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DP/108/2017

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December 2017

ISBN 978-619-7409-02-4
ISBN 978-619-7409-03-1 (e-book)

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Contents

Abstract: This study provides a current and comprehensive overview about the theory and practice of macroprudential bank stress-testing. It builds on the existing stress test literature and covers theoretical fundamentals, framework, and challenges. First, a review of underlying aspects such as definitions, characteristics, principles, and mechanism of transmission reveals the art of stress-testing with its benefits and complexities. Next, the main elements for a fitting framework are examined in details: preparation, application, presentation of results, and if applicable, follow-up and feedback. Finally, remaining challenges and possible ways forward are addressed given the stress-testing development is far from complete. The paper argues that macroprudential stress tests are effective for assessment of banks' resilience when appropriate design and expert judgement are well combined. Thus, they enhance monitoring of potential vulnerabilities to the banking system, add valuable input to the process of implementing policy actions, and consequently contribute to ensuring financial stability.

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Acknowledgment:

I would like to thank two anonymous referees for their constructive suggestions and insightful comments. The support and guidance of my colleagues from the Macroprudential Supervision and Financial Stability Directorate are also highly appreciated. I am solely responsible for all remaining mistakes and errors. The views expressed in this paper are my own and do not necessarily reflect those of the Bulgarian National Bank.

Introduction

Macroprudential Stress-Testing (MpSTing) has become a prominent practice in the modern banking world for risk assessment. It emerged widely as a crisis management instrument in the aftermath of the global financial crisis 2007/8, but since then has been established as a regular supervisory tool for financial stability. The Federal Reserve (FED) and the Bank of England (BoE) have issued official frameworks for annual public stress-testing, while the European Banking Authority (EBA) is carrying out an EU-wide stress test biennially. In the European Union, competent authorities are required under the CRD IV[1] to run at least annually supervisory bank stress tests to facilitate the review and evaluation process. More globally, MpSTs play a major role in the International Monetary Fund Financial Sector Assessment Programs (IMF FSAPs). Together with an asset quality review, stress-testing was also an integral part in the recent comprehensive assessments in Ireland (2011), Spain (2012), Greece (2013), Slovenia (2013), Bulgaria (2016), and in the process of establishing the Banking Union by the European Central Bank (ECB) during 2014 - 2016.

At present, there is a vast and on-going body of research about the theory and practice of MpSTing. But in a constantly developing and complex stress test universe, a need for an up-to-date review emerges continuously. In that manner, the goal of this paper is to provide a current and comprehensive analysis about the MpSTing that covers theoretical fundamentals, framework, and challenges. By building on the existing prolific stress test literature and incorporating both the academic and practical side of the matter, the study utilizes "lessons learned" from past experiences, formulates guidelines for effective MpST, and adds another piece to the debate over how best to carry out the macroprudential exercise among regulators, academics, and bankers. Accordingly, this research contributes to the better understanding of MpSTs in several ways. First, the article updates the theory of MpSTing with the most present concepts. It also identifies specific features and presents taxonomy of MpSTs by a rich set of leading indicators. Next, in this study I propose a detailed framework for MpSTing. The main elements for the overall stress test design are thoroughly covered. Moreover, different options for approaching them are outlined together with corresponding strengths and weaknesses. Where an issue for practical implementation arises, methodological guidance is provided. Finally, the current challenges ahead of MpSTing are discussed. The examination is accompanied with recommendations from my point of view in order to cover concrete setups and circumstances for conducting MpSTs.

The current review shows that MpSTing is beneficial for promoting financial stability if appropriate design and expert judgement are well combined. The

[1] Directive 2013/36/EU of the European Parliament and of the Council of 26 June 2013, art. 100 (1).

underlying fundamentals of a stress test reveal its analytical advantages for identifying potential vulnerabilities to the banking system and mechanism for increasing bank resilience. A fitting framework, which consists of clear goals, robust process (assumptions, methodology, scenarios, risk modeling, results, and follow-up), and sufficient transparency ensures the relevance and credibility of the exercise. Present challenges display that work on MpSTs' development is far from complete, as their application differs across jurisdictions and in time. Acknowledging the inherent limitations and imperfections of stress-testing, it serves as a complement, rather than as a substitute, to the existing regulatory and supervisory tools. As a result, an effective and unambiguous MpST enhances the process of assessing banks' resilience, which ultimately provides valuable input for policy actions purposes.

The rest of the paper continues as follows. Section 2 provides an overview of the theoretical fundamentals, which include definitions, characteristics, principles, and mechanism of transmission. Taxonomy for MpST types is also formulated. Section 3 presents the main elements in the stress test framework: preparation, application, presentation of results, and if applicable follow-up and feedback. Section 4 discusses the current challenges about MpSTing and possible ways forward, while Section 5 concludes.

1. Theoretical fundamentals

The perception of MpSTs has evolved over time. In the early stages of application, the concept of stress-testing is described in a broad manner by IMF 2003 and IMF, World Bank 2005 as a "what if" analysis or a "rough estimate" of a given world (portfolio) in which certain major changes in one or more variables (risk factors) are assumed. More narrowly, several studies attribute the macro stress test to "a range of techniques" for quantitatively assessing the resilience of a financial system to "extreme but plausible" macroeconomic and contagion shocks (Sorge 2004, Čihák 2004, and ECB 2006). A decade later, central banks, supervisory authorities, international organizations, and policy bodies view the MpSTs as important "tools for financial stability" both in advanced and emerging countries all over the world (Jobst et al. 2013, Hristev 2014, and Hsiao, Jiang 2015). With regards to the use of stress-testing to manage systemic risk, Henry, Kok 2013 show that it has proved valuable as an early warning device for identifying potential systemic fragilities, while Borio et al. 2012 argue for its effectiveness as a crisis management and resolution tool. Recently, Dent et al. 2016 provide a governance point of view on the matter and describe a "concurrent" stress test as an exercise conducted under the direction of an official body (usually the banking authority) and in which the entire balance sheets of selected group of banks are simultaneously assessed. To date the most comprehensive

definition for MpSTing is given by the IMF 2012 study, which builds on the quantitative perception of the stress test to the view of a whole process:

"A complete stress testing exercise involves choices on the coverage of institutions, risks, and scenarios; the application of a quantitative framework to link various shock scenarios to solvency and liquidity measures; a strategy for the communication of the results; and follow-up measures, if warranted."

From the presented concepts, the main characteristics could be identified. First, the MpST is a forward-looking technique applied on a system-wide level. This instrument determines the current capacity of a relevant set of banks or the system as a whole to absorb hypothetical future losses. Second, stress-testing is a quantitative (numerical) exercise. It provides for a certain awareness of potential shocks by projecting an estimate of their materiality. Third, it is comprehensive by allowing for incorporation of multiple risks. MpSTs are complementary to the Basel concept of "one instrument – one risk" by combining different risks such as credit, market (interest and FX), operational, sovereign, funding, etc. into one framework. Fourth, stress-testing encompasses "tail risk" events. Simulated shocks are extreme by design and drawn from the tail of the distribution. Fifth, stress tests can be public. If mandated, the process could be accompanied with disclosure of results to foster market discipline. Sixth, being used as a supervisory tool, MpSTing is actionable. In response to the exercise, policy measures including capital and liquidity requirements may be taken. Finally, macro stress tests are dynamic and flexible. They incorporate series of approximations, assumptions, and constraints to project the evolution of the balance sheet, credit quality, profitability, liquidity position, interbank exposures, etc. Accordingly, MpSTing loosens the standard (point-in-time) financial analyses by stretching the accounting and regulatory principles and thus contributes to the financial stability assessment by providing additional insights on bank's resilience to negative extremes and on shock propagation channels.

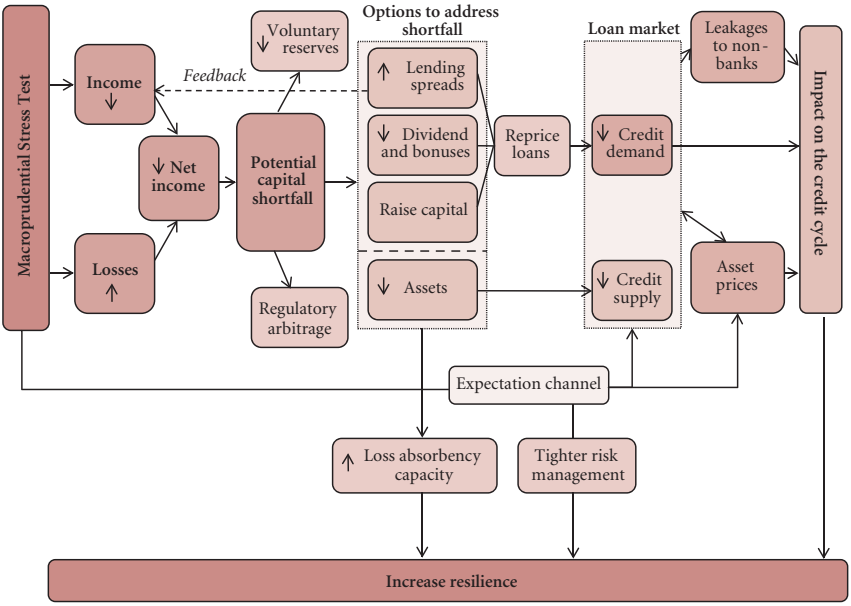
Along with the stress test characteristics expert judgment is applied throughout the process. Expertise is important for validating risk models, but also for fine-tuning and calibrating adversity (Moretti et al. 2008). In Committee on the Global Financial System (CGFS) 2012, it is further elaborated that as modeling uncertainties remain present, sound judgement is required during the conduct of stress-testing as well as for the interpretation of outcomes. As a result, MpSTs inherently go along with the impediment of error and inaccuracy. Hilbers et al. 2004 emphasize on that complexity and points out to the difficulty of regarding the simulation as a "precise tool with scientific accuracy". The works of Quagliariello 2009, Henry, Kok 2013, and Jobst et al. 2013 provide additional caution on the matter of imperfection by raising the issues of associated subjectivity, evolution of risk, and impossible standardization. In that manner, the authors

express the common perception among scholars and practitioners that MpSTing is fundamentally "an art, rather than a science".

