A MACRO STRESS-TESTING FRAMEWORK FOR BANK SOLVENCY ANALYSIS

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The financial and sovereign debt crises have highlighted how important it is for banks to have solid capital buffers that enable them to withstand extreme and unexpected shocks to their balance sheets and thus ensure that they can act as effective financial intermediaries even in periods of turbulence. A macro stress-testing framework is often used to assess in a forward-looking manner the resilience of the banking sector to (adverse) macroeconomic and financial developments. In line with its responsibility for safeguarding financial stability in the euro area, the ECB also employs macro stress-testing tools in its regular macro-prudential assessments.

Against this background, this article gives an overview of the main elements of the ECB's (top-down) macro stress-testing framework for solvency assessments and gives examples of how it is used for policy analysis. The framework is applied in forward-looking bank solvency analysis in many different contexts, such as to analyse the impact of pertinent systemic risks on broad financial stability, to challenge the results of bottom-up stress tests carried out at the supervisory level and to calculate bank capital shortfalls in order to assess the impact of conditions in the financial sector on macroeconomic developments. Furthermore, the stress-testing framework can be used for both micro and macro-prudential purposes once the ECB takes up its supervisory powers in the context of the establishment of the Single Supervisory Mechanism (SSM).

1   INTRODUCTION

One of the major implications of the financial and sovereign debt crises has been to put significant downward pressure on the solvency positions of euro area banks. Losses incurred as a result of disruptions in the financial system and the ensuing economic downturn created serious concerns about the level of capitalisation among euro area banks, which amplified the crisis-related funding difficulties of many banks and ultimately hampered their ability to finance the real economy.

A crucial step in resolving a banking crisis is to assess whether banks are appropriately capitalised and able to withstand further adverse shocks. Stress-testing tools are especially useful for gauging potential capital shortfalls in the banking sector when it is faced with severe headwinds. For this reason, macro stress tests have been employed frequently by the competent authorities, including the ECB, during the financial and sovereign debt crisis to calculate bank capital shortfalls against commonly agreed capital ratio benchmarks. In this context, it is important to distinguish between the bottom-up stress tests carried out by the banks, although often under constrained rules set by their micro-prudential supervisors, and top-down stress tests, whereby all calculations are carried out at a central level (without involving the banks).[1] The latter tend to have a more macro-prudential perspective with a focus on assessing system-wide resilience to the materialisation of systemic risks.

The ECB has worked hard to develop a "top-down" stress-testing framework that currently covers the largest 80-90 banking groups in the European Union.[2] There are a number of reasons why forward-looking solvency analysis is pursued by the ECB.

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1   With regard to supervisory bottom-up stress tests, in both the United States and the EU, stress tests have become part of the policy toolkit for crisis management. In the United States, the Supervisory Capital Assessment Program (SCAP) was implemented in 2009 while in the EU, the European Banking Authority (EBA) coordinated EU-wide stress-testing exercises in 2010 and 2011. Macro stress tests were used during times of crisis at the individual country level in the context of the EU-IMF financial assistance programmes to selected EU Member States.

2   The ECB has also developed a stress-testing framework for insurance corporations, although this tool is currently somewhat less developed than the tool covering the banking sector.

First and foremost, such analysis is of relevance to the ECB from a broad financial stability perspective, but it can also provide important insights that are useful for monetary policy analysis, crisis-related activities and potentially also for macro-prudential policy purposes. Beyond having prime responsibility for monetary policy, the responsibility for safeguarding financial stability figures prominently in the mandate of the ESCB.[3] This task requires the systematic review of possible sources of risk to the financial system in order to identify risks with a potential systemic nature and assess their potential magnitude. To this end an evaluation needs to be carried out of the impact these risks would have were they to materialise. The monitoring of risks and the assessment of their severity are, thus, complementary for the detection of systemic risk. Systemic risk is defined as the risk that financial instability would become so widespread that the functioning of the financial system would be impaired to the point where economic growth and welfare would suffer materially.

Second, the assessment and analysis of the impact of specific shocks on banking sector resilience is also important from the perspective of monitoring the effectiveness of the monetary policy transmission mechanism. This is particularly the case in the euro area context owing to the predominant role of banks in the financial structures prevailing in the currency union.[4] In other words, if banks are resilient to various adverse shocks, they are more likely to be able to transmit monetary impulses to the real economy even under stressed circumstances.

