingly, one of the key stages of NBP stress tests involves a quantification of the influence of the macroeconomic variables generated for the baseline and adverse scenario on credit risk costs and net interest margin (NIM). This is achieved by applying satellite models that establish a relationship between the economic and financial variables and the banking system variables (see Section 3.3.1.).

Figure 5. Macro stress-testing at NBP – building blocks
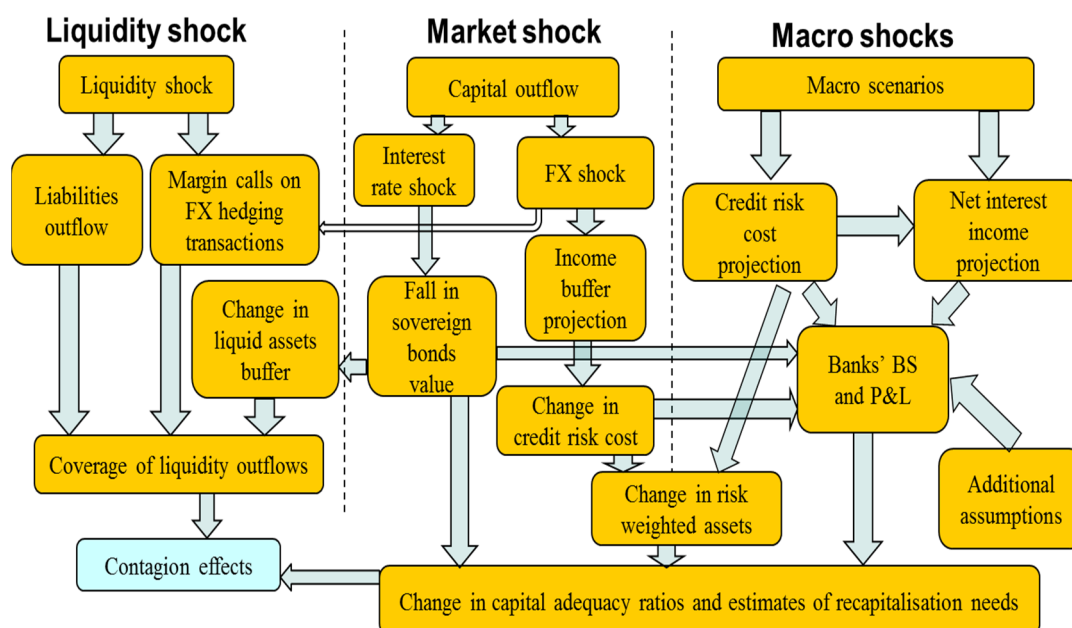
Source: NBP.

Macroeconomic shocks tend to coexist with market and liquidity shocks (Figure 5). As Poland still qualifies as a small-open economy, like the rest of emerging markets, it is vulnerable to foreign capital flows. An abrupt repricing of risk on global markets can lead to capital outflows that result in interest rate shock and FX shock (see Section 3.3.2.). The higher risk premium is then reflected in the rise of government bond yields. An increase in yields influences banks by a reduction in their sovereign bonds valuation, while a depreciation of PLN influences households that have loans denominated in foreign currencies. The share of households that would default on their mortgages due to FX changes is calculated using data on households' income buffers. The result is added to the credit risk cost increase caused by other macroeconomic shocks. Liquidity shock is accounted for by liabilities' outflow and margin calls on FX hedging transactions. These two together with the shrinkage of liquid assets resulting from a fall in the valuation of sovereign bonds may lead to insufficient coverage of liquidity outflows (see Section 3.3.3.). In the final stage banks that may not be able to fulfil capital adequacy ratios are identified and the effect of their inability to repay debts to other financial institutions is accounted for (contagion effects) (see Section 3.3.4.).

With regard to the remaining components of banks' income statements, certain simplifying assumptions had to be made, mainly due to the idiosyncratic nature of these P&L positions and the poor performance of regression equations. In most cases a constant relationship to assets is assumed (administration costs and depreciation) or some simplified approach is employed (net trading and net fee and commission income) (Table 2).

Table 2. The simulation procedure concerning individual items of the income statement

Income statement position	Calculation method / assumptions
Fee and commission income	Depending on the observed trend in recent years (in relation to assets): ▪ downward trend – continuation of the trend with its gradual dampening (with a slower pace in a shock scenario) ▪ upward trend – fixed relation to assets
Net trading income	Determined as fixed relations to assets – in the reference scenario the average of the last three years, in the shock scenario the average of the worst two years of the last five years. In the shock scenario, the loss on debt securities due to a rise in risk in yields is subtracted respectively.
Administration costs and depreciation	Determined as fixed relations to assets with the exception of fees for the Deposit Guarantee Scheme (DGS).
Tax on some financial institutions	Calculated based on the provisions of law introducing this tax.

Impairment on financial assets	Separate satellite models for provisions to retail loans, corporate loans and mortgage loans.[5] Additionally, sensitivity analysis covering the portfolio of residential foreign currency loans.
Other operating gains (losses)	Determined as a fixed relation to assets
Income tax	Total profit before tax multiplied by the effective tax rate (the ratio of income tax to gross profit). If gross income is negative – zero.

Source: NBP.

3.3.1. Credit risk and net interest margin models

A key question of any macro stress-test is how macroeconomic scenarios are linked to the banks' risk exposures. Macroeconomic models typically do not include financial variables crucial to the assessment of the condition of banks, such as credit risk or interest margins. Stress-testing exercises therefore use so-called 'satellite models', which translate macroeconomic outcomes into figures on balance sheets and profit and loss accounts.

Projections of banks' interest margins and credit losses in a crisis are very uncertain and vary both in methodology and underlying data. The relationship between macroeconomic developments and banks' risks is probably non-linear. In a crisis, historical relationships can break down and lead to (i) an unexpectedly strong surge in banks' funding costs (ii) a market decline in borrowers' ability and willingness to service their debts. Therefore, it seems reasonable to estimate models exclusively on data from crisis periods to ensure that they capture correlations that materialise under conditions of stress. However, there is often insufficient data coverage to permit a focus on crisis periods alone. The other drawback of this approach is that the regulatory environment changes over time, shaping banks' reactions to developments in economic conditions. As a result, satellite models are usually estimated on a full sample from mostly non-crisis periods, producing two projections: baseline and adverse. Model projections are subject to judgement-based adjustment to account for regulatory and market changes in lending standards.[6]

The NBP framework with regard to satellite models has two main objectives. First, it aims at examining in more depth the relationship between selected elements of the profit and loss

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[5] Impairment flows are estimated on the basis of changes in provisions after adjusting for the effect of portfolio sales and other write-offs. This adjustment is made by adding the average difference between those two positions from the last 12 quarters.

[6] Just as all models do, stress tests rely on historical data to estimate empirical relationships among data series. Given typical econometric techniques, these models reflect average past relationships between variables, rather than the variables' interactions under stress. This renders the substantial role of judgement in the exercise acceptable, even desirable.

account and the set of macro-financial variables. Second, it strives to develop models that can be used to project the loan loss provision ratio (LLP) and net interest margin (NIM) into the future, taking as input the macroeconomic projections from a specific scenario.

The effect of realisation of adverse macroeconomic scenarios on credit risk cost projection and NIM projection is captured using econometric panel models. These models combine data from individual banks' regulatory reports with macroeconomic indicators. Credit losses are modelled separately in three portfolios: consumer[7], corporate, and housing loans. Due to the lack of data on individual borrowers, it is assumed that these portfolios are homogeneous.

In the credit risk models, the accumulated credit risk losses are represented by the (balance-sheet) stock of loan loss provisions[8], which reduce the balance sheet value of impaired loans (stage 3 loans under the current IFRS9). This choice of this variable (normalised between banks by dividing it by the gross value of loans' portfolios) is motivated by several causes (Głogowski, 2008):

- Data on non-performing loans with division into different categories of loans are available only since mid-2003. In addition, the definition of non-performing loans (NPL) changed several times during the sample period. The changes in classification rules brought about large changes in the share of adversely classified loans in banks' portfolios. The changes in regulations also influenced the flows of impaired loans and consequently the stock of LLP, but the changes were much less severe.

- The format of supervisory data does not allow to split the flows of impaired loans by type of borrower, type of loan, or loan currency before 2008. Such a breakdown is available for data on the level of LLP.

- Data on PDs and LGDs of banks' portfolios are not available for a representative sample. It is also not possible to proxy these parameters from IRB reporting templates as most of the banks in Poland use STA for credit risk.