The guidelines of EBA 2015 and IMF 2012 reveal the basic principles for designing and conducting a MpST: credibility, relevance, and consistency. The first principle mainly encompasses the corporate governance of the process and its transparency. For an effective stress test that is further linked to supervisory use and actions, there should be a formal program in place with appropriate organization, structure, data support, and IT arrangements. Disclosure of sufficient information regarding the process' assumptions and outcomes should also be considered for achieving reliability. The second principle of relevance is related to the conservativeness of the exercise based on coverage of material risks and propagation channels, adequate scope, suitable scenarios, and comprehensive approach. Accordingly, the focus should be to capture the tail historical events and ultimately to incorporate unthinkable ones (black swans). The third principle of consistency ensures level playing field among participants for common application of the stress test and comparability of results.

The MpST mechanism of transmission as mapped by CGFS 2012 (p. 19) is presented in Figure 1. The direct channel of the exercise is to ultimately promote resilience by assessing bank's capital capacity to scenario shocks. Under stress, banks face constrained income and elevated losses that jointly erode the net income, which has a subsequent effect on the regulatory capital. In the case of a shortfall, a bank could internally turn to its current capital buffers or if manageable to a strategic shift aiming at less risky business. Other options when capital is not available and solvency is called into question by the MpST are to increase lending spreads, retain dividend and bonuses, issue new capital, or reduce assets. The corresponding tightening of stringent credit standards, payment restrictions, costly capital, and risky holdings sales, has a direct impact on the loss absorbing capacity. In addition, resilience could also be enhanced indirectly via the MpST effect on the credit cycle and on the expectations related to market participants' reactions and banks' risk management practices. The former stems from the loan market, in which credit demand and supply are brought down by the tightened banks' businesses ("fasten the seat belts"), while the latter stems from increased market discipline and more robust bank risk management. Kapinos et al. 2015 document that if outcomes are made public and transparent, MpSTs contribute to market discipline by reducing bank opacity and asymmetric information among market participants. Moreover, the authors continue that risk management improves as stress-testing creates incentives for better data collection, richer risk models, and stronger governance practices. The involvement of bank managers in regular exercises keeps the participants alert of potential severity and mindful of their risky behaviour, thereby mitigating "disaster myopia".

Figure 1. **Macroprudential stress test mechanism of transmission**



Source: CGFS 2012, p. 19.

There are different ways for organizing the types of stress-testing on a macro level given a predefined leading preference. In Table 1, I present a specific taxonomy of MpSTs according to their use on the horizontal and their characteristics on the vertical. The former consists of tools by their goal - for supervisory monitoring (surveillance of banks' resilience), crisis management, and calibration of macroprudential instruments (MPIs). The latter categorizes types by scope, methodology, risks, scenarios, approach, balance sheet, transparency, process, and frequency. MpSTs for supervisory purposes encompass elements from across the presented spectrum. The system-wide and macroeconomic, solvency and liquidity, bottom-up and top-down, static and dynamic stress tests fall under this classification. A particular feature of this category is the inclusion of the reverse and market-based type. The crisis management dimension is usually tailored, solvency-focused, bottom-up, accounting-based, and always by design public. For calibration of MPIs the stress-testing is typically internal, low frequent, top-down with sensitivity to a specific risk area analysis.

A vertical cross section of the stress tests' taxonomy reveals further acute links. Solvency stress tests could be static or dynamic, based on sensitivity analysis or macro scenario, and are low frequent. Liquidity stress tests on the other hand are highly or medium frequent ones, but are only structured around accounting (regulatory) data. Market-based stress test is by default tailored, contagion is a top-down type, and the hybrid approach is usually related to solvency. Moreover, complex stress tests are internal and top-down, whereas reverse stress tests involve solvency and liquidity. Public stress tests are run at least annually and incorporate a macroeconomic scenario, direct (traditional) process, and solvency focus.

Table 1. **Taxonomy of macroprudential stress tests**

		Supervisory monitoring	Crisis management	Instruments calibration
Scope	System-wide	✓		✓
	Tailored	✓	✓	
Methodology	Accounting-based	✓	✓	✓
	Market-based	✓		
Risk(s)	Solvency	✓	✓	✓
	Liquidity	✓		
	Contagion	✓		✓
	Complex	✓		
Scenario design	Sensitivity analysis	✓		✓
	Macroeconomic scenario	✓	✓	
Approach	Top-down	✓		✓
	Bottom-up	✓	✓	
	Hybrid	✓		
Balance sheet	Static	✓	✓	✓
	Dynamic	✓	✓	
Transparency	Internal	✓		✓
	Public	✓	✓	
Process	Direct (traditional)	✓	✓	✓
	Reverse	✓		
	Back-testing	✓		
Frequency	High (daily, monthly)	✓		
	Medium (quarterly)	✓		
	Low (annually, biennially)	✓	✓	✓

Note: The table uses insights from IMF 2012 with author contributions on organizing and linking the types of stress tests on the vertical and the horizontal, as well as adding the macroprudential dimension of instruments calibration.

Overall, the solvency macro stress test for supervisory monitoring is to date the most wide-spread and regular form of MpSTing. The exercise is mainly public and goes along with disclosure of either individual bank results (FED CCAR (comprehensive capital analysis and review), EBA EU-wide stress tests, ECB comprehensive assessments, BoE stress tests) or only system aggregated values (central banks' stress tests for financial stability analyses and IMF FSAPs). There are several instances of crisis management stress tests (FED SCAP (supervisory capital assessment program), CEBS EU-wide stress tests, and EU country comprehensive assessments[2]), while the application of stress tests for fine-tuning MPIs is still in early development to be officially formalized.

2. Framework

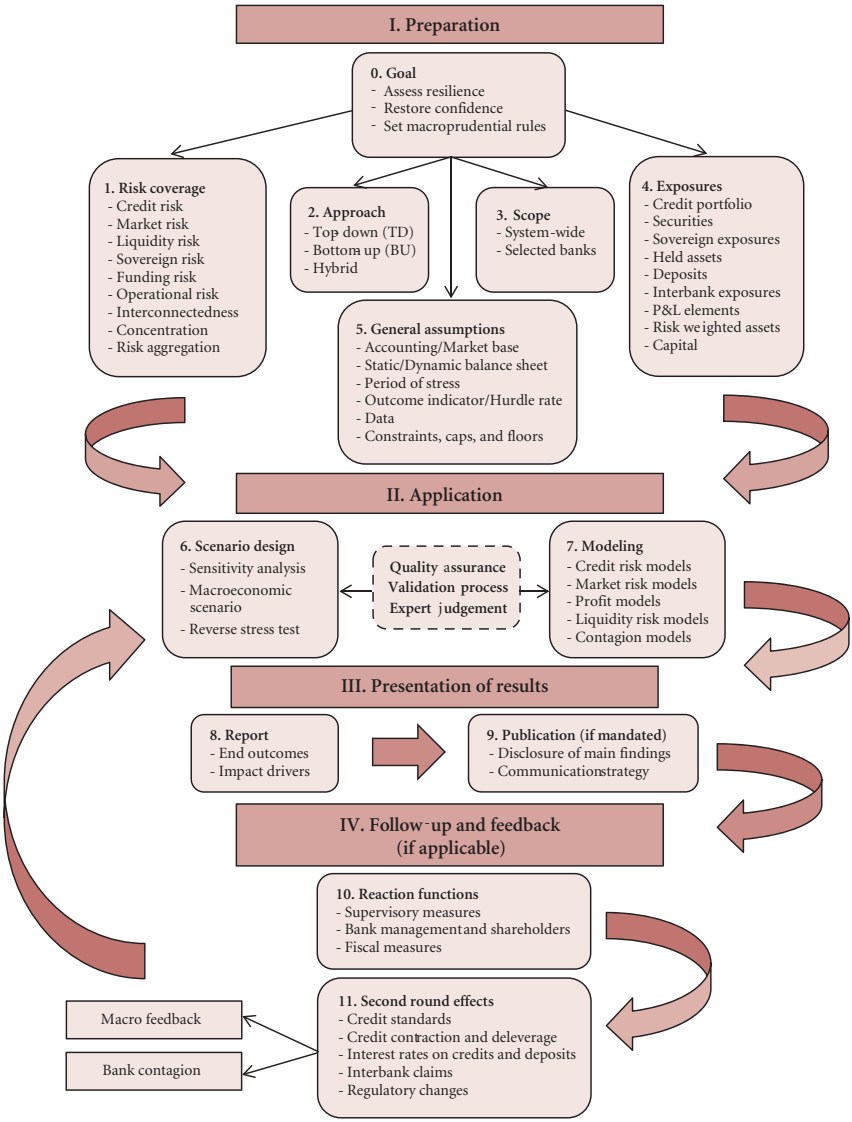
The building blocks of a MpST are preparation, application, and presentation of results (Figure 2). In more details, I propose a framework consisting of the following elements: goal definition, risk coverage, choice of approach, selection of scope and exposures under stress, structuring of general assumptions, scenarios' design, risk modeling, generating a report with assessment of main outcomes, and ways for eventual publication. The process continuous (if applicable) with follow-up measures and a reaction function from banks that could feed back in the stress scenario as dynamic and behavioral second round effects.