Third, the ECB's top-down stress-testing framework is employed on a regular basis as a tool for cross-checking the results of bottom-up stress tests, such as the EU-wide stress-testing exercises coordinated by the European Banking Authority (EBA) or the national-level stress tests conducted in various countries in the context of joint EU-IMF adjustment programmes. The top-down stress-testing toolkit has proved an effective means to ensure the quality of bottom-up results, for example by helping to detect outliers in the form of unreasonable results among the stress-tested banks.

Finally, by exploiting the forward-looking nature of the top-down stress-testing tool combined with its granular information set across a large number of banks, the framework is able to capture aspects of both the time-dimension and the cross-section dimension of systemic risk that is relevant for assessing macro-prudential policies.[5] The top-down stress-testing framework could thus complement other modelling approaches that calibrate and assess macro-prudential policy instruments.[6]

These various uses notwithstanding, it is important to recognise that stress-testing tools also have limitations. Importantly, stress-testing frameworks do not capture the general equilibrium effects of the impact of shocks on a banking sector. For example, endogenous adjustment of banks' balance sheets is generally only partially covered, and various types of feedback to markets are often ignored. That such elements are ignored can be considered a virtue of stress tests, as it allows for a

3 In the euro area, this responsibility is conferred on the European System of Central Banks (ESCB) in Article 127(5) of the Treaty on the Functioning of the European Union "The ESCB shall contribute to the smooth conduct of policies pursued by the competent authorities relating to the prudential supervision of credit institutions and the stability of the financial system", as well as in Article 25(1) of the Statute of the ESCB and of the ECB.
4 See, in particular, the following articles in recent issues of the ECB's Monthly Bulletin: "The role of banks in the monetary policy transmission mechanism", *Monthly Bulletin*, ECB, August 2008; "The external financing of households and non-financial corporations – a comparison of the euro area and the United States", *Monthly Bulletin*, ECB, April 2009; "Monetary policy and loan supply in the euro area", *Monthly Bulletin*, ECB, October 2009; "Monetary policy transmission in the euro area, a decade after the introduction of the euro", *Monthly Bulletin*, ECB, May 2010.
5 See, for example, "Operationalising the selection and application of macro-prudential instruments", Committee on the Global Financial System, *CGFS Papers*, No 48, Committee on the Global Financial System, December 2012. For a detailed discussion on the concept of systemic risk, see Special Feature B in the December 2009 Financial Stability Review.
6 For a review of the recent literature on models for assessment of macro-prudential policies, see Special Feature A entitled "Exploring the nexus between macro-prudential policies and monetary policy measures", *Financial Stability Review*, ECB, May 2013.

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more robust projection of banks' balance sheets based on a number of assumptions. Clearly, a full equilibrium analysis at the level of detail required for stress tests is impossible. On the other hand, the missing (or incomplete) elements are important when it comes to the transmission of monetary policy, macro-financial feedback and macro-prudential analysis. While the ECB's stress-testing framework aims to address some of these analytical challenges, the obvious limitations to these approaches should not be downplayed. Finally, while the ECB's stress-testing framework is primarily attuned to forward-looking solvency assessments, analytical tools for carrying out liquidity/funding risk assessment are also important in order to complete a macro-prudential analysis toolkit. This notwithstanding, even the forward-looking solvency assessment can also be carried out taking into account liquidity and funding shocks and thus to some extent capture the impact of liquidity stresses.

Against this background, this article provides an overview of the ECB's top-down stress-testing framework and presents some examples of how the framework is employed along the four policy dimensions highlighted above: (i) for broad financial stability analysis purposes; (ii) to support monetary policy analysis; (iii) as a cross-check of bottom-up stress test results; and (iv) as a tool for evaluating macro-prudential instruments.

2 SOLVENCY ANALYSIS FRAMEWORK

Forward-looking bank solvency analysis, or top-down macro stress testing, especially when carried out using information at the individual bank level, requires a number of different but intertwined analytical steps. The ECB's solvency analysis framework reflects this approach and can be broadly described as a modular system with a four-pillar structure (see Chart 1).