In order to perform stress-testing exercises, LLPs (a balance sheet item) must be converted into impairment losses (an income statement item). Due to the high correlation between these, impairment flows can be estimated on the basis of changes in LLPs after adjusting for the effect of portfolio sales and other write-offs.

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[7] Loans to households other than housing loans.
[8] They cumulate over time on the bank's balance sheet after subtracting loan write offs. They account a "contra-asset" account, accounting for the difference between the gross loans and the net loans recorded on the asset side of the bank's balance sheet.

In the net interest model, the dependent variable is the relation between annualised net interest income and average levels of assets. However, some small corrections are made to the nominator, where interest earnings from debt securities are deducted and loan commissions are added. The rationale for this adjustment is that interest on bonds is in most cases fixed until the bond expires, while loan commissions are sensitive to market conditions and economic developments (in other words, they largely depend on credit growth). Another reason is the changes in accounting standards and supervisory policy, which have forced the recognition of part of credit commissions as interest income (accounted for using the effective interest rate). In this regard, by adding commissions from the beginning of the sample we get a more consistent series.

Figure 6. Development of NIM, LLP, and economic cycles in Poland
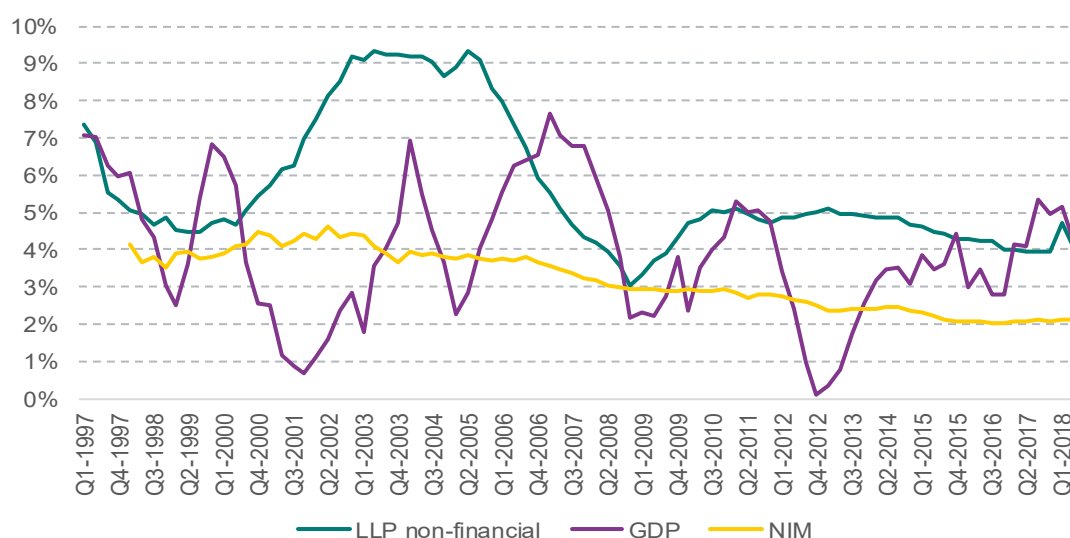
Source: NBP.

Many bank risk studies highlight the strong negative relationship between economic cycle and bank risk exposure. As economic conditions for businesses worsen during recessions, the riskiness of intermediation tends to increase. Thus, macroeconomic conditions can be a trigger for systemic changes that are of great significance for credit risk. On the other hand, NIM exhibits persistence over time and tends to react very slowly to any change in economic conditions. In comparison to the LLP ratio, NIM shows less variability during the period analysed (Figure 6). The downward trend is mainly associated with interest rate cuts, which were historically very high in Poland. The relationship with other macroeconomic variables

is not so obvious or straightforward, which means that the process of model specification is not an easy task.

Credit risk is inherent in lending – the traditional activity of banks – and creates the most significant risk exposure for all the banks in our sample. At the end of December 2018 Polish banks' balance sheets largely consist of loans and receivables (68%). Of these loans and receivables, the mortgage loan portfolio is the biggest, representing 33% of all outstanding loans. Other relevant lending portfolios include corporate and consumer loans (30% and 13%, respectively). As credit risk is the most significant type of risk exposure for Polish banks, factors driving losses in credit portfolios merit a great deal of attention.

Net interest income represents a substantial part (65%) of the operating income of all banks in the sample, as most of the Polish commercial banks maintain a traditional business model, with a large share of loans and deposits in relation to total assets. For this reason, the importance of NIM as a measure of the profitability of financial intermediation cannot be neglected.

Given the above, we base the model selection process on an expert judgement, a statistical procedure (see below) and a literature review. The latter helps to identify the macroeconomic determinants for credit risk (see Nkusu, 2011; Klein, 2013; Castro, 2013;) and net interest margin (see Horvath, 2009; Gunter et al., 2013; Bologna, 2018).

Economic growth, the condition of the labour market and financial markets are considered as the main determinants of NIM and LLP. The final selection results are summarised in Tables 3 and 4. Along with the variables specified in the tables, many other explanatory variables that, according to the literature, could have a significant impact on NIM (e.g. interest rate volatility, or the shape of the yield curve) and LLP (e.g. house prices, or CDS spreads) are tested. In fact, more than 30 explanatory variables for use in the models are considered. Preference is given to variables for which forecasts can be obtained from the macro model (NECMOD).

Table 3. Credit risk models – explanatory variables

Variable	Abbreviation	Sign	Description	Unit
CHF exchange rate	CHF_PLN	+	Influence on instalment of mortgages denominated in CHF	Level (PLN)
GDP (Poland)	GDP	-	Proxy for economic activity in Poland	Change (YtY, %)
GDP (Eurozone)	GDP_EZ	-	Proxy for economic activity of the closest trading partners	Change (YtY, %)
IFRS	IFRS	+	Introduction of the IFRS standard led to an increase in provisions at the commencement date of the standard	Dummy equals 1 in the first quarter of 2018
Interest rate	RATE	+	Most loans in Poland are floating rates loans so it impacts the level of instalment	Level (%)
Employment	EMP	-	Proxy for the labour market condition and companies' condition	Change (YtY, %)
Capital expenditure	INVEST		Investment outlays provide a useful barometer of the condition of firms	Change (YtY, %)

Notes: This table presents variables (with notion and description) that influence the loan loss provision ratio of Polish banks. The sign stands for theoretically expected signs.

Table 4. NIM model – explanatory variables

Variable	Abbreviation	Sign	Description	Unit
GDP	GDP	+	Rise in economic activity leads to higher demand for credit that allows banks to use higher margins	Change (YtY, %)
Interest rate	RATE	+	The rise in short-term rates typically passes through faster to interest-earning assets than to bank funding costs[9]	Level (%)
Credit losses	PROV_RATIO	-	No interest is paid on non-performing loans	Level (%)

Notes: This table presents variables (with notion and description) that influence the net interest margin of Polish banks.

The principal rationale for including only macro-financial variables and not considering bank-specific variables (with the exception of the provision ratio in the NIM model) is to be able to stress these parameters in the adverse scenario. Although adding some of the traditional risk- and financial performance indicators (e.g. C/I, CAR, Size, or ROE) would possibly improve the historical model fit, we would not be able to simultaneously establish a reliable forecast for these variables given our scenario. The only exception is credit losses (LLP), which are included in the NIM equation, but these are a direct result of the credit risk models. Given that the econometrics results are used for forecasting purposes rather than for

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[9] The majority of Polish banks exhibit a positive short-term interest rate gap.

policy analysis (for which the size of the estimated coefficients is the focus of the analysis) the potential bias related to omitted variables is not an issue of concern.

To account for banks' individual characteristics in terms of their credit loss and the NIM-generating process, we decided to use a fixed effects panel model. The standard version of the fixed effects model takes the following form (Diggle et al., 2002):

$$y_{it} = \alpha_i + X_t^T \beta + \varepsilon_{i,t} \quad (5)$$

where: $y_{i,t}$ – dependent variable, α_i – individual effects, x_t – explanatory variables, β – parameters, common for all banks, $\varepsilon_{i,t}$ – error term. The macroeconomic macro variables x_t play a major role in this approach. These variables describe the relevant macroeconomic scenario that affects the whole set of banks. In this model we assume that the reaction to changes in economic environment (β) is the same for each individual bank. This obvious shortfall of the particular model is caused by the lack of data to estimate individual banks' elasticities to the external changes in the economic environment.