2.1. Preparation

In my view, defining a goal is the foundation (ground zero) of macro stress-testing on which all other elements are composed around. It is usually set according to the supervisory perspective of monitoring the potential threats to financial stability by assessing the resilience of banks and the system as a whole to withstand negative shocks. In that manner, the exercise yields thorough insights on banks' capital capacity to adversity and thus can serve as a mean for identifying pockets of vulnerability in the sector. When the MpST is carried out for analytical purposes, the level of severity is stretched, as long as it adheres to the practical golden rule of "severe enough, but plausible". Another objective follows the crisis management concept.

[2] Stress-testing plays an important part of the comprehensive assessments in Europe. To date such exercises on a country-wide (besides the ECB) basis were conducted in Ireland, Portugal, Greece, Cyprus, Spain, Slovenia, and Bulgaria. Although, the nature of assessment is similar, the originating goal and setup is different across the sample. With the exception of Bulgaria, all other comprehensive assessments had a crisis management element reflecting the need for clear capital shortfall measurement. The recapitalization process in Ireland, Portugal, Greece, and Cyprus was part of the financial assistance programmes by the Troika (EC, ECB, and the IMF), while for Spain the scope concerned only a bail-out for the banking sector. In Slovenia, there was not a programme with the Troika, as banks with capital shortfall were recapitalized with own state-aid. The stress test of Bulgarian banks, however, was of a supervisory nature, as the goal was to assess their capital resilience for absorbing negative shocks.

Figure 2. **Macroprudential stress-testing framework**

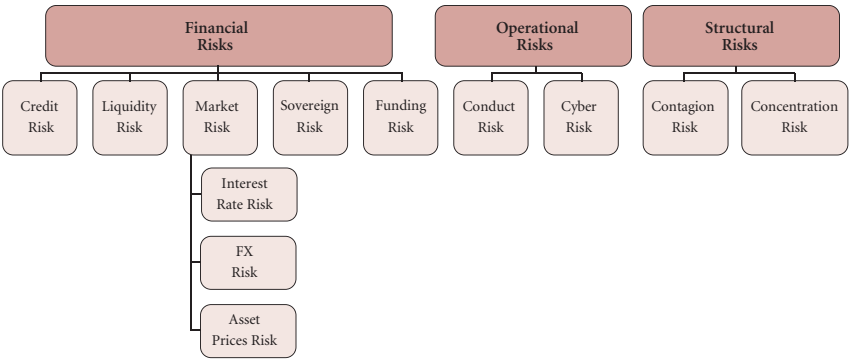


Source: Jobst et al. 2013, Henry, Kok 2013, and author contributions on designing the overall composition, adding goals, quality assurance, follow-up and feedback, and expanding other sections with further details.

The corresponding stress test aims to restore public and market confidence in the banking sector by providing an exact quantification of banks' recapitalization needs. For successful conduct of crisis stress-testing, credibility is of utmost importance (Ong, Pazarbasioglu 2013). It requires a clear objective, sufficient transparency, full commitment, appropriate follow-up actions, and explicit financial backstop. A third goal for MpSTing is to contribute the process of setting macroprudential rules. More specifically stress tests could play additional input for calibration of capital buffer. As the topic is yet to be explored, applying such objective is not that common. There is also another goal that implicitly goes along with stress test conduct - to enhance market discipline (Goldstein, Sapra 2014 and Woo et al. 2014). Even though it is not a primary objective, disclosing bank information with a clear communication on results serves as a complementary to the three main goals by promoting transparency of the risks in banks.

For the next step of the process, the risk coverage is identified. It mainly comprises of financial, operational, and structural risks (Figure 3). Typically for a solvency stress test, credit risk is in the focus, as lending is the center of the traditional banking business. Market risk or the movements in interest rates, currencies, and asset prices (equities, debt securities, commodities, etc.) is also considered together with sovereign risk (haircuts on general government exposures). Additional risks come from higher costs of funding and operational events (including conduct and cyber risk[3]).

Figure 3. **Risk coverage**



Source: Kunghehian 2013, author contributions on adding sovereign and funding risk together with operational and structural risks.

[3] Currently, cyber risk is not part of stress tests but there are strong calls from EBA, ECB, and BoE for including it in the future (Financial Times, 2016).

The liquidity risk is based on the concept of Brunnemeier, Pedersen 2009, which comprises market illiquidity (securities are no longer liquid) and funding illiquidity (bank run). Counterparty structural risk is also important for financial stability that arises from interconnectedness (interbank contagion) or concentration (group of clients or a sector). On aggregate, credit risk and market risk are predominantly combined for solvency purposes with certain additions from sovereign, funding, operational, and concentration risk. As a second order complement, when a bank is insolvent, contagion risk could crystallize (Elsinger et al. 2006). Liquidity risk is normally tested individually but with the works of Puhr, Schmitz 2013, Pierret 2014, and Basel Committee on Banking Supervision (BCBS) 2015 research attention on the solvency-liquidity nexus is growing. Given the systemic importance of limited market access, fire sales and financial contagion, I share the view that an integrated approach is the way forward for incorporating all risks.

There are two alternative approaches in a MpST: top-down (TD) and bottom-up (BU). In the first option authorities run internally the exercise themselves by applying a uniform methodology on aggregate data. In the second, banks evaluate individually the impact on their balance sheets from a centrally pre-defined macroeconomic adversity in a more granular way. The selection of an alternative is central to the defined goal as both approaches have their strengths and weaknesses (Table 2). For instance, the TD approach is more flexible, relatively easy, and cost efficient. In my opinion it also allows for severity calibration, as well as incorporation of contagion analyses and macro feedbacks. By applying common methodology and assumptions, comparability across banks and consistency are ensured. On the downside, TD stress-testing may lack precision, transparency and applicability for banks with internal risk modeling. The BU option tends to be more tailor-made, as it incorporates bank idiosyncrasies, granular data, and risk models specifics. In addition, the involvement of bank management in the process provides better understanding of risk management practices and culture. As results are confirmed by banks, I would argue that a BU approach is more appropriate for individual disclosure and thus it is widely used for public exercises. However, such method comes with a great expense in terms of labor, time, and resources. Moreover, in order to ensure a certain degree of comparability, quality assurance (QA) process is necessary, which in times could be a lengthy and cumbersome procedure. Therefore in practice, a hybrid (constrained BU) option that combines both approaches is present as well[4]. The stress test is run by banks but under pre-defined constraints together with TD challenges and centralized QA. Accordingly, Jobst et

[4] The constrained BU approach is used in the EBA and BoE exercises, as well as in the Bulgarian National Bank (BNB) 2016 stress test.

al. 2013 advocates on behalf of IMF staff for the use of both approaches by considering them as complementary, rather than as substitutes.

Table 2. **Comparison of approaches for macroprudential stress-testing**

	Top-down (TD)	Bottom-up (BU)
Advantages	- Ensures objective comparability across banks by uniform methodology and consistent assumptions - Full aggregation of bank-by-bank results - Relatively easy to implement and resource-effective - Allows for incorporation of second round effects, interconnectedness and dynamic elements - Controlled framework and common environment - Calibration of severity with different scenarios and shocks	- Utilization of granular proprietary data on loan portfolios and exposures - Bank management engaged in the process - Banks' advanced internal models capture risk idiosyncrasies in business models and institutional differences - Confirmed results by bank - Appropriate and credible for individual publication - Widely used in public exercises - Refer banks to severity benchmarks and tail-events - Better understanding of banks' risk models, practices, and risk management culture
Disadvantages	- Low precision and fewer details due to data limitations - Application of simple models may produce overstandartization with inaccurate aggregates - Unsuitable for sample of banks with internal models - Lack of transparency and "black box" to banks and the public - Difficult to account for bank characteristics and institution specific information	- Contagion and second round effects are not accounted for - Requires extensive quality assurance process to challenge results - Labour-intensive and time-consuming - High-level of cooperation and coordination among participants - Possible influence on results by institution-specific assumptions - Conditional aggregation and comparison of results due to banks' risk models - Ex-ante predefined methodology

Source: IMF 2012, Jobst et al. 2013, author contributions on expanding the matrix in terms of usage, calibration, transparency, and management of the process.