Chart 1 The four-pillar structure of the ECB's solvency analysis framework
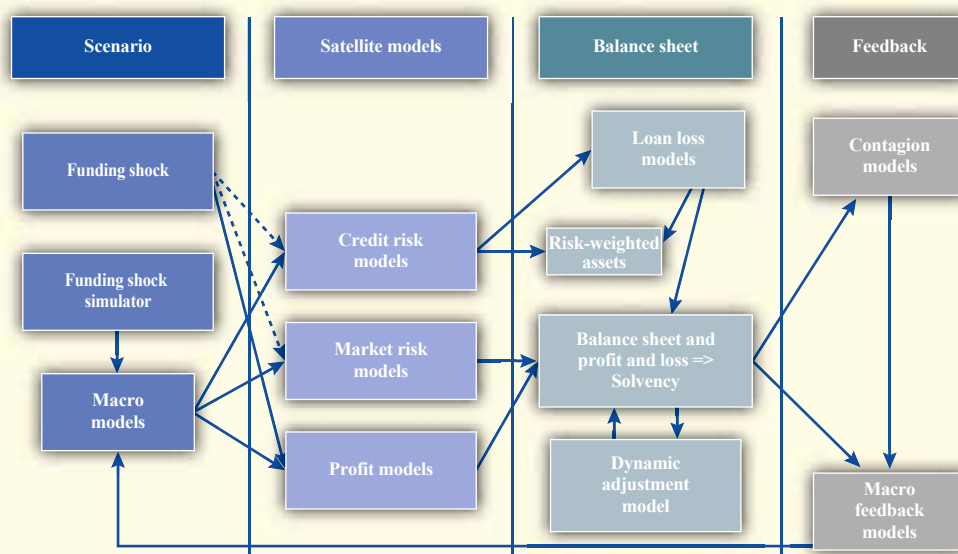
Source: ECB.

The first pillar (scenario design) consists of the design of the macro-financial scenarios to be imposed on the banking sector; in turn, the second pillar (satellite models) expands the macro-financial scenarios into a wider range of financial market and loan impairment variables affecting the valuation of bank balance sheet components, i.e. credit and market risk models, and banks' loss absorption capacity; the third pillar (balance sheet module) takes the projected profit and losses derived from the satellite models to individual bank balance sheets with the aim of calculating the resulting impact on each bank's solvency position. Finally, the fourth pillar (feedback modules) takes the analysis beyond the first-round impact on bank capitalisation to assess what could be the derived second-round effects of the initial bank solvency impact in terms of propagation, or feedback, throughout the financial system and beyond to the real economy. Each of the modules underlying the four-pillar, forward-looking solvency analysis framework in place at the ECB are described below.[7]

MACRO-FINANCIAL SCENARIO DESIGN

The first pillar of the framework is the macro-financial scenario design module, which is the starting point of the analytical chain that ultimately leads to a forward-looking assessment of banking sector capitalisation. The process of designing an appropriate (adverse) macro-financial scenario broadly consists of two steps. First, on the basis of the main systemic risks identified as pertinent at a given juncture, these risks will need to be mapped to scenario building blocks that correspond to the general storyline that the stress test is aimed at capturing. Second, once the scenario building blocks have been defined and expressed as exogenous shocks to specific variables representing the relevant risk factors, the impact of these shocks on the wider macroeconomic and financial environment needs to be quantified using relevant modelling techniques.

When designing the scenarios due consideration needs to be given to ensure that the stress imposed is of an appropriate level of severity (i.e. having a sufficiently strong impact on the banks) and at the same time not too implausible (i.e. it should reflect a material risk).

A variety of approaches is used in the calibration of shock profiles. These include ad hoc calibration based, for example, on developments in a specific variable during previous crisis episodes, but without recourse to any model or historical distribution of risk factors. Another approach is model-free shock size calibration based on historical distributions. This is typically applied in the calibration of shocks to financial asset prices whose dependence structure and high frequency nature are difficult to model. Shock size calibration based on shock distributions, with shocks being inferred from a dynamic model produce fit, and the resulting residuals, i.e. the portion of variation in the model variables that the model cannot explain, are interpreted as shocks. Those shocks can be calibrated using the size and distribution of the corresponding model residuals.

Once the relevant shock profiles reflecting underlying systemic risks have been calibrated, they are input into the relevant dynamic macroeconometric models. Importantly, for the scenario design module of the ECB's stress-testing framework, an eclectic approach has been adopted, whereby the modelling technique to generate the macro-financial scenarios depends on the specific risks the scenarios are supposed to reflect.