Both LLPs and NIM do not tend to change rapidly over time, because credit conditions and loan quality are the result of past decisions to grant a loan. The quality of a credit portfolio largely depends on the credit policy from the moment the credit is granted. The NIM of a portfolio is influenced by the conditions of a contract which is already signed. To capture the high persistency of both credit losses and macroeconomic processes, lagged dependent variables are used:

$$y_{it} = \phi y_{i\,t-1} + X_t^T \beta + (\alpha_i + \varepsilon_{it}) \quad (6)$$

The use of a dynamic model creates a problem concerning the correlation between lagged dependent variables and individual effects. It is proven that the inclusion of a lagged dependent variable in a panel framework can yield biased and inconsistent estimates due to the correlation between the lagged dependent variables and the error terms (Nickell, 1981, and Kiviet, 1995). However, this problem can be avoided by the use of the estimation techniques proposed by Blundell and Bond (1998), based on the System Generalised Method of Moments (S-GMM) method. The approach combines the original equation in levels and an equation in differences:

$$y_{it} - y_{i\,t-1} = (\phi y_{i\,t-1} - \phi y_{it-2}) + (X_t^T - X_{t-1}^T)\beta + (\varepsilon_{it} + \varepsilon_{it-1}) \quad (7)$$

Turning to prediction in this model, assuming that the model has been estimated for the sample indexed by the time periods $t = 2, 3, \ldots, T$, the forecast of the income component in time $T + h$ is given by:

$$\hat{y}_{i,T+h} = \hat{\alpha}_i + \hat{\phi}\hat{y}_{i,T+h-1} + \hat{\beta}'\mathrm{x}_{T+h} \quad (8)$$

for h = 1, 3, …, H, where $\hat{\alpha}, \phi, \beta$ are the estimated parameters resulting from the GMM approach, including $\hat{y}_{i,T} = y_{it}$. Here, H is a given forecast horizon (e.g. 3 years).

To conclude, as our baseline estimator, we use the S-GMM technique for the dynamic panel data models to estimate cross-bank regressions. As GMM becomes inconsistent as the number of instruments becomes too large, we restrict the maximum lag to four periods.[10] In comparison with the conventional static panel data regression model, the S-GMM technique seems more efficient and consistent in estimating the coefficients, and also controls for the potential issues of heterogeneity, autocorrelation, and endogeneity. Finally, we perform several post-estimation validation tests, including the Hansen test, which verify the overall strength of the instruments. The estimated models are also checked for autocorrelation using the AB test.

The stress-testing model is properly estimated if it can reproduce real credit losses in real-life macroeconomic conditions. Thus, it is essential for the credit loss or NIM model to have the correctly specified sign, so that hypothetical worsening of economic conditions leads to an increase in credit losses and dwindling NIM. To account for this, model selection is based on the statistical significance of the explanatory variables, the consistency of the signs with economic theory, the determination coefficient, and the shock sensitivity of the model.

Moreover, to evaluate the models in terms of their forecast accuracy, a pseudo in- and out-of-sample forecast exercise is performed. The in-sample estimation sheds light on the tightness of the link between the macroeconomic variables and the performance indicators of key banks, namely LLPs and NIM, with the benefit of hindsight. With regard to the out-of-sample test, the sample is divided into an estimation sample and a forecast sample. The estimation sample is used to extract initial estimates of the model parameters and to produce a dynamic forecast of the relevant bank income component. Next, the following in- and out-of-sample forecasting errors are calculated (Wooldridge, 2010):

- MAE (ABSOLUTE) – mean average absolute error

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[10] GMM performs best with large cross-section dimension N and relatively small time dimension T, so N in most cases should be greater than T. An important issue with GMM is the problem of 'too many instruments', since the number of instruments should be less than the number of the cross-sections, as was highlighted by Roodman (2009).

- MAPE – mean average percentage error
- MAPE ASSETS – MAPE weighted by each bank's assets
- RMSE – root mean squared error

All those errors are calculated in-sample and, more importantly, out-of-sample, with a three-year testing horizon. Asset-weighted errors are included so that the models better reflect the general condition of the banking sector instead of concentrating on smaller banks' behaviour. Another reason for this is that smaller banks tend to shape their credit portfolio in accordance with reasons that may not be correlated with economic conditions, but rather with internal corporate capital flows or regional events. In the case of small banks, it should be noted that a relatively limited number of events (such as defaults) that can happen at random may result in bigger portfolio changes.

It is worth remembering that there is a trade-off between fit and parsimony. On the one hand, adding more variables and/or more lags improves the model fit (the R-squared will improve). On the other hand, including non-significant variables that do not really add to the forecast quality could degrade the forecast quality. Therefore, the final models contain about three or four explanatory variables.

Finally, models with the lowest average forecast errors are selected. Although the forecasting performance of the dynamic panel model is considered satisfactory, more work is necessary to improve the forecast performance and to relate the proposed approach to alternative methods. The BMA procedure (Gross and Población, 2015; ECB, 2017) and quintile regressions (Covas et al., 2014) – which are currently being tested – seem to be among the most promising approaches.

In Table 5, the estimation results are presented in detail. Here, the focus is on the implied long-run macroeconomic elasticities. These elasticities are given as the sum of the macroeconomic coefficients divided by one minus the coefficient of the lagged dependent variable (Wooldridge, 2010). The estimated coefficients for macroeconomic variables in credit risk equations have the expected signs and are statistically significant. All economic variables in credit risk models are lagged for two periods in order to take into account the delayed impact of the macroeconomic situation on banks. The lagged LLP ratio is significant in each estimated model, which indicates the high persistency of loss provisions over time. Looking at the macroeconomic variables, it can be seen that consumer credit losses diminish with GDP and employment growth, while IFRS adoption results in an increase in provisions. Corporate losses are strongly adversely correlated with firms' investments expenditures and

economic situation abroad. Both of these variables can be treated as a proxy for the current and expected economic condition of firms. The other significant factor is employment. Its negative sign indicates that a drop in employment may herald a worse economic situation and, consequently, lower firms' capacity for servicing debt. Housing loans depend on interest rates and the CHF exchange rate. This is a result of the significant portfolio of foreign currency housing loans, which are denominated mostly in CHF. An increase in interest rates and weakening of the national currency reduces the clients' income buffers, which leads to an increase in the share of non-performing loans.

Table 5. Estimation results

	Cons_loans _ratio	Corp_loans _ratio	Hous_loans _ratio	NIM
Cons_loans_cover(-1)	0.9330*** (0.03)			
Corp_loans_cover(-1)		0.9310*** (0.02)		
Hous_loans_cover(-1)			0.9158*** (0.07)	
NIM(-1)				0.9605*** (0.00)
GDP(-2)	-0.0867*** (0.03)		-0.0031 (0.01)	0.0089** (0.00)
GDP_EZ(-2)		-.05426*** (0.01)		
INVEST (-2)		-.0102*** (0.00)		
IFRS	1.1659*** (0.38)			
RATE(-2)			0.01704*** (0.01)	0.0039** (0.00)
EMP(-2)	-0.09028*** (0.03)	-.0553*** (0.018)		
CHF (-2)			0.1529** (0.06)	
PROV_RATIO(-1)				-0.0013 (0.00)
Observations	2321	2964	1389	3095
Number of banks	39	44	29	58
Hansen test	0.526	0.539	0.865	0.615
AR(2)	0.451	0.179	0.314	0.626

Notes: Standard errors in parentheses, *** $p<0.01$, ** $p<0.05$, * $p<0.1$.
Parameter estimates for other insignificant explanatory variables are not reported in the table. All models have also undergone a series of statistical tests (AR (2) Arellano-Bond test (1991) and Hansen J test) for the GMM approach. The test results indicate the validity of the instruments used, as the over-identifying restrictions are fulfilled, and further show the absence of second-order autocorrelation in the residuals when using this estimator.
Source: own calculations.

In the NIM equation, interest rates are found to be positively associated with banks' NIMs. This result is also found in other studies (e.g. English et al., 2012; Claessens et al., 2018; Altavilla et al., 2017). The short-term interest rate result reflects the fact that bank deposit rates are typically lower and stickier than market rates (since banks provide transaction services). In particular, banks often fund a portion of their interest-earning assets with non-interest-bearing liabilities, which primarily correspond to demand and transaction deposits. Therefore, a shift of the yield curve primarily affects the income side. NIM are also found to be positively associated with economic growth. Indeed, improving macroeconomic conditions should lead to an increase in credit demand and consequently in supply, and thus to an expansion of banks' interest-earning opportunities. Although the LLP ratio has the expected sign – low asset quality (higher provisions) tends to compress NIMs – it is not statistically significant. Conversely, interest rate volatility and the shape of the yield curve, two common drivers of NIM often mentioned in other studies, were economically and statistically insignificant and are excluded from the estimation process (as are the rest of the insignificant variables).