The stress test scope follows the selected approach by targeting banks' coverage. Inclusion of all banks in the macroprudential exercise is usually done in a TD manner, while for a BU approach only a number of banks participate, especially the systemically important ones. A specific case is the BNB 2016 stress test, which has a BU approach with system-wide coverage. In terms of exposures, the appropriate level under stress corresponds to the risk materiality but should capture the on- and off-balance sheet dimension, as well as the domestic and foreign one. For credit risk, the focus is on the banking book. Loan exposures are generally aggregated as corporate lending, mortgages, and consumer lending. The trading book comprising of held for trading (HfT) and fair value through profit or loss (FVO) instruments is stressed for market and sovereign risk together with securities (incl. general government exposures) designated as available-for-sale (AfS) and held-to-maturity (HtM). Components of the liquidity stress test are liquid assets (cash, financial assets, bank placements) and funding liabilities from wholesale and retail (deposits) sources. For contagion analyses, a matrix based on interbank claims is typically employed. They can be defined on gross (interbank assets) or net (interbank exposure accounting the difference on the asset and liability side) basis. The effects from stress-testing concern the balance sheet, the profit and loss (P&L) statement, the liquidity position, risk weighted assets, regulatory capital, and pricing of financial instruments.

MpSTs can be generally based either on accounting or market data. The former choice incorporates on- and off-balance sheet positions, as well as supervisory and regulatory items (Čihák 2007 and Schmieder et al. 2011). Frequency of data depends on reporting and is usually at least on a quarterly basis. Balance sheet approach is convenient for designing a macroeconomic scenario, estimation of regulatory risk factors (non-performing loans (NPLs), loss rates), and provision of supervisory capital and liquidity outputs. The latter captures public information embedded in asset prices across financial instruments and bank equities (Acharya, Steffen 2014). Market data is obtained on daily basis and bank specific default frequencies are estimated through sensitivity analyses (for instance a decline in global stock market). The outcome of the market exercise comprises of expected losses and spillover probabilities among banks. IMF 2012 and Demekas 2015 provide extensive overviews of these assumptions and agree on both advantages and disadvantages present. Accounting-based stress test is widely used, as it allows for incorporation of various risks, macroeconomic link to banks' performance, and expert judgment assumptions, but market-based stress-testing steps on data that is forward-looking and easy to update. Weaknesses of the market data method, though, correspond to data availability and possible unrelated to fundamentals market swings. In support of market stress tests, Kapinos et al. 2015 point out that exclusive reliance on book equity may yield benign

results, while Acharya, Steffen 2016 criticize the regulatory approach of measuring capital adequacy (capital definition and risk weights) for being less accurate. In practice, however, for macroprudential and especially policymaking purposes, Constâncio 2016a advocates for the accounting based stress test as the more suitable for application. First, it is linked to a macroeconomic and financial narrative and second it is not subject to substantial procyclical volatility or "whims of the market". Additional limitations stem from the deepness of the market that puts challenges on comprehensiveness. In that manner, Jobst et al. 2013 conclude that the accounting approach remains the "cornerstone" of MpSTing.

The next common assumption posts the dilemma of static or dynamic balance sheet to the extent that accounting base is employed. Under the static balance sheet assumption there are several specifications. First, there is no credit growth and write-offs, as gross loans remain constant. Second, banks maintain the same business model (geographical exposure, currency composition, product mix), there are no management actions (e.g. restructuring, assets sale, one-off effects, risk mitigation techniques), and capital support is disallowed. Finally, maturing securities are replaced by identical instruments in terms of issuer, currency, balance sheet classification, and remaining maturity. Under the dynamic balance sheet assumption, on the other hand, balance positions evolve in line with the scenarios and management actions are allowed to a certain degree. With regards to the evolution of credit, the static approach keeps the total amount of gross loans unchanged, but the quality composition worsens as NPLs increase on the account of performing ones. In the dynamic stress-testing, gross loans are extended with applied credit growth and subsequently for the new lending the general practice is to remain performing, i.e. no credit shocks. The static balance assumption eases the life of stress-testers, as it is simple and straight-forward. It enhances comparability across banks and facilitates communication of results, but there are flaws as well. The stationary balance is regarded as additional constraint and being unrealistic, because banks never stay static. Accordingly, dynamic stress-testing is gaining momentum. Henry, Kok 2013 describe the ECB framework for projecting balance sheet elements, while BCBS 2015 provides an overview of methodologies that incorporate solvency and liquidity dynamics. A general practical rule associates the static balance sheet assumption to a BU stress test and the dynamic elements to a TD stress test, but the vice-versa option is present as well.

Moreover, the horizon of stress is also relevant. As it takes a longer time period for effects to unfold, solvency stress-testing assumes typically at least one year[5]. Liquidity stress tests are shorter-term - between 5 and 30 days, while for market and contagion risk, the shock is instantaneous. When setting the

[5] The stress period in the US, EU, and UK (standard) exercise is 9 quarters, 3 years, and 5 years, respectively.

outcome indicator, the common practice is to follow regulatory measures (risk based capital ratios[6], leverage, liquidity ratios). As far as the corresponding hurdle rates (pass or fail threshold) are concerned there are various experiences. One practice is to set the bar in terms of minimum regulatory requirements (financial stability perspective) or a combination with capital buffers (BoE 2015). The reference levels could also be determined by expert judgment. An alternative approach is to apply no hurdle rate (EBA 2016 and BNB 2016a). The stress test results accordingly serve as an input to the supervisory assessment under the Supervisory Review and Evaluation Process (SREP). For recapitalization purposes (crisis stress test), Ong, Pazarbasioglu 2013 highlight the importance of committing to a pre-defined pass/fail hurdle rate for achieving credible capital shortfall estimates. They in turn affect subsequent capital raising or potential fiscal support. The cut-off period for data is selected as of year-end prior to the stress test on either individual (unconsolidated) or consolidated basis. Semi-annual reference is also possible but less popular. Certain limitations could be assumed on P&L items, RWAs, capital and pricing of instruments. For instance, caps are imposed on dividend income, net fee and commission income, net trading income, and capital while interest expenses and RWAs could be floored by the starting point. One major constraint is the restriction of accruing interest income on NPLs or defaulted assets under adversity, which differs from the usual going concern accounting principles. Another assumption does not allow for optimization of administrative expenses during stress or inclusion of one-off adjustments. In case of assumed funding shock, banks may be restricted to fully pass forward the higher cost of financing to borrowers. Finally, rules for dividend distributions could be set – allowed payout, zero payout, or both.

2.2. Application

The application part of MpSTing begins with the scenario design[7]. In its simplest form sensitivity analysis evaluates the impact of an instantaneous shock of one or a set of risk drivers. Typical examples of sensitivity stress reflect parallel interest rate shifts, currency devaluations, rise of NPLs, and many others. Although it is simple and intuitive, it has no economic justification and therefore has limited suitability. On the other hand, implementing a macroeconomic scenario is more complex, however, the effects are quantified in a comprehensive and continuous manner. Usually in a MpST, a single scenario is constructed in two

[6] A common used outcome indicator is the CET 1 capital ratio. It equates to the division of common equity tier 1 (CET 1) capital as a numerator and risk exposures (RWAs) as a denominator.

[7] Scenarios are designed mainly for solvency stress tests. For liquidity stress-testing, bank runs and haircuts on realized assets are assumed in the short-term.

aspects - baseline and adverse. The baseline scenario mostly follows the current official central bank macroeconomic forecast but alternative sources such as the IMF WEO outlook, EC economic forecast, ECB macroeconomic projections are also possible. The adverse scenario represents hypothetical but plausible negative (extreme) macroeconomic developments. It is based on historical or newly constructed episodes. The techniques for designing an adverse scenario fall into three main categories – model-consistent (Foglia 2009 and Licari, Suárez-Lledó 2013), judgmental (Melecky, Podpriera 2010), and combination of both (Hristev 2014). The first type consists of dynamic stochastic general equilibrium (DSGE), vector autoregressive (VAR), and structural econometric models, as well as statistical approaches like copulas or standard deviations. The second one employs solely expert judgment and is used when modeling is not available or not capable of generating appropriate scenarios. The third category combines a macroeconomic model and expert judgment for fine-tuning. In practice, it is difficult to disentangle a specific technique, as more than one is typically integrated. For instance, the adverse scenario for EBA 2016 EU-wide stress test combines predominantly models[8], multi-country EU-wide stress test elasticities (STEs)[9], and expert judgment (European Systemic Risk Board 2016), while the BNB 2016 stress test utilizes central bank macroeconomic econometric model, EU-wide STEs, statistical approach (standard deviations), and national expertise (BNB 2016b). Regardless of designing techniques, the selected option should be wrapped in a convincing narrative. The story behind the numbers starts with identification of main sources of risk to the economy and subsequently to the banking sector, which materialize as economic (foreign and domestic demand, investment, consumption) and financial (interest rates, volatility, depreciation of local currency, house prices) shocks[10]. Typical macroeconomic variables in scope are real GDP growth rate, inflation (HICP), unemployment rate, short- and long-term interest rates, FX rates, and asset prices (equities, bonds, residential and commercial property prices). Key variables may follow a W-shaped (double dip), V-shaped (fast recovery), U-shaped (slow recovery), or L-shaped (stagnant recovery) recession. Presentation of scenarios is usually against historical time series, crisis episodes, or other scenarios in different stress tests.