For shocks reflecting risks to the EU external environment, scenarios are often based on the NiGEM model, which is a large-scale estimated multi-country/multi-regional macroeconomic model with

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7   In this article, the framework is described in relatively non-technical terms. For a more detailed description of the underlying modules, see "An analytical framework for conducting macro stress tests", *Occasional Paper Series*, ECB, 2013 (forthcoming).

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global reach. To calibrate international spillover effects (of, for instance, stock price or bond yield shocks), NiGEM can be complemented with a global vector autoregressive (GVAR) model.[8]

On the domestic side, if the shocks to be imposed are meant to reflect risks that mainly come from the broader economic environment (such as investment and consumption, factor prices, external demand), use is typically made of a "stress-testing elasticities" (STE) tool. The STEs are impulse responses produced by models in place at the national central banks of the ESCB, which are embedded in an integrated toolbox for scenario-generating processes. Hence, on the basis of the STEs, exogenous shocks to a wide range of real economic variables and some financial variables (e.g. stock prices, short and long-term interest rates) can be imposed in order to derive projections of a large number of macro-financial indicators for all 28 EU countries, while also taking into account trade links between the countries.

In other instances, scenarios should rather reflect systemic risks that may emerge from within the financial system and that only spill over to the real economy once the shocks are triggered. This could, for example, reflect risks surrounding bank funding that might emerge as sharp rises in funding costs, inability to rollover wholesale funding or deposit outflows. Quantitative funding constraints, in particular, would be expected to lead in turn to asset side adjustments that may entail "fire sale" losses (when banks are forced to sell assets in an illiquid market) and possibly loan supply restrictions. To generate broad macroeconomic scenarios on the basis of such "financial sector" shocks, macro models explicitly embedding real-to-financial interlinkages are usually employed. Models available at the ECB that are appropriate for this purpose include dynamic stochastic general equilibrium (DSGE) models including banking sector specifications,[9] as well as various types of vector autoregressive (VAR) model with estimated interrelations between real economic and banking sector variables.[10]

TRANSLATION OF SCENARIOS VIA SATELLITE MODELS

For scenario translation, satellite models are applied to credit and interest rate risk as well as to other types of market risk (e.g. affecting the trading portfolio). Concretely, satellite equations are used to translate an assumed scenario (baseline or adverse) into a path for the dependent variable that captures some risk pertaining to a bank's balance sheets.

The most prominent economic indicators that the analysis of credit risk is based upon include probabilities of default (PDs), loss given default (LGD) and loss rates (LRs); with the LR being the product of PD and LGD. Additional balance sheet-type indicators that can be used in parallel to assess credit risk are the amounts of non-performing loans (NPLs) and the stock of loan loss reserves (LLRs). Moreover, MFI statistics on country-specific banking sector write-off rates (WRO) can serve as an additional measure of credit risk, although this is likely to reflect a rather delayed credit risk response, as write-offs come at the final stage of the banks' process of recognising credit losses. Finally, default rates (e.g. the number of defaulting loans to total outstanding loans) are another source of information that can be used as a basis for modelling credit risk.[11]

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8   For details on the GVAR model, see Dees, S., di Mauro, F., Pesaran, M.H., Smith, L.V., "Exploring the international linkages of the euro area: a global VAR analysis", *Journal of Applied Econometrics, Vol.* 22(1), 2007, pp. 1-38.
9   See, for example, Darracq Pariès, M., Kok, C. and Rodriguez Palenzuela, D., "Macroeconomic propagation under different regulatory regimes: evidence from an estimated DSGE model for the euro area", *International Journal of Central Banking*, December 2011.
10 See, for example, Giannone, D., Lenza, M. and Reichlin, L. "Money, credit, monetary policy and the business cycle in the euro area", *CEPR Discussion Paper,* No 8944, April 2012.
11 Arguably, the various measures of credit risk can have somewhat overlapping definitions, but can be considered to differ in terms of their time perspective with PDs, measuring the probability of borrower default x-days ahead, being the most forward-looking metric and WROs, reflecting the point in time when non-performing loans are ultimately written off, being the least forward-looking metric.