Finally, a baseline and an adverse economic scenario for a three-year horizon between end-2018Q2 and end-2020Q4, prepared for stress-testing purposes, were plugged into the models to determine how the models projected banks' behaviour under conditions of stress. The results are presented in Figure 7. The deterioration of economic and market conditions tends to negatively affect the ability of borrowers to service their debts, thus leading to higher provisions for bad loans. The impact of the adverse scenario is economically meaningful and spreads similarly over the three different portfolios. NIM exhibits persistence over time and tends to react rather slowly to changes in economic conditions. Under the baseline scenario it can been seen that LLP ratio and NIM also deteriorates slightly, which can be explained by the outlook for the profitability drivers of key banks. In sum, all models are sensitive to changes in economic assumptions and produce reasonable forecasts under both baseline and adverse scenarios.

Figure 7. Forecasts for LLP ratio and NIM – baseline and adverse scenarios
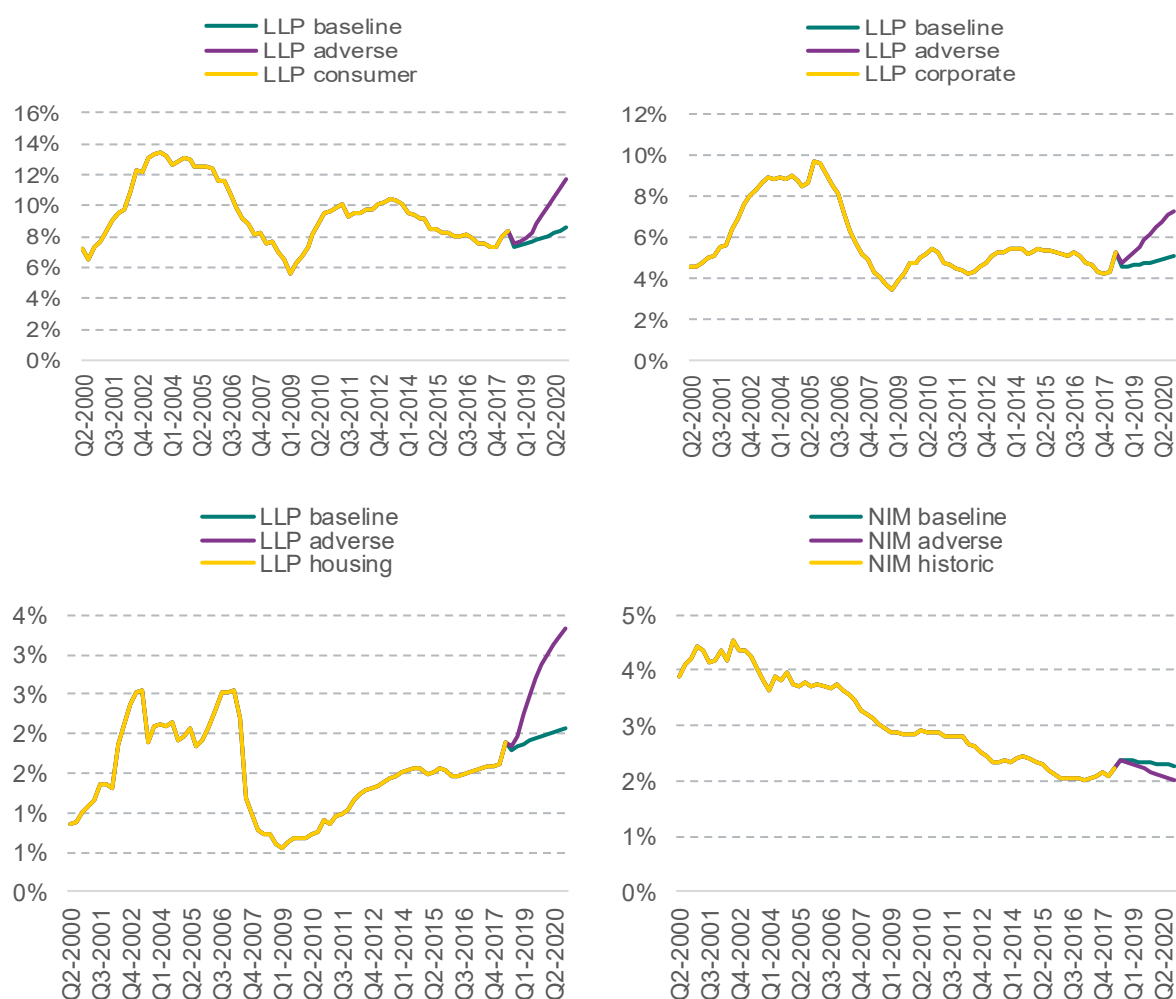
Source: NBP.

3.3.2. Market risk

A market shock is added to the macroeconomic shock scenario to assess the impact of a potential rise in foreign investors' aversion to risk towards emerging markets and the region (resulting in capital outflow from Poland) on the situation of the banks. It is assumed that the outflow of capital would be reflected in the growth of yields of Polish Treasury debt securities and the depreciation of the zloty. Depreciation of the zloty would, in turn, result in an increase in the capital requirements and the deterioration in the quality of bank's loan portfolios due to the rising domestic value of loans denominated in foreign currencies.

Figure 8. Financial crisis vs. stress test market risk assumptions
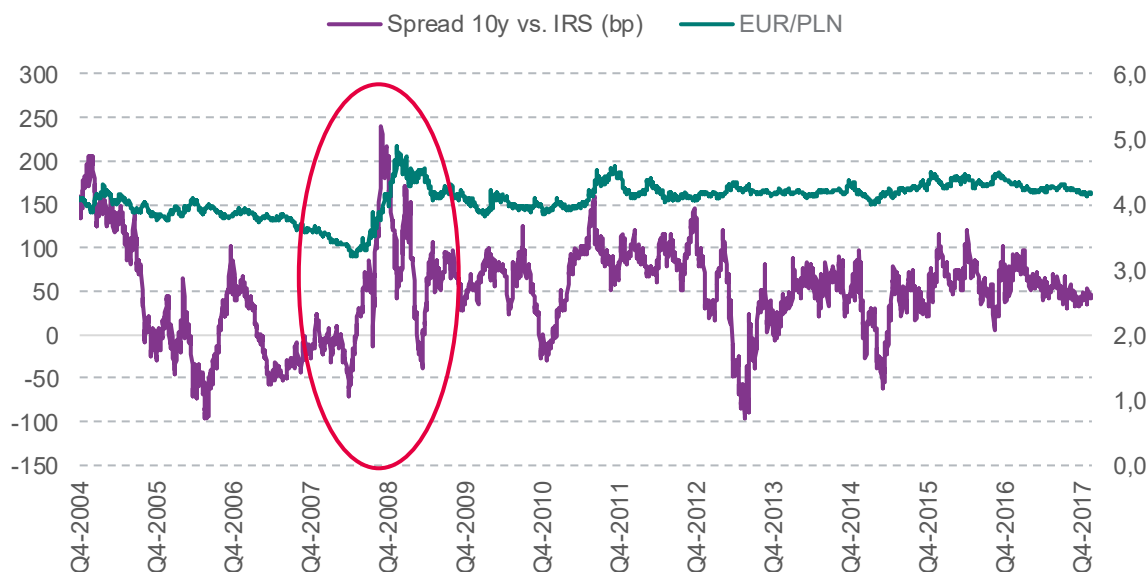
Source: NBP.

Calibration of the magnitude of the market shock can be drawn on historical experience, the experience gained during the global financial crisis. The analysis of historical behaviour of risk factors often helps to identify worst case scenarios and the probability associated with those scenarios, which can also serve as a benchmark for comparing the severity among scenarios. Alternatively, the calibration of a shock can be based on an arbitrary assumption of the increase in bond yields by 200-400 bp. and the depreciation of the zloty against all major currencies by 30-50%. This simplified approach is often employed by banks and supervisors although it has many limitations. In the case of Poland, at the moment of an outbreak of the GFC, the zloty depreciated against the euro by around 50% and the spread between a 10-year government bond yield and a 10-year IRS contract increased by 240 bp. in a relatively short time (see Figure 8). As both approaches lead to similar results, the second one is used.

Interest rate risk

The market risk taken by Polish banks arises mainly from the balance-sheet structure mismatch in terms of interest and currency. The scale of trading activity and type of held-for-trading financial instruments suggest that the risk associated with it is negligible. As a consequence, the interest rate risk relates almost exclusively to the banking book positions.