For producing a credible and relevant MpST, the level of severity is critical. Breuer et al. 2009 raise the question on credibility that concerns the link between severity and plausibility. The authors provide a sound statistical solution for find-

[8] Among others, there are DSGE models, Bayesian and Global VAR models, and large scale global econometric (NiGEM) models.

[9] The STEs are impulse responses based on forecasting national models in the central banks of the ESCB and integrated by the ECB as an instrument for scenario-generating processes.

[10] In a liquidity stress test, a bank run crisis is designed that incorporates withdrawal shocks and market haircuts.

ing the worst case scenario, which in their view enhances objectivity and makes the "disaster myopia" obsolete. In my opinion, however, it is difficult to link such method with a consistent narrative that captures the "unthinkable" and the next "black swan". Accordingly, a stress-tester may alternatively opt for a combination of scenarios or reverse stress-testing. The multiple scenarios topic attracts supporters, as being a good practice and common sense (Dowd 2015), flexible for exploring new or emerging threats (Dent et al. 2016), and a backstop for banks to "game the test" (Demekas 2015). By using multiple in terms of number and type scenarios, the assessment of bank resilience is enriched with a variety of shocks and the coverage of reledet risks is ensured. Alongside the advantages, there are pitfalls as well. With multiple scenarios, the resource burden is stronger for both banks and regulatory authorities, especially when conducting BU stress tests. Moreover, difficulties with summarizing and publishing stress test outcomes pose a challenge on communication of results. Taking into account both sides, the following question arises: how multiple is optimal (plausible)? I share the pragmatic view of Quagliariello 2017 that at the moment multiple scenarios have limited practical application in a system-wide stress test, but "specific add-ons and sensitivities can add to the severity of the scenario". In a different paradigm, reverse stress-testing is also useful for identifying severe paths in the scenario (Bookstaber et al. 2014). The assessment of tail risks that most likely render a bank unviable reveals additional inputs to the traditional scenario design. Bologna, Segura 2016 bring up the question of scenario relevance regarding severity and cyclicality. Their research calls for procyclical severity generating countercyclical regulatory capital requirements, which in the light of the macroprudential principles I find warranted[11]. It means that during economic expansions, severity should be increased in order to attain higher capital requirements and vice versa during recessions. The proposed mechanism exhibits macroprudential features and helps the setup of Basel III capital buffers along the cycle. In practice, the Bank of England's approach to stress-testing accounts for the issues on severity (BoE 2015). The BoE stress test framework incorporates two types of adverse scenarios – annual cyclical scenario (ACS) and biennial exploratory scenario (BES)[12]. The first one is a standardized macroeconomic scenario with a 5-year horizon and is associated with the financial cycle. Its severity increases as risks buildup and decreases as they materialize or fade away, but the precise calibration integrates judgment from policymakers. The role of ACS is to put focus on capital adequacy and contribute the setting of capital buffers. The second type of scenario explores a wider and mostly unusual from historical perspective set of risks and their

[11] Constâncio 2016b and Brazier 2017 advocate for strong countercyclicality as a fundamental principle when conducting macroprudential policy.

[12] Both scenarios overlap for the first time in the 2017 BoE stress test exercise.

evolution over the period of 7 years. Unlike the ACS, the BES attempts to sketch the future outlook of the financial system by assessing banks' business models prudence, strategies, and resilience. As the subject of scenario severity is yet to be practically and academically settled, expert judgment remains crucial for scenario fine-tuning and calibration.

Risk modeling that translates scenarios into quantifiable effects for banks' balance sheet is an integral part of the MpST. There is a vast universe of models, which could be categorized by risk type. Henry and Kok 2013 provide a detailed overview of various models for different risks, while Foglia 2009 and BCBS 2013 focus exclusively on credit and liquidity risk models, respectively.

For credit risk, the link with the macroeconomic variables has been widely constructed on credit-quality regression (satellite) models. They can be grouped into two main approaches. The first approach employs indicators for credit quality drawn from banks' balance sheet on the left-hand side of the equation and on the right-hand side - macroeconomic indicators coupled with specific for the banking sector factors. A typical dependent variable is the NPL amount or ratio based on supervisory data[13]. When NPL modeling is considered, corresponding credit shocks are generated from the macro scenario and then are applied to the non-working side of the loan portfolio. NPL models could be further specified for corporate and retail credits, thus accounting for their respective propensity to changes in output, interest rates, unemployment, and other macro variables. Finally, the effect for the P&L stems from the impairment costs, which are calculated as the product of the newly formed NPL flows and a provisioning rate under stress. Alternative mechanism is to model directly the loan loss reserves (stock of accumulated impairments) or impairment costs (flow of impairments).

The second approach utilizes the risk parameters from the Basel frameworks. It is currently the most prominent modeling of credit risk and follows the formula:

$$EL = EAD * PD * LGD \qquad (1)$$

Where:

EL is the expected loss;

EAD is the exposure at default, which represents the outstanding amount if the borrower defaults;

PD is the probability of default of a counterparty over a one year period;

LGD is the loss given default, which represents the ratio of the loss on an exposure due to the default of a counterparty to the amount outstanding at default, or the non-recovered part.

[13] Other models could employ different options like write-offs (monetary statistics) or defaults (credit registers).

The *PD* estimation is mainly performed via logistic regressions, as the output is bounded between 0 and 1. Selection of the dependent variable follows a logistic transformation of a bankruptcy rate or a similar deterioration of quality (e.g. loans past due 90 days). The independent variables are of macroeconomic and obligor-specific nature. For the *LGD* factor, the calculation encompasses information on borrower's payments and collateral value. Contrary to the previous approach, *PD* and *LGD* parameters are applied on the performing loans in order to obtain losses. A further modeling consideration expressed by Buncic, Melecky 2012 is the choice of implementing the factors through-the-cycle (TTC) or point-in-time (PIT). TTC risk factors are estimated over the whole cycle and their conservativeness depends on the downturn deepness. If the cycle includes a number of crises, then additional credit risk shocks should be applied with caution. PIT risk factors reflect the current state of business. Usually, they are stressed with higher adversity, but the estimation may pose volatility challenges (or over-conservatism) due to unrelated to macroeconomic conditions or one-off factors. A prudent rule to capture current risks is to apply PIT parameters on newly defaulted exposures (EBA 2016), while for already defaulted exposures a TTC approach is also suitable (BNB 2016c). Additional calibration stems from the starting point of risk parameters, i.e. lower starting points are associated with higher credit shock, and vice versa.

The market models map the stress in the trading book positions to projections of net gains and losses. As the models require high-frequency data, usually they are implemented in a BU stress test with a given set of market risk parameters (stock prices, credit spreads, swap rates, etc.). A TD option is a more simplified version that links the net trading income to its historical volatility. For sovereign exposures, haircuts are derived from the price deviation, which is typically based on discounted cash flow method incorporating a shock to the yield curve. In the profitability models, satellite calculations are translated into the evolution of net interest income, non-interest items, and other P&L elements. The liquidity risk models typically comprise the market and funding part of the shock in a three-step process (van den End 2008). First, a liquidity shortfall is envisaged, which reflects the lack of liquid assets to absorb assumed withdrawals. Second, banks' reaction is modeled via fire sales and third the corresponding feedback effects amplify the initial shock. Contagion models assess the spillover effects from a failing bank. They are rather static and mechanical because are often based on balance interbank claims. Different approaches include a "domino effect" analysis (Espinosa-Vega, Solé 2010), clearing mechanism (Eisenberg, Noe 2001), and post-shock network equilibrium (Gouriéroux et al. 2012).