For modelling retail interest rates, interest rate data for loans and deposits are taken from the ECB's MFI interest rate (MIR) statistics. This database contains country and euro area aggregate series of retail interest rates applied by monetary and financial institutions to deposits and loans vis-à-vis households and non-financial corporations.

In total, the modelling framework for market risk covers over 40 market risk parameters across over ten jurisdictions: non-European stock prices, credit spreads, swap rates, volatility parameters and macro-financial variables in the emerging markets. The links to the macro-financial scenario are constructed using the financial variables which are commonly directly stressed under the adverse macro scenarios (for example, stock prices in the United States and the euro area, and money market interest rates). These variables are in turn used as origins of shock for the estimation of the remaining market risk parameters.

Within the ECB's framework, the satellite modelling technique applied to credit, interest rate and market risk parameters is characterised by two key features:

1) autoregressive distributed lag (ADL) models allow for the translation of a macro-financial scenario to the chosen measure of risk, with a risk measure, such as a PD for a certain loan portfolio, being a function of its own lagged history, as well as contemporaneous and lagged indicators that describe the state of the real economy and financial markets, including predictors such as GDP, unemployment, inflation, interest rates, etc.

2) to address model uncertainty, a model averaging approach is chosen. This approach is particularly useful for modelling risk parameters as historical time-series (for example PDs, WROs or NPLs) are typically rather short, which in turn implies that to economise on the "degrees of freedom" the satellite equations are bound to have only a few predictors (e.g. up to four in a single equation). A model averaging approach allows a reasonably large number of predictor variables across equations to be employed.[12]

BALANCE SHEET MODULE – SOLVENCY CALCULATIONS

The balance sheet modelling in the ECB's top-down stress test is based on a dynamic balance sheet tool, which allows either exogenously given or endogenously optimised paths to be applied for key balance sheet items. The module used to endogenously derive dynamic balance sheets is based on a risk-return modelling approach, whereby banks rebalance their asset-liability allocation depending on shocks to asset riskiness and return under a given scenario.[13] The starting point for the projection of the balance sheet evolution is the level of balance sheet items as at the cut-off date for the stress test.[14] Then, external paths for key balance sheet items over a stress-testing horizon are applied, which are based on a set of assumptions and projections from satellite models and/or expert judgement. For certain items, caps or floors are applied, so that the change in the balance sheet composition remains consistent with the macro-financial scenario or anticipated market conditions.

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12 Such a theory-free approach, while necessary given the data at hand, also has its drawbacks, such as the fact that specific financial market variables depend heavily on the types of shock considered and average historical links may therefore be misleading.

13 The model underlying the endogenous dynamic balance sheet is based on Hałaj, G., "Optimal asset structure of a bank – bank reactions to stressful market conditions", *Working Paper Series*, ECB, No 1533, April 2013.

14 Information on balance sheet items is either based on: (i) publicly available data for individual banks, as well as bank exposure data disclosed in the 2011 EU-wide stress test and the 2011 EU capital exercise, as coordinated by the European Banking Authority (EBA); or (ii) country-specific supervisory data in the case of countries under EU-IMF financial assistance programmes. The set of banks analysed for EU countries covers at least the sample of banks considered in the EBA's EU-wide stress test in 2011.

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Notably, the third pillar of the framework is based on granular bank-level balance sheet and profit and loss data. In other words, each bank in the system is modelled individually using bank-specific starting points for balance sheet items. The level of precision with which the solvency calculations can be done crucially depends on the level of granularity of the underlying bank data being fed into the tool.[15] The approach also allows for a specific treatment of individual banks if a mandatory restructuring plan set by the competent authorities is in place or in the case of already completed acquisitions or divestments that have not yet been reflected in the initial balance sheet.

Profit and loss calculation

For the profit and loss calculation, the assumptions and projections from the satellite modules are translated into revenues, expenses, losses and provisions. The approach can be divided into four modules: the net interest income calculation, the loan losses and impairment calculation, the market risk calculation and the final profit and loss calculation in accordance with the assumptions for other income components (see Chart 2).

In the net interest income module, interest income and expenses are calculated separately. The main input for the net interest income calculation is the evolution of the relevant balance sheet items (such as loans, deposits and wholesale funding) that can be either exogenously given or derived using the optimising approach mentioned above, as well as the retail interest rate projections derived from the satellite models. The country-specific projections and assumptions are translated

Chart 2 Schematic overview of the profit and loss calculation

Source: ECB.