The majority of securities held by Polish banks are fixed-income high quality instruments in the form of Polish government bonds. In general, this implies that the rise of government bond yields has a negative impact on banks' earnings. However, banks' exposure to interest rate risk arising from the portfolio of Treasury securities is hedged by derivatives, such as IRS. Thus, a simultaneous parallel change of the IRS curve offsets the risk of a reduction in the value of a securities exposed to interest rate risk. Given the above, the adverse scenario assumes that although the yields on government bonds rise by 300 bp., the IRS curve does not change, so a change in yields fully reflects a change in credit risk premium and has a direct impact on banks' earnings, while in the case of instruments classified as "Fair Value through Other Comprehensive Income" it has an impact on banks' capital level.

FX credit risk

Starting from the mid-2000s, Poland experienced a period of rapid growth in mortgage lending, with banks offering foreign-currency, high-LTV housing loans. This exposed the banking sector to rising credit risk (through the direct and indirect channel) and funding challenges (e.g. rollover risk of hedging transactions) (Bierut et al., 2015).

The direct risk of sizeable losses arising from foreign exchange rate fluctuation is relatively low, despite a substantial currency mismatch of assets and liabilities in the Polish banking sector. This is due to the fact that the long on-balance FX position (related mainly to the portfolio of FX housing loans) is hedged with derivative contracts (FX swap and CIRS), and hence the net position is minor. However, the indirect credit risk channel stemming from the FX portfolio of housing loans is considered much more significant. An external sector shock, emanating from a depreciation of the exchange rate, would increase the debt burden for borrowers unhedged against FX risk with exposures denominated in foreign currencies and lead to an increase in the number of defaults on housing loans.

The NBP-developed panel model explaining loan losses at the level of individual commercial banks does not fully allow to account for the risk of deterioration in the quality of foreign currency loans as a result of the depreciation of the foreign exchange rate. Therefore, an additional simulation based on data from GUS Household Budget Surveys is conducted.

The simulation allows to estimate the growth of the share of foreign currency housing loans repaid by households with negative income margin (income decreased by loan repayments and basic living costs), stemming from a 30% depreciation of the zloty rate, in

line with the scenario of turbulence on financial markets. It is assumed that the share of impaired loans in the foreign currency housing loans increases by the scale equivalent to the proportion of non-performing loans with negative income margin. The resulting change in the amount of non-performing loans, coupled with historical data on the average loan provisions coverage, helps to determine the loan losses arising from the deterioration of the quality of foreign currency housing loans.

3.3.3. Liquidity risk

Liquidity crises originate from a sudden dry-out of funding sources. What makes them highly challenging is that they usually occur very suddenly and turbulently, spread by a mix of facts and rumours that can contribute to significant loss of funding due to withdrawal (Schmieder et al. 2012). Unsurprisingly, too much reliance on uninsured deposits, wholesale funding concentrations and sizeable maturity mismatches were among the top drivers of liquidity stress during the financial crisis.

Bank liquidity was traditionally viewed as equally important as solvency. The 2008 crisis showed that even well-capitalised banks could run into liquidity shortages.[11] Liquidity risk is inherently connected with maturity the transformation function of a bank (Goodhart, 2008). In short, banks can be affected by liquidity risk either directly, through the funding decisions of their creditors or indirectly, through rising funding costs (De Haan et al., 2011). Both of these dynamics were observed during the global financial crisis, which clearly demonstrated that neglecting liquidity risk comes at a substantial price.

The current discussion on liquidity focuses on the Liquidity Coverage Ratio (LCR) and, to a lesser extent, the Net Stable Funding Ratio (NSFR). However, the biggest improvements in the area of liquidity risk management in recent years have undoubtedly been made under stress test framework (Borio et. el., 2012; Bouveret, 2017). This is because the liquidity stress testing goes far beyond compliance with the regulatory liquidity ratios. From the microprudential point of view, liquidity stress tests constitute a tool for assessing the bank's liquidity risk profile and its capacity to withstand extreme liquidity stress by looking at the bank's liquidity position and funding sources under different scenarios (Constâncio, 2015). On the other hand, from the macroprudential perspective, liquidity stress testing is an effective

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[11] During the crisis, liquidity stresses were a key factor in the downfall of banks such as Lehman Brothers, Northern Rock and Washington Mutual.

toolkit that authorities may use to detect system-wide liquidity risks, taking into account that systemic risk is an endogenous concept.[12]

In the NBP macro stress test, the shock scenario also includes an analysis of the impact of market shock on the liquidity position of banks. In specific, top-down liquidity stress tests based on the ad-hoc model, common assumptions across banks and reported supervisory data are conducted. They take into account bank-specific characteristics (e.g. funding mix), country-specific circumstances, common sources and risk channels. The purpose of this simulation is to assess whether banks had an adequate buffer of liquid assets in the event of adverse scenario materialisation (see Table 6).

Table 6. Liquidity stress tests assumptions

Shock scenario*	Implications for banks	Assumptions	Results

▪ Rise in risk aversion
▪ Foreign capital outflow
▪ PLN depreciation
	▪ Closing of domestic interbank market
	▪ Outflow of foreign funding
	▪ Outflow of some part of non-financial clients' deposits due to risk aversion
	▪ More PLN sources needed for hedging the long FX balance sheet position (due to depreciation)
	▪ Fall in the market value of Treasury bonds
		▪ General assumptions of the macro stress test:
		▪ Zloty depreciation
		  o Fall in T-bond prices
		▪ Specific additional assumptions:
		  o All short-term liabilities towards other domestic banks come due and cannot be rolled-over
		  o Outflow of selected fraction of foreign funding depending on its stability
		  o Heterogeneous outflow of unstable part of deposits
		  o Outflow of 5% (stable) core household deposits and 10% of core enterprises and public entities deposits
		  o Outflow of funds due to extended credit lines (10% of the notional)
		▪ Fall in the market value of Treasury bonds
			▪ For each bank a ratio of liquid assets to projected outflows is calculated
			▪ If this ratio is below 100% the shortage of liquid assets is estimated
			▪ At the end the distribution of banks' assets by the above ratio and the aggregated shortage of liquid assets is presented**

Source: NBP.
*Consistent with the one used for macro stress test.
** This can be equally interpreted as excess of unstable funding.

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[12] Danielsson et al. (2010) emphasis that systemic risk is an endogenous concept, as it arises from disturbances in the functioning of financial intermediaries in a system. While the trigger may be an exogenous shock, systemic crises involve endogenous amplification mechanisms in the interaction between different players in the system.

The wholesale interbank market allows banks to engage in maturity transformation by investing more funds into less liquid and more profitable investment projects (Brunnermeier and Oehmke, 2013). This advantage may come at the expense of banks' underinvesting in liquid assets, which are safeguards against liquidity stress, or other distortions. Unsecured wholesale funding is vulnerable to changes in business sentiment, noticeably due to the fact that usually considerable funds are at stake, tenors are often short, and counterparties tend to be more sensitive to bank reputation and market rumours (Schmieder et al., 2012).

Pre-financial crisis literature on banking argues that an interbank market improves economic efficiency thanks to its liquidity management function (Allen and Galel, 2000). Another strand of literature notes that unsecured funding can play a role as disciplinary device (Huberman and Repullo, 2011). However, the experience of the financial crisis shows that the positive features of unsecured funding have downsides. Huang and Ratnovski (2011) point out that there may be incentives for banks to over-rely on this type of funding, so that underinvestment in the liquid asset occurs. Unsecured funding tends to evaporate extremely quickly when a borrower goes through financial difficulties or during market turbulence. Several empirical studies analyse the availability of wholesale funding during the global financial crisis. In general, it is found that the market did not entirely dry up, but rather that several features changed (BCBS, 2013).

In NBP stress tests it is assumed that during the first phase of market shock, there would be a full clearing of short-term transactions in the domestic interbank market. In the situation that a given bank did not hold sufficient liquidity buffers to clear its net obligations in this market, it would liquidate deposits held by respective creditor-banks in proportion to their share in its total obligations in the interbank market. Each bank-creditor would also post a loss amounting to the value of the unpaid obligations, which would be reflected in lower inflows.

The GFC gave rise to episodes of ring-fencing, which restricted the transferability of capital and liquidity during stress times (Cerutti et al., 2010). Foreign funding is an important source of financing for Polish banks due to ownership structure. It is favourable due to the lower roll-over risk than in the case of market funding but brings high concentration risk and makes Polish subsidiaries prone to the standing of parent-banks. In order to capture this risk, the outflow of funds obtained from foreign financial institutions (mainly parent entities) is assumed under the stress scenario. Specifically, it is envisaged that Polish banks are not able to roll over funding from parent entities maturing within one month. In addition, they have to face an outflow of a significant portion (25%) of remaining funds obtained from parent

entities. Banks also have to confront the rise of foreign currency obligations expressed in zlotys due to zloty depreciation.