An important element of the stress test application, especially for BU exercises, is the quality assurance (QA) process and validation of outcomes. The goal

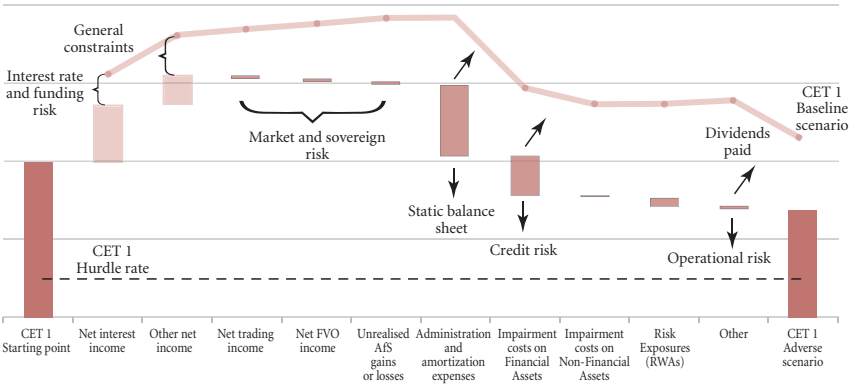
of the QA is to check compliance with the prescribed guidelines, appropriate level of conservativeness, and adherence to the technical constraints. Robust supervisory challenging of results increases relevance and comparability. It also ensures the level playing field, so that more conservative banks and those with less prudent methods are treated equally. For that purpose, stress test outcomes are compared in a TD manner with cross-section benchmarks, historical time-series, and general rules of thumb. Practical guidance on the QA process is provided in the ECB 2014 note. The ECB approach represents a score card that has a Red/Amber/Green (RAG) attributes. Green color corresponds to full compliance and no modification, amber color refers to "comply or explain", and red color stands for non-compliance and further resubmission of results. Traditional areas of examination are input data, credit risk parameters, market and funding shocks, one-off events, inconsistencies with assumptions, sufficient volume of qualitative explanations, etc. TD tools supplement the QA with independent stress test quantification that challenges consistency of results. For additional analyses, qualitative information is employed, as well. As one MpST involves a vast amount of quantitative and qualitative information, the QA process follows the principle of materiality and accordingly focuses on issues that significantly alter the stress test outcome. Moreover, validating results is essential for credibility. By back-testing the models, robustness of shocks is enhanced by not overshooting or underestimating them. Finally, expert judgment is applied for the QA and validation process in order to detect inconsistencies and manage outliers.

2.3. Presentation of results

The MpST ends with a report of the main outcomes. Stress test results can be summarized on a system or bank-by-bank level. Further options are by peer groups or statistical distributions. The evolution of capital or liquidity outcomes is provided for each period of the scenario, as well as the number of banks that fail to meet the pre-defined hurdle rate (if applicable). In that manner, absolute and relative to GDP shortages are given together with a percentage of total system's assets under consideration. The stress test is by design an analytical tool, so even if all banks are above the minimum threshold ("pass the stress test") that does not mean there are no vulnerabilities. Assessment of banks' sensitivities to shocks, propagation channels, and risk amplifications provides valuable insights to policymakers. For example in a solvency framework, the stress test reveals credit risk evolution, market risk sensitivity, capacity of net interest earnings, cost efficiency and sustainability of bank's business model. Moreover, in a liquidity stress test, the liquidity position is analyzed against different patterns of depositors' behavior and corresponding asset management strategies, while in the contagion exercise the

degree of interconnectedness and systemic importance is revealed. Accordingly, stress test results are supplemented with detailed information about credit risk parameters, NPLs and provisioning, liquid assets, P&L items, pricing of loans and deposits, etc. Technical notes describing the scenario design, methodology, models, qualitative summaries, assumptions and limitations also accompany the report for better clarification.

Figure 4. **Stylized contribution of main drivers to the change of CET 1 capital ratio**



Notes: Impact of specified bars is generally colored and it could vary from one bank case to another.

Other net income mainly comprises net income from fees and commissions and net other operating income. Net FVO income is generated from financial assets and liabilities designated at fair value through profit or loss. Unrealized AfS gains or losses correspond to available-for-sale financial assets and liabilities. Impairment costs on financail assets are typically from loans and advances and held-to-maturity investments. Other category consists of operational risk losses, paid dividends and taxes, and capital adjustments.

The figure has an illustrative purpose and does not represent a specific numerical expression of bank results. All impacts are of exemplary nature.

Additional granularity on the impact of different risk factors is included in the report to appropriately convey the stress test findings. In the solvency stress test the contribution of each driver to the change of CET 1 capital ratio is shown via the widely-used format of a waterfall chart (Figure 4). Under the baseline scenario and static balance sheet assumption, net operating income remains intact with additional gains from market instruments. Fixed costs like administration expenses reflect the biggest financial burden for a bank to support its business, whereas credit impairments affect the P&L moderately. End-

capital position depends on the assumed dividend policy - it improves when profits are retained and declines when dividend pay-out exceeds the current profit with reserves from previous financial years. Under the adverse scenario and static balance sheet assumption, net interest income shrinks from interest rate and funding shocks or could even become negative. Next, the economic activity slowdown subdues the net income from fees and commissions, while imposed general constraints like one-offs restrictions affect the net other operating income. Market and sovereign shocks are typically negative, but the net trading income could be positive, however with less impact than the one in the baseline scenario. The static balance sheet assumption keeps the burden of administrative expenses intact[14], while loan losses surpass the baseline figures by a factor of two, three, or more. Impairments on non-financial assets mainly related to lower real estate prices contribute to the CET 1 capital ratio reduction. Final shocks to solvency come from higher risk exposures and operational losses reflecting the deterioration of credit quality and processes (including conduct), respectively. Usually, in the end of the adverse period, CET 1 ratio is lower than the starting point or it could even become negative, i.e. the bank is technically insolvent. In the liquidity stress test, the impact of market illiquidity and funding illiquidity risk drivers is presented for every period via the available liquidity buffers and the cumulative deposit withdrawals. In a contagion simulation, the effect on the interbank network reflects the inflicted capital losses from the insolvency of each bank.

If mandated, a stress test could be publicly disclosed. The decision to communicate the exercise in public together with its granularity and scope relies entirely on the authority's approach and adopted goals. Practices of MpSTs disclosure vary substantially across jurisdictions. Some authorities opt for broad transparency with scenarios, methodologies, and bank-by-bank results, while others limit the publication to aggregate results. There is also the case when stress test outputs are kept private for internal purposes. In the US for example, publication of aggregate and individual results is required by law[15], while in the EU-wide context the EBA founding regulation compels the supervisory authority to disclose bank-specific results if "appropriate to do so"[16]. The UK experience on transparency follows the official stress-testing framework of the Bank of England (BoE 2013, 2015), in which the central bank commits to disclosing its approach, results (both aggregate and individual), and policy actions. Other instances like the IMF FSAPs and com-

[14] Under the dynamic balance sheet assumption (contingency plans) administrative expenses could be limited as banks may respond to a crisis with cost-cutting strategies like lay-offs, business scale downs, remuneration adjustments, etc.

[15] See Sec. 165i (1) and (2) of the Dodd-Franc Act.

[16] See Art. 22 (1a) of the Regulation (EU) No. 1093/2010.

prehensive assessments have unique degree of transparency as each exercise differs from one another. The former always has aggregate results at minimum (Jobst et al. 2013), whereas the latter is traditionally accompanied with bank-by-bank disclosure (ECB practice). From theoretical point of view, a vast body of researchers advocate for publication of results to promote financial stability (Bookstaber et al. 2014, Goldstein, Sapra 2014, and Woo et al. 2014 among others). In their view disclosure of stress test outcomes produces valuable information to the market, reduces banks' opaqueness, strengthens the supervisory position for demanding more capital, improves bank management through market discipline, and induces further voluntary transparency. Empirical papers employing event study and bank performance methods confirm in general the theoretical benefits of stress test transparency. In the US, publication of results generates significant new information to the market, which reduces asymmetry and mitigates bank opacity (Fernandez et al. 2015 and Flannery et al. 2017). The result is affirmed as well for European banks by the market reactions to the EBA 2011 stress test (Petrella, Resti 2013). Candelon, Sy 2015 compare the market reaction to U.S. and EU-wide stress tests in the period of 2009 – 2013 and observe that the qualitative aspects of the stress test governance such as strong institutional framework and credible financial backstop seem to matter more for market participants. Along with the positives of disclosure, stress test publications are also associated with potential costs. Hirtle, Lehnert 2014 alert that there is also the risk of investor panic (self-fulfilling prophecies) or bank managers focusing solely on short-term results (beauty contest). When publishing results, accompanying communication strategy is also key (Enria 2017). It is needed to make sure that stress test nature is understood properly and results are interpreted with caution. While plausible, the MpST is a hypothetical exercise under specific assumptions with outputs that are not perceived by the authority as likely to happen. Moreover, stress test results are intend to illustrate potential vulnerabilities in a quantified manner and are not considered to represent a prediction about the financial stability of the banking sector or an individual bank. Finally, the public should be informed how the stress test results affect the supervisory decision-making process. Taking the costs and benefits together, there is a positive information value of disclosing stress test results, but any decision to go public has to be considered carefully and communicated clearly.

2.4. Follow-up and feedback

The main stress test outcomes feed into the supervisory assessment of banks. They provide for another source of evaluating banks' capital and liquidity position, reviewing their business plan and strategy, and examining the recovery and contingency plans. For solvency purposes, stress test results contribute to determining the adequate level of capital. If deemed necessary a reaction function is possible. Based on the results, supervisors could prompt direct recapitalization or as part of the SREP, they could prescribe capital requirements (P2R) or capital guidance (P2G) under Pillar 2. Other supervisory measures could restrict dividend payout, staff remuneration, and share buybacks. In turn, banks may have to respond with raising capital, adjusting their business model, selling business lines, or restructuring. A fiscal backstop serves as an option from last-resort. Other follow-ups to banks could target their risk governance processes, which fosters further development of efficient and adequate risk management tools. Finally, stress test results are incorporated in the microprudential (e.g. on-site inspections) and macroprudential (e.g. setting capital buffers) supervisory toolkit.