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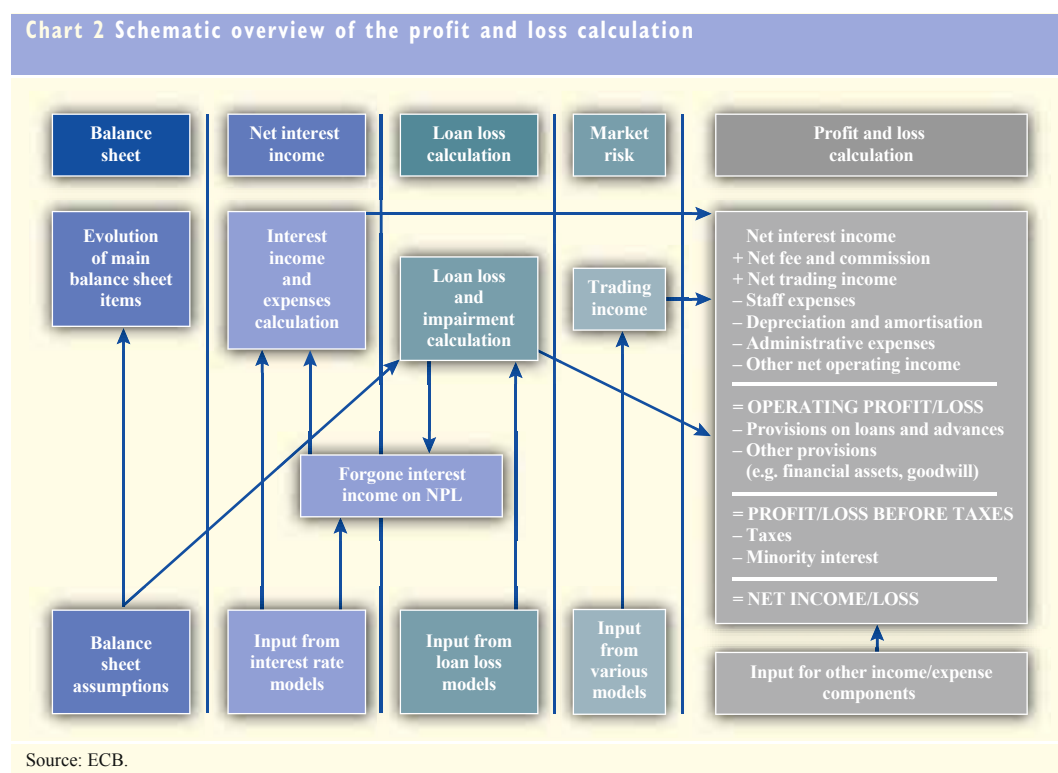
15 This limitation also relates to the data input for the reduced-form models applied in the second pillar to translate the macro scenarios into impacts on banks.

for each year over the horizon of the stress test via annual changes or factors into balance sheet components of the participating institutions. This computation is done on the basis of a granular balance sheet breakdown by instrument, geography, maturity and counterpart sector. Bank-specific characteristics, such as residual maturities and refinancing needs, are also considered. These calculations result in projected interest income and expenses for each participating institution.[16]

The second module, which consists of the loan loss and impairment calculation, combines the output from the balance sheet assumptions and the projection of asset quality indicators from the satellite models to address the impact of credit risk. The module combines conditional projections of country-level credit risk with bank-specific balance sheet evolutions. The projected changes to the loss rates at the country level are then applied to bank-specific loss rates to calculate the expected losses. Taking into account existing asset protection schemes, the evolution of the exposure and LGDs, in a second stage these results are translated into impairments over the stress-testing horizon.[17] The impact of foregone interest income from non-performing/defaulting loans is subsequently calculated and subtracted from interest income.

The market risk module attempts to capture any profit and loss impact from the investment portfolio of the participating institutions. It applies shocks (e.g. haircuts on the valuation of securities held on the trading book), which are as derived from satellite models, to specific portfolios at a given point in time or over the horizon of the stress testing.