While derivatives were a contributing source of liquidity stress during the GFC, their contribution was of secondary importance for most banks. However, FX derivatives can become problematic in some cases. A mismatch between off-balance sheet FX derivative assets (liabilities) and liabilities (assets) can create material rollover risk due to the limited availability of foreign currency funding (e.g. US dollar, Swiss franc) to local banks and the shortening of its tenors during periods of market stress. Another problem might be elevated margin calls resulting from local currency depreciation.

In the Polish banking sector FX liquidity is important due to large portfolios of FX mortgages. Under NBP liquidity stress test methodology it is assumed that banks that hedge their foreign currency exposures by means of off-balance sheet transactions would require a larger amount of funds to roll over these transactions.[13] This is because zloty depreciation would lead to an increase in the level of zloty funds needed to roll over hedge transactions for the same level of underlying foreign currency assets.

Deposit run-off can be an important source of funding stress, especially in banks where they constitute the main form of financing. The GFC showed that retail deposit outflows can be material and corporate clients are even more reactive. Nevertheless, the literature does not agree on deposit runoff rates in response to idiosyncratic institutional stress measures. Taking into account the additional implications of system-wide crisis, proper assessment of deposit withdrawals becomes even more problematic.[14] This is one of the reasons why financial safety net institutions draw upon supervisory experience and sets of hypothetical shocks, whilst conducting liquidity stress-tests. In NBP liquidity simulation it is expected that a market shock would cause reduced confidence of non-bank entities toward banks, which would result in the withdrawal of some of their deposits. In the case of households[15], enterprises and public sector entities, it is assumed that apart from the outflow of the non-core deposits with a maturity of

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[13] Due to the lack of data on the maturities of hedge transactions, it is conservatively assumed that in the projection horizon, banks must roll over all their hedge transactions or supplement their margin deposits.

[14] Iyer and Puri (2008) find that deposit insurance does not completely eliminate a depositor's incentive to run, albeit less than their uninsured counterparts which exert "market discipline" to a greater extent than insured depositors. Davenport and McDill (2006) show that insured deposits experienced a runoff in the 10 to 20% range.

[15] Despite the wide-spread availability of the deposit insurance system, retail funding considered stable can be subject to a run, as Northern Rock has vividly demonstrated (BCBS, 2013).

up to 1 month[16], these entities would withdraw 5%, 10% and 10% of their core deposits, respectively.[17]

The last stage of the liquidity simulation is to establish whether banks hold buffers of liquid assets sufficient to absorb the abovementioned outflows of funds. Liquid funds include receivables and debt securities with a residual maturity of up to 1 month, cash, deposits with the central bank and portfolios of government bonds. The value of the government bond portfolio is adjusted in line with the adverse scenario, which assumes an increase in the yield of these bonds of 300 basis points. Past simulations show that the liquidity outflows under stress test are much more severe than outflows indicated by LCR, which assumes a one-month period of severe market stress.

3.3.4. Domino effect

The network features of the financial system are an important issue for the assessment of systemic risk. Danielsson and Zigrand (2010) emphasise that systemic risk is an endogenous concept, as it arises from disturbances in the functioning of financial intermediaries in a system. While the trigger may be an exogenous shock, systemic crises involve endogenous amplification mechanisms in the interaction between different players in the system. Thus, the distribution and strength of linkages between financial institutions can affect both the intensity of systemic risk and the propagation mechanisms of risk materialisation (Garratt et al., 2011). These issues, often grouped under the label of interconnectedness of financial institutions, are gaining increased attention in stress tests, which arguably have the greatest potential to add value from a macroprudential policy perspective through illustrating how a shock could impact the financial system as a whole (BCBS, 2015).

Macroprudential authorities have a comparative advantage over individual banks in the area of including feedback and amplification channels in the stress testing framework because they are able to access projections across stress-test participants. This allows them to take a much broader view of the market conditions that may prevail during the stress scenario and assess the feasibility of individual banks' envisaged responses in light of this. From this standpoint, it is often amplification and feedback channels that prove to have significant

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[16] For each bank, a stable portion of current deposits was established with primary maturity of up to 1 month (core deposits) based on statistical methods.
[17] Similarly to LCR, the smaller value of outflow of funds from households is a result of the fact that these deposits are covered by the Polish deposit guarantee fund (BFG).

influence on contagion losses and the exacerbation of the impact of an initial shock, thus contributing to systemic risk (Constâncio, 2015).

Prior to 2007-2008, most empirical literature showed that an individual institution was typically not able to trigger a domino effect (Upper, 2011). However, during the financial crisis, contagion via direct and indirect channels (e.g. through asset price changes and related behavioural responses) played a critical role in propagating the initial, relatively mild, subprime shock.

Financial contagion is an important element of the NBP macro stress testing framework. It is analysed through direct contagion via the interbank channel (the so-called domino effect). Under the domino effect it is assumed that one of the potential channels of emergence of systemic risk in the banking sector are the linkages between banks resulting from mutual exposures in the interbank unsecured deposit market. Following the realisation of credit, market and liquidity losses, some banks may be unable to repay their full obligations to other banks. A collapse of one bank may cause a domino effect, i.e. the successive collapse of other banks as a consequence of losses due to unpaid debt owed by the originally insolvent bank.

Figure 9. Interlinks in the Polish banking sector in December 2017
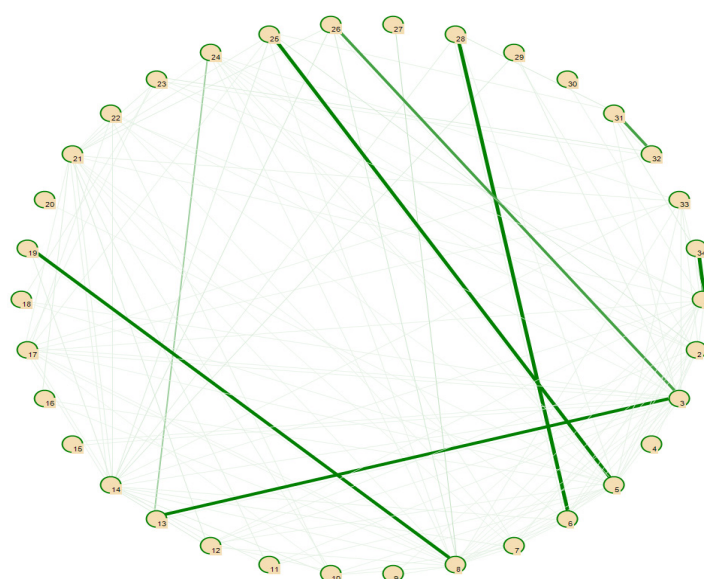
Source: NBP.

In the scale of the whole Polish banking sector, debt arising from interbank deposits constitutes a relatively small share of assets. However, there is a group of banks for which the level of interbank exposures in relation to own funds is relatively high and may constitute a risk to solvency in the case of materialisation of counterparty risk. In order to evaluate the

risk of a domino effect materialising in the domestic banking sector, detailed data on interbank claims and liabilities reported by the covered sample of commercial banks in the FINREP reporting system are used. Using this data, one may identify each counterparty of a given bank together with the value of interbank loans and deposits received from and granted to that particular counterparty (Figure 9).

The simulation assumes the netting of mutual assets and liabilities. This implies that in the situation where a troubled bank fails to repay its debt to another bank, then the latter, in order to minimise its losses, will likewise fail to repay its debt to the troubled bank. The study takes into consideration all types of loans and interbank deposits, regardless of their maturity. The simulation is conducted to test the impact of the primary insolvency of each commercial bank resulting from macro-financial shock. The secondary insolvency of a counterparty bank arises when the realised loss would cause a fall in the capital adequacy ratio (TCR) to below 4%.[18] Equivalently, a failure of the counterparty bank may lead to the insolvency of other banks.

The experience gained so far indicates that the risk of a domino effect occurring in the Polish banking sector is insignificant. This can be explained by the fact that Polish banks are net recipients of liquidity from their parent entities. Another reason is the fact that the interbank market of short-term unsecured deposits in Poland is very small and is rarely used by banks for the purpose of liquidity management.

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[18] Indirect effects stemming from the necessity to recapitalise DGS resources after a pay-out of guaranteed deposits of an insolvent bank are not included yet.