Policy and bank actions lead to behavioral and dynamic feedbacks that could if applicable further aggravate the initial macroeconomic scenario (second-round effects). These macro-financial linkages are modeled in a TD manner (Henry, Kok 2013). A major response channel is through adjustments on the asset side. For example, one way to address a stress test shortfall is to contract credit and tighten credit standards. The corresponding feedback causes limitations in credit supply and thus creates a further shock to output. Another reaction comes from industry deleveraging, which could induce firms to constrain production and spur lay-offs. Finally, higher interest rates contract consumption and may cause additional credit quality deterioration. Through the liability side, bank contagion (Lehman episode) could also surface as a second round effect.

3. Challenges

Evidently MpSTs are here to stay. The topic attracts attention from various sides – academics, bankers, supervisors, policy makers, market analysts and the wide public. The growing body of research provides a far better understanding about the theory and practice of stress-testing but there are still a few questions that remain a challenge.

To publish or not to publish stress test results

As publication of stress test results goes along with costs and benefits, the debate on transparency continues. To publish or not to publish stress test

results? And if so, to what extent? The decision to go public with a stress test firstly corresponds to its mandate, which is usually embedded in the exercise beforehand. Then, it should also consider the underlying goal and approach (EBA 2015). If disclosure is not specifically mandated, authorities use their own discretion to publish results or not when they deem appropriate[17]. Overall there are three ways of approaching transparency – stress test results remain private (no publication), stress test results are disclosed only at aggregate level (partial publication), or stress test results are disclosed at both aggregate and bank-by-bank level (granular publication). Schuermann 2016 suggests that in "peacetime" (supervisory stress test) less detailed results are necessary, while in "wartime" (crisis management) high transparency and individual disclosure is required. Goldstein, Leitner 2015 propose similar disclosure policy. In normal times and banks are perceived as strong, no disclosure is needed, but if banks are viewed as undercapitalized partial disclosure emerges as optimal. In bad times, if results are not known to the bank before the stress test, a distribution of strong and weak banks could be presented. However, if the results are known to the bank beforehand (but not the market), optimal disclosure favors multiple categorization of banks, i.e. publishing individual results.

In practice, the general approach is indeed to publish aggregate TD results as part of the regular monitoring in a financial stability report (central bank stress tests and IMF FSAPs). The system-wide exercises in US, EU, and the UK began with publication of bank data to restore confidence in the banking sector as part of the response to the financial crisis and since then sustained the level of public granularity. Moreover, comprehensive assessments in Europe were finalized with disclosure of individual findings. A distinct feature of public exercises, though, is that they are conducted in a BU manner and the lesson learned is to ensure a credible backstop if individual results are disclosed. Taking into account the academic practical side of the matter, my recommendation is towards appropriate transparency. For sophisticated exercises in terms of scope and governance magnitude, publication of results should suffice market expectations. In that manner, bank information is disclosed together with detailed notes on the overall stress test design. For regular supervisory exercises, on the other hand, individual data may not be published, but there are positives for presenting results of the banking system. Publication of aggregate outcomes enhances the relevance of the risk analysis report and serves as an instrument to draw public awareness on analytical tools for bank assessment. It also increases transparency and is in line with the current IMF FSAP practices. Disclosing of minimum banking system results should be the pursued benchmark by supervi-

[17] In the EU, competent authorities are compelled to run at least annually supervisory stress tests in their national jurisdictions, but there is no standardized requirement for their transparency (CRD IV art. 100).

sors and presented from their discretion in a form deemed most recognizable by the general public.

In the end, the choice of publication and corresponding granularity relies solely on the banking authority taking into account the sophistication of financial intermediation, market development, and environment expectations. Given the considerations of transparency, credibility, and backstop (fiscal) availability, the decision for disclosure is far from being straightforward and still poses a challenge.

Top-down vs bottom-up conundrum

In line with the previous discussion, there are advantages and disadvantages for the TD and BU approach, but the final choice comes down to the decision of disclosing individual results. When the exercise is conducted in a public fashion, it would be unusual to disclose bank data without banks participation. Accordingly, credibility of results must be preserved, which is trade-off with a certain price. Thus, for a public stress test the constrained BU approach is the first step and QA – the second. Due to the resource intensive process, an optimal practice for authorities is to conduct a public BU stress test when deemed necessary[18]. As for the TD approach, there is no bound to the number of in-house simulations, but the common practice is to have at least an annual exercise with disclosure of aggregate outcomes.

One key feature in the TD and BU conundrum is the requirement of resources. In a setting with constrained human capital and compressed time-schedule, an annual BU exercise might seem redundant and overly burdensome to the banking industry. Also, as structural changes appear in longer periods of time, utilization of granular data could be sub-optimal as results do not yield much added-value to the TD approach. If dynamic elements or subsequent contagion effects are sought as important, a TD stress test is currently the way forward. Therefore, when resources are available both approaches could be applied on annual basis, but if not I would suggest the EBA practice of conducting a BU stress test every two years or in a year of implementing new regulatory or accounting frameworks. The recommendation could be applied as well to traditional banking systems, for which the external bank assessment by the market or by other analysts does not depend on regular results from public stress-testing.

[18] The frequency of BU exercises is set annually in the stress test frameworks of the FED (31 participants in 2016) and the BoE (7 in 2016), biennially for the EBA EU-wide stress test (51 in 2016), and ad-hoc for the comprehensive assessments in Ireland 2011 (4), Greece 2013 (4), Spain 2012 (14), Slovenia 2013 (8), Bulgaria 2016 (22), and ECB 2014 (130), 2015 (9), 2016 (4).

Static vs dynamic balance sheet assumption and the inclusion of second round effects

The balance sheet dilemma continues to be a struggle. On one hand, the static assumption ensures comparability especially across diversified sample of banks and is straightforward to implement. The corresponding convenience attracts many practitioners, as well as all EBA stress tests. On the other, including dynamic elements makes the exercise more realistic and its outcome more reliable for capital planning (US CCAR) and recapitalization needs (Greece 2013). The UK approach emphasizes on the banks' financial intermediation function and mandates them to sustain lending under stress (BoE 2015). Demekas 2015 also discusses the dynamic practice as growing worldwide in a TD way. Other country stress tests examples show some degree of dynamism in terms of balance sheet and credit growth (Jobst et al. 2013 and Hristev 2014). On the downside, BCBS 2015 points out to the present need of a satisfactory approach to dynamic modeling given the complex macro-financial linkages that banks are part of. Accordingly, both assumptions are currently applicable.

The dynamic balance sheet is indeed superior in theory. It allows for inclusion of macroprudential aspects in the setup and second round effects such as macroeconomic feedbacks or bank contagion. Nevertheless, in my view due to present significant comparability and modeling challenges, the use of dynamic stress tests for supervisory purposes should correspond to the goal and the approach of the exercise. It is also subject to the necessary resources for ensuring consistency and comparability across banks. Although being more realistic, projecting the balance in a dynamic way brings complexity to a degree that is directly dependent to the sophistication of banking intermediation and business models. Thus, based on the available analytical resources and the level of banks' development as a system, I would advocate for both alternatives of the assumption underlining the dynamic side as the one to move forward.

Application of stress tests for MPIs calibration and systemic risk analyses

There are clear calls for inclusion of stress test results into the calibration process of MPIs (Brazier 2015, Constâncio 2016a, Tarullo 2016) and the analyses of systemic risk (Demekas 2015). At present, few evidences attribute the use of MpSTs for setting capital buffers[19], while for other MPIs information is scarce. A recent relevant step forward to the pure macroprudential aspects of stress-testing is the ECB STAMP€ (Stress Test Analytics for Macroprudential Purposes in the euro area) instrument (Dees et al. 2017). It represents a TD tool

[19] For example, in the US and the UK, stress test results are incorporated in the setting of countercyclical buffer. The practice of the Czech National Bank and the Central Bank of Estonia is to consider simulation findings when determining the level of systemic risk buffer and the buffer for other systemically important institutions.

for supporting design and calibration of macroprudential policy. The analytical framework contributes to the macroprudential purposes of stress-testing by incorporating a dynamic dimension, interaction with the real economy, interconnections between financial institutions, system-wide liquidity assessment, and interaction with non-financial sectors. As a result, the enhanced ECB TD stress-testing allows for impact assessment of macroprudential policy instruments. Contribution of banks to systemic risk assessed via networks analyses or agent-based models is the new frontier in stress-testing. These methods are viewed as better suited for analyzing systemic resilience due to the option of including specific agent dynamics that are not linked with past experiences, assessing their responses to events, and updating all variables in the system accordingly. The computational complexity and technical requirements still pose a practical hurdle to agent-based modeling, but the opportunity to stress test the next "black swan" is an incentive worth for further investigation.

In my view, there is avenue for exploring the accommodation of stress test results in the macroprudential setup. The simulation provides comprehensive analysis about banks' capital and liquidity resilience together with their endurance to contagion. By identifying specific quantitative shortages and general pockets of vulnerability, the MpST could provide additional information to the process of implementing capital instruments. For example, the former may contribute as a supplement indicator to the process of setting a buffer for systemically important institutions, while the latter – for systemic risk buffer. In addition, liquidity rules could be imposed to enrich the current regulatory framework with more conservative stress test assumptions. As MpSTs are hypothetical exercises they could be a valuable source of information for macroprudential policy, but not the solely one. Accordingly, supervisory expertise is important to utilize findings from stress-testing into the application of MPIs.