4. Challenges and future developments

Stress testing is an important component of the tool kit available to authorities, including NBP, to assess risks to the financial system. However, it is important to highlight that, despite recent significant progress in the development of stress-testing models, stress testing remains challenging because it attempts to capture the effects of tail events. What is more, it has to take into account many simultaneous dynamics in banks' balance sheets. Calibration of stress-testing models is still in many circumstances rooted in the quantitative risk management framework that underpins the risk management models exploited by banks for business and regulatory purposes. In such a framework, it is supposed that the evolution of the value of a given set of exposures is driven by a set of exogenous systematic risk factors. Such a setup does not allow for feedbacks, even though these lie at the heart of financial instability. A number of recent studies have shown that when liquidity risk and spillover effects are considered jointly and simultaneously in addition to solvency risk, the aggregate capital position of banks declines by an additional 20 – 50% (Anand et al., 2014). Therefore, there is a consensus that macroprudential stress tests should capture such feedback effects, albeit doing so in practice has proved very difficult. Finally, these feedback and amplification effects depend on market participants' behavioural responses that are exceedingly hard to model. Irrespective of the difficulties or challenges that have to be faced, it is important to take them into account in an integrated and interdependent manner when assessing financial stability risk. To this end, NBP has developed an integrated stress-testing model which, on one hand, incorporates various types of risk for banks (solvency risk, liquidity risk and direct contagion effect), but on the other hand, still does not fully include all potential sources or risks e.g. stemming from indirect contagion effects and risks' interactions. Although good progress has already been made over the last several years, further analytical work should be continued. In view of the above, the revised methodology should allow for the inclusion of a dynamic approach, integrating the optimised reaction of banks' balance sheets to the variables being shocked. It should also cover feedback to the real economy about the consequences of the scenario for credit institutions, through the use of macroeconomic model that includes the financial sector. It should consider a system-wide liquidity assessment and its tide link to solvency, analyse the interconnectedness of banks with other financial institutions and the economic behaviour of market agents e.g. households and businesses (see Annex 1 for details); and finally, it should be employed to investigate the impact of some macroprudential instruments.

References

Allen F., Carletti E., Gale D., *Interbank market liquidity and central bank intervention*, Journal of Monetary Economics, vol 56, no 5, 2009, pp. 639–52.

Altavilla, C., Boucinha, M. and Peydró, J.-L., *Monetary Policy and Bank Profitability in a Low Interest Rate Environment,* ECB Working Paper Series, N 2105, 2017.

Anand K., Bédard-Pagé G., Traclet V., *Stress Testing the Canadian Banking System: A System-Wide Approach Bank of Canada* , Financial System Review, June 2014

Arellano M., Bond S., *Some tests of specification for panel data: Monte Carlo evidence and an applicationto employment equations*, Review of Economic Studies 58: 277–297, 1991.

BCBS, *Literature review of factors relating to liquidity stress – extended version*, Working Paper No. 25, 2013.

BCBS, *Making supervisory stress tests more macroprudential: Considering liquidity and solvency interactions and systemic risk*, Working Paper No. 29, 2015.

BCBS, *Principles for sound stress testing practices and supervision*, May 2009.

BCBS, *Stress testing principles,* October 2018.

Bierut B., Chmielewski T., Głogowski A., Stopczyński A., Zajączkowski S., *Implementing Loan-To-Value and Debt-To-Income ratios: Learning from country experiences. The case of Poland*, NBP Working Paper No. 212.

Blundell R., Bond S., *Initial Conditions and Moment Restrictions in Dynamic Panel Data Models*, Journal of Econometrics, 87(1), pp. 115–143, 1998.

BoE, *Stress testing the UK banking system: 2016 results*, November 2016.

Bologna, P., *Banks' Maturity Transformation: Risk, Reward, and Policy,* IMF Working Paper, N 45, 2018.

Bonfim D., *Credit risk drivers: Evaluating the contribution of firm level information and of macroeconomic dynamics*, Journal of Banking & Finance, Volume 33, Issue 2, February 2009.

Borio C., Drehmann M., Tsatsaronis K., *Stress-testing macro stress testing: does it live up to expectations?,* BIS Working Papers No 369, January 2012.

Bouveret A., *Liquidity Stress Tests for Investment Funds: A Practical Guide*, IMF Working Paper No. 17/226, October 2017.

Brunnermeier M., Oehmke M., *The maturity rat race*, Journal of Finance, 68(2):483–521, 2013.

Bruno B., Carletti E*., How demanding and consistent is the 2018 stress test design in comparison to previous exercises?*, European Parliament, June 2018.

Budnik K., Kolasa M., Hulej M., Greszta M., Murawski K., Rot M., Tarnicka M. and Rybaczyk, B*. The New Macroeconometric Model of the Polish Economy*, National Bank of Poland Working Paper, N 62, 2009.

Busch R., Memmel Ch., *Banks' Net Interest Margin and the Level of Interest Rates,* Credit and Capital Markets – Kredit und Kapital: Vol. 50, No. 3, pp. 363-392.

Campa M., *The EU-wide stress test: can the glass be more than half full?*, 20th Handelsblatt Annual Conference on "European Banking Regulation", Frankfurt, 11 November 2019 (speech).

Castro, V., *Macroeconomic Determinants of the Credit Risk in the Banking System: The Case of the GIPSI. Economic Modelling,* 31, pp. 672–683, 2013.

Cerutti E., Ilyina A. Makarova Y., Schmieder Ch,, Bankers Without Borders? Implications of Ring-Fencing for European Cross-Border Banks, IMF WP no. 10/247/, 2010.

Chaibi H., Ftiti Z., *Credit risk determinants: Evidence from a cross-country study*, Research in International Business and Finance, Volume 33, January 2015, Pages 1-16.

Chan-Lau J. A., *Market-Based Top-Down Macro Stress of the Banking System,* IMF Working Paper WP/13/88, April 2013.

Christian Schmieder C., Hesse H., Neudorfer B., Puhr C., Schmitz S., *Next Generation System-Wide Liquidity Stress Testing*, IMF Working Paper, January 2012.

Claessens, S., Coleman, N. and Donnelly, M. (2018). "Low-For-Long" Interest Rates and Banks' Interest Margins and Profitability: Cross-Country Evidence, *Journal of Financial Intermediation*, 35, pp. 1–16, 2012.

Constâncio V., *The role of stress testing in supervision and macroprudential policy*, London School of Economics Conference on "Stress Testing and Macroprudential Regulation: a Trans-Atlantic Assessment", London 29 October 2015.

Constâncio V., Cabral I., Detken C., Fell J., Jerome H., Hiebert P., Kapadia S., Nicoletti A.S., Pires F., Salleo C., *Macroprudential Policy at the ECB: Institutional Framework, Strategy, Analytical Tools and Policies*, ECB Occasional Paper No. 227, July, 2019.

Covas F. B., Rump B., Zakrajsek E., *Stress-testing US bank holding companies: A dynamic panel quantile regression approach*, International Journal of Forecasting, July 2014.

Danielsson J., Shin H. S., Zigrand Z.P., *Risk Appetite and Endogenous Risk*, AXA WORKING PAPER SERIES NO 2 DISCUSSION PAPER NO 647, 2010.

Davenport A., McDill K, *The depositor behind the discipline: a micro-level case study at Hamilton Bank*, Journal of Financial Services Research, vol. 30,no 1, 2006, pp. 93–109.

De Haan L., Willem van den End J., *Banks' responses to funding liquidity shocks: lending adjustment, liquidity hoarding and fire sales*, Dutch Central Bank, Working Paper no. 293, 2011.

Diggle P., Heagerty P., Kung-Yee L. Zeger S., *Analysis of Longitudinal Data (2nd ed.)*, Oxford University Press, 2002, pp. 169–171.

ECA, *EU-wide stress tests for banks: unparalleled amount of information on banks provided but greater coordination and focus on risks needed*, European Court of Auditors, November, 2019.

ECB, *STAMP€: Stress-Test Analytics for Macroprudential Purposes in the euro area*, February 2017.

ECB, *Macroprudential stress test of the euro area banking system*, ECB Occasional Paper Series, No 226 / July 2019.

English, W. B., Van den Heuvel, S. J. and Zakrajsek, E., *Interest Rate Risk and Bank Equity Valuations.* Federal Reserve Board Finance and Economics Discussion Series, N 26.

Enria A., *What we have learnt from EU-wide stress tests*, speech: 15 November 2018.

Foglia A., *Stress Testing Credit Risk: A Survey of Authorities' Aproaches*, International Journal of Central Banking, International Journal of Central Banking, vol. 5(3), pages 9-45, September 2009.