Marrying the solvency and liquidity stress test frameworks

The global financial crisis of 2007/8 revealed that solvency and liquidity shocks interact together. Accordingly for stress-testing purposes, integrating the solvency and liquidity nexus into one framework gives a more complete view of banks' resilience (BCBS 2015). If taken separately, important interconnections may be missed. To illustrate, signs of capital depletion may prompt funding shocks, fire sales, or run-offs, and vice-versa. Several instances attempt to model solvency and liquidity linkages For example, the Bank of England's Risk Assessment Model for Systemic Institutions (RAMSI) includes shocks to funding liquidity, while Bank of Canada's MacroFinancial Risk Assessment Framework (MFRAF) assumes fire sales and possible runs on top of the macroeconomic scenario[20]. In a similar

[20] For more information about the RAMSI and MFRAF model see Burrows et al. 2012 and Anand et al. 2014, respectively.

fashion, the systemic modules of the ECB's STAMP€ tool bridge the solvency and liquidity link by modeling explicitly the lender of last resort function, fire sales, and funding contagion. The corresponding accumulated losses affect banks' solvency position and consequently trigger higher wholesale funding spreads not only for banks with capital deterioration, but also for those with similar business models. A particular feature of an integrated solvency and liquidity framework is mirrored in its TD feasibility, thus making it not applicable for BU exercises. Moreover, modeling and calibration of a liquidity crisis is challenging due to its "low frequency-high impact" nature. As a result, the majority of regulatory stress tests still assess solvency and liquidity separately[21].

With regards to the importance of the solvency and liquidity nexus, I would suggest that future work on the matter is essential. The link between solvency and liquidity emerges in different channels. One effect reflects higher funding costs as lenders adjust the risk premium for counterparty risk when bank capital depletes. Other channels result in limited market access, fire sale losses, and liquidity run-offs. Finally, the solvency and liquidity issues could turn into interbank market breakdown and cause contagion across the financial system. The solvency and liquidity shocks are mutually amplifying and so an integrated approach for marrying both frameworks is a pressing need.

Limitations, imperfections, and lessons learned

All models are inherently fallible, as Haldane 2009 puts it, because they are not reality. And MpSTs are not an exception. As such they are carried out with certain limitations and imperfections. The overall design of a stress test is coated by expert judgment, which brings a certain degree of subjectivity. Every exercise has predefined assumptions that go beyond the risk modeling and affect the whole process. The stress test is also as robust and credible as the underlying data[22], methodology, and governance. Indeed, significant progress has been made to improve the stress-testing frameworks, data collection, and risk management, but a notch of uncertainty always remains. Further, the stress test happens with some lag, which could have implications on specific risks materialization. The rapid unwinding of financial adversities casts doubt on the scenarios as relevant risks may not be covered (2011 sovereign debt crisis or 2016 UK referendum). Another limitation stems from using historical series and standardized frameworks. As financial intermediation and corresponding risks evolve, stress-testing could miss capturing new risks and create false sense of security. That said, MpSTs are continuously in development to address the

[21] In the US, the annual CCAR goes along with CLAR (comprehensive liquidity analysis and review). Similarly, the 2011 financial measures programme in Ireland had prudential capital assessment review (PCAR) and prudential liquidity assessment review (PLAR) as stand-alone analyses.

[22] Asset quality reviews (AQR), if available, are beneficial for stress test credibility, as they ensure accurate starting data and adequate reporting of risks.

present shortcomings and at the same time attempt to follow Keynes' humble view of being "roughly right than precisely wrong". They are simply an analytical tool that does not substitute a robust regulatory framework, but rather complements the microprudential and macroprudential supervisory arsenal (capital and liquidity instruments, regular risk assessments, financial soundness indicators (FSIs), early warning systems (heat maps), network analyses, systemic risk models, etc.). Accordingly, stress-testing enriches the assessment of banks' health and adds valuable input to the process of implementing policy actions.

Along with the MpSTs' insufficiencies, there are positives related to lessons learned from past experience. One main lesson is that the overall stress test process should follow the set goal. For public exercises such as bank comprehensive assessments or crisis stress tests, credibility must be ensured, which corresponds to adequate severity, sufficient transparency on bank level, and a clear communication. The stress test thus implies a BU approach, a relevant adverse scenario and risk coverage, a QA check, and a fiscal backstop. In order to achieve these prerequisites significant resources should be allocated both in terms of human and financial capital. For the purposes of supervisory monitoring, the stress test is more flexible, which gives an opportunity for including dynamic elements, second-round effects, and solvency-liquidity interactions. The TD approach is currently the way forward to accommodate these complexities and expand the supervisory view of bank reactions under stress. Another lesson follows the use of supervisory data as the central input for MpSTing. It fosters comparability across the sample and is available for both large systemically important and small banks. Regardless of the presented shortcomings, the use of balance-sheet and regulatory capital information is linked to macroeconomic and financial rationale, which promotes the basis for a meaningful supervisory dialogue with banks. If market data is present and the market is well-developed itself, it could be included as an additional source of analysis, but I would recommend keeping supervisory data as the main input for the MpST. A third lesson accounts for the level of severity to the applied stress test framework. The design of scenarios, risk modeling, and assumptions should account for the economic and financial cycle, as well as for the current conservativeness of implemented macroprudential instruments. The final lesson brings the necessity of expert judgment. National expertise utilizes supervisory and economic knowledge that could be reflected in expert add-ons if needed for calibrating the overall severity or managing outliers. The right balance between adverse shocks (tail events) and observed reality (common sense) brings the stress test one step closer to the golden rule of "severe enough, but plausible".

MpSTs are imperfect, yes, they face challenges and have limitations. After all, to quote Charles Goodhart: "fallible as they may be, the conduct of annual

stress tests gives the regulatory authorities their best available chance of dealing with fragile banks while there is still enough time to avert a, potentially contagious, failure."[23] Therefore, as long as the illusion of impeccable precision is avoided, the inherent weaknesses of stress-testing are acknowledged, and the lessons from past experience are accounted for, MpSTing does contribute to a better understanding of potential threats to the banking system and consequently to ensuring financial stability.

Conclusion

In conclusion, the acute combination of appropriate design and expert judgment is essential for the effective conduct of a MpST. The theoretical aspects reveal the art of stress-testing with its benefits and complexities. It indeed fosters resilience, as long as the principles of credibility, relevance, and consistency are accounted for. Additional decisions shape the stress test architecture. First a clear goal has to be set as the foundation of the exercise. Then, the scope of banks, risk coverage, the type of exposures, assumptions, and constraints are defined. A specific attention is drawn on the selected approach considering the stress test purpose and available resources. For instance, the review shows that public exercises should be carried out in a BU manner, while the ones of supervisory nature could employ a BU or TD approach. Also, if the stress test is envisaged to cover dynamic features and second-round effects, the TD option is the leading preference. Next, application of scenarios and risk modeling provides the mechanism channel for translating severe, but plausible events into bank-specific shocks. Quality assurance and validation have a central role in the process in order to ensure robustness of outputs. The analysis brings forward the importance of supervisory data as the main input for quantitative estimates and the necessity of expert judgment as a way for channeling supervisory knowledge and managing consistency. The MpST ends with a report, which presents the results, assesses banks' capacity for absorbing negative shocks and points out the main fragilities. Depending on the mandate or when deemed appropriate, a public disclosure of outcomes may follow. In that manner, accompanying clear communication on the whole stress test process is a must. The simulation proceeds with a follow-up to the results that may prompt a reaction function from supervisors, bank management, or sources of last resort. If applicable, the dynamic responses could aggravate the stress test via second-round effects – macro feedbacks and/or bank contagion. In addition, several issues that remain a challenge are addressed with recommendations as a way forward. Most importantly, the decision on publication of results, approach, and balance-sheet

[23] See Goodhart 2016.

assumptions rely on the banking authority given the stress test goal and design, but supervisors could pursue a minimum disclosure of aggregate results for the banking system and more dynamic elements. Further work on the development of stress tests for calibrating MPIs, analyzing systemic risk, and merging the solvency and liquidity risk is welcomed and would be beneficial for macroprudential purposes.

MpSTing is part of the recipe for financial stability, not the panacea. It is a prominent instrument for assessing potential threats and vulnerabilities to the banking system, but a prudent way is to complement stress tests with other macroprudential tools. Being under the spotlight of growing interest, it is easy to attribute exceptional view to the exercise and form exaggerated expectations. However, stress tests are not prophetic or trying to tell the future, as they remain hypothetical exercises with underlying assumptions and limitations. In the words of Sir Henri Deterding: "It is impossible to see into the future, and it is dangerous not to". Thus, instead of predicting the future, MpSTing contributes to the analytical macroprudential assessment by highlighting areas with vulnerabilities and facilitates preparations for the unexpected.

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ISBN 978-619-7409-03-1

ELEMENTS OF THE 1 LEV BANKNOTE, ISSUE 1999, ARE USED IN COVER DESIGN.