Garratt R., Mahadava L., Svirydzenka K., Mapping systemic risk in the international banking network, Bank of England Working Paper, No. 413, 2011.

Głogowski A., *Macroeconomic determinants of Polish banks' loan losses – results of a panel data study*, NBP WP Np. 53, Warsaw, November 2008.

Goodhart C., *Liquidity risk management*, Special issue on liquidity No. 11, Banque de France, Financial Stability Review, February 2008.

Gross M., Población J., *A false sense of security in applying handpicked equations for stress test purposes*, ECB Working Paper Series, No 1845 / September 2015.

Gunter, U., Krenn, G. and Sigmund, M., Macroeconomic, Market and Bank-Specific Determinants of the Net Interest Margin in Austria, *OeNB Financial Stability Report*, 25, pp. 87–101, 2013.

Haben P., Quagliariello M., *EU-wide Stress Tests: Rationale and Basics*, in M. Quagliariello (ed.), Europe's New Supervisory Toolkit: Data, Benchmarking and Stress Testing for Banks and their Regulators, RiskBooks, 2015.

References

Henry J., Kok M., *A macro stress testing framework for assessing systemic risks in the banking sector*, Occasional Paper Series 152, European Central Bank, 2013.

Hodrick R., Prescott R., *Postwar U.S. Business Cycles: An Empirical Investigation*, Journal of Money, Credit and Banking, vol. 29, issue 1, 1-16, 1997

Horvath, R. (2009), *The Determinants of the Interest Rate Margins of Czech Banks.* Czech Journal of Economics and Finance, 59(2), pp. 128–136, 2009.

Huang R., Ratnovski L., *The dark side of wholesale funding*, Journal of Financial Intermediation, vol. 20, no 2, 2011, pp. 248–63.

Huberman G., Repullo R., *Moral hazard and debt maturity*, CEMFI, 2011.

IMF (2012), *Macrofinancial Stress Testing – Principles and Practices*, August 2012.

IMF (2019), *Euro Area Policies: Financial Sector Assessment Program-Technical Note-Stress Testing the Banking Sector*, Country Report No. 18/228.

Iyer R., Puri M., *Understanding bank runs: the importance of depositor-bank relationships and networks*, NBER Working Paper 14280, 2008.

Klein, N., *Non-Performing Loans in CESEE: Determinants and Impact on Macroeconomic Performance,* IMF Working Paper, N 72, 2013.

Kok Ch., Mirza H., Pancaro C., *Macro stress testing euro area banks' fees and commissions*, ECB Working Paper Series, No 2029 / February 2017.

McNeil, A, R Frey and P Embrechts (2005): *Quantitative risk management: Concepts, techniques and tools,* Princeton Series in Finance, Princeton University Press.

NBP, *Financial Stability Report*, June 2017.

Nickell S., *Biases in Dynamic Models with Fixed Effects*, Econometrica, 49(6), pp. 1417–1426, 1981.

Nkusu M., *Nonperforming Loans and Macrofinancial Vulnerabilities in Advanced Economies.* IMF Working Paper, N 161, 2011.

Schmieder Ch., Puhr C., Hasan M., *Next Generation Balance Sheet Stress Testing*, IMF Working Paper (WP/11/83), April 2011.

Schwaiger M.S., Liebeg D., *Determinants of the Interest Rate Margins in Central and Eastern Europe*, Oestereichische Nationalbank, Financial Stability Report No. 14, 2009.

Skrzypczyński P., *Metody spektralne w analizie cyklu koniunkturalnego gospodarki polskiej*, Materiały i Studia NBP. Nr 252. Narodowy Bank Polski. Warszawa, 2010.

Sologoub D., *The determinants of Bank Interest Margins and Profitability: Case of Ukraine*, 2006, www.bof.fi/bofit/seminar/bofcef06/sologub.pdf.

Tennant D., Folawewo A., *Macroeconomic and Market Determinants of Interest Rate Spreads in Low and Middle Income Countries*, "Applied Financial Economics" 2009, 19(6).

Upper C., *Simulation methods to assess the danger of contagion in interbank markets*, Journal of Financial Stability 7, 111–125, 2011.

Wooldridge J. M., *Econometric Analysis of Cross Section and Panel Data*. 2nd ed. MIT Press, 2010.

Annex 1

Prospects for further developments of InSTA

- Scenario development process

In the majority of econometric models, it is difficult to capture the link between financial and macroeconomic variables. Large confidence shocks to demand are needed to compensate for this missing link when using traditional macro-models. The correlation between macroeconomic variables and the link between macroeconomic and financial variables is generally stronger in downturns. This is also difficult to capture, if data are not sufficiently long to allow estimating time-varying models. The proposal for a new methodology can be based on joint historical empirical distributions using the copula approach. Under this framework the path of the variables would be defined on the basis of historical crisis paths.

- Sovereigns and financial institutions

Under the current methodology, only government bonds measured at fair value and a loan portfolio to the non-financial sector are subject to credit risk losses. Future methodology should also take into account a controversial aspect of the nexus between banks and sovereigns and the treatment of sovereign and financial exposures from a credit risk perspective. This could be done by developing the implied PD satellite models based on a market risk indicator due to lack of historical default rates for these types of exposures.

- Dynamic balance sheets

While traditional stress testing assess the level of banks' capital adequacy relative to regulatory requirements through a hypothetical crisis, macroprudential stress testing evaluates the macroeconomic consequences of the impact of banks' adjustments to the capital requirements. In the adverse scenario, banks might pre-emptively raise their capital buffers by, e.g., changing their portfolio allocation, issuing equities or deleveraging in order to avoid negative effects on their solvency. Such banks' behaviour in the shock scenario could create second-round effects on the macroeconomic environment, thus, amplifying the impact of the shocks that initially hit only the banking sector. The macro-feedback analysis, which considers interactions with the economy, is not modelled in NBP stress tests. One possible way to analyse the feedback effects between macroeconomic and financial variables could be through using Dynamic Stochastic General Equilibrium (DSGE) models or Vector Autoregressive (VAR) models (see ECB, 2017).

- Extension of satellite models to other income statement components

The key task of the macro stress test is to translate the macroeconomic scenarios into an impact on the capital available via P&L and risk-weighted assets. Net interest income and loan losses are among main variables that should be modelled in a stress test exercise. Nonetheless, there are other items of the income statements that might be dependent on the macro-financial indicators. One of them is fee and commission income (F&C) which is the second most important source of revenue for banks after net interest income. Some empirical studies have already shown some cyclical features of this component (see ECB, 2017). Therefore, treating this item as strictly independent of macro-financial developments when conducting stress tests might lead to an underestimation of banks' income sensitivity to the macroeconomic environment.

- Sensitiveness of RWA

The use of a risk sensitive exposure measure is essential for stress testing, as the evolution of risk under stress (i.e., the changes of RWAs) and the initial level of risk (before applying stress) will otherwise be misleading (often with the effect of underestimating risk). One way to sensitise RWA of banks that use the standardised approach for credit risk to the changing risk of underlying assets could be the use of the scaling factor that would adjust the level of the STA RWA to the level of the IRB capital requirements. The probability of default (PD) parameter that is needed in this case could be then implied from the already existing satellite credit risk models (see Schmieder et al. 2011). Another way would be to assign a risk weight at least one bucket higher than the risk weight determined by the external rating bucket of the exposure.

- Modelling amplification channels

The GFC highlighted the need to place a stronger emphasis on mitigating systemic risks in the banking system. This includes understanding how feedback and amplification channels during a stress period may drive contagion losses and exacerbate the impact of an initial shock. In order to better capture the role that system-wide dynamics could play in the stress period, bank staff should continue to develop additional feedback and amplification models with the aim of enhancing the capability of assessing the resilience of the banking sector. Possible improvements can include modelling all channels of financial contagion, both direct and indirect, ideally between all key macro-financial sectors.

- Interaction between liquidity and solvency

At present, the stress-testing frameworks run by many authorities are skewed towards assessing capital adequacy as opposed to other potentially important resilience metrics.

Although NBP stress tests capture liquidity metrics, solvency and liquidity stress tests are only partially interlinked. Future research should focus on better understanding the interrelation between banks' solvency and liquidity strains. Both are inherently linked, and stand-alone stress tests that only examine either liquidity or solvency potentially risk producing a downward biased result.

- Stress testing other sectors

Assessing the impact of a large shock on the financial soundness of non-bank financial institutions, stress testing can improve measurement of risks and can help in the calibration of the instruments mitigating those risks. There is a need to further develop these policy tools, while at the same time the adaptation of stress test models towards integrating different agents (insurance companies, CCPs and asset managers) into a system-wide tool is important.

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