In the final module, net interest income, loan loss impairments and the market risk impact for each of the participating institutions are merged with other income components. The profit and loss impact of these other components is derived from the output of an averaging approach[18] in accordance with overall or bank-specific assumptions, such as minimum contribution to minority interests or constant tax rates.
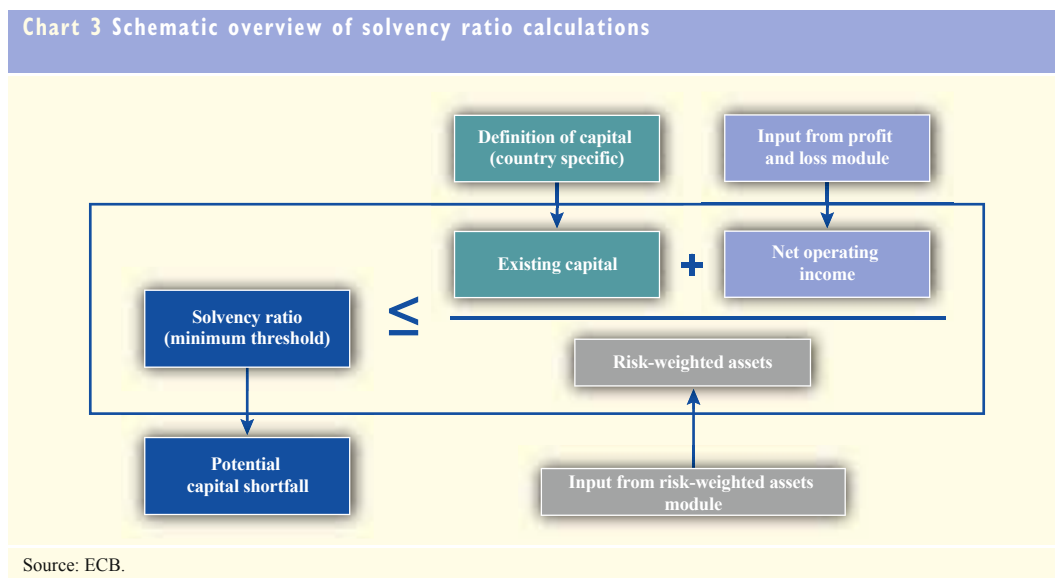
Solvency ratio calculations

The solvency ratio calculation comprises the existing capital, net operating income and risk-weighted assets (RWAs) (see Chart 3). Over the horizon of the stress test, the output from the profit and loss module and the risk-weighted asset module triggers changes in various capital ratio measures, such as total capital, Tier 1 capital or core Tier 1 (CT1) capital ratios. For example, if an adverse macro scenario results in negative profits for a bank it will be subtracted from the bank's already existing capital base and hence, for unchanged RWAs, imply a decrease of the solvency ratio.

The change in average risk weights for the loan portfolios is estimated on the basis of projected credit loss rates using the Advanced Internal Rating-Based (IRB) formula of Basel II. The calculations are made at the portfolio level for three regulatory portfolios: corporate, residential mortgage and retail loans. Risk weights on assets, which are subject to capital measurement under the Standardised Approach of Basel II, are currently not changed in the ECB's framework.

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16 The net interest income module mainly captures changes in interest income and expenses related to banks' retail customer business and their wholesale funding costs. Other interest-related income and expenses are assumed to be constant. In addition, no assumptions are made regarding changes in interest rate hedging over the forecast horizon.

17 In the context of some country-specific stress exercises, the loan loss calculations are also done on the basis of projected non-performing loans and coverage ratios. An application of this approach in an EU-wide context is not feasible, not least because the definitions of non-performing loans are not harmonised across countries.

18 The averaging approach is typically based on the performance of other income or expense components in past years, for exemple, fee and commission income/expenses, staff expenses or depreciation and amortisation. The covered time horizon is mostly depending on the selected scenario and the availability of historical data. In order for a path to be conservative enough under an adverse scenario, a historic reference period over which an average is computed would be set to comprise a past recession period, for example covering the years 2007-09.

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Chart 3 Schematic overview of solvency ratio calculations

Source: ECB.

RWAs relating to market and counterparty risk are scaled up by a fixed factor in line with the minimum requirements set in the methodology of the EU-wide stress-testing exercise conducted by the EBA in 2011. If the adverse scenario were to result in an increase in RWAs (e.g. as a result of higher probabilities of borrower default), the solvency ratio would be reduced.

The capital charges for operational and other risks are not stressed.[19] Based on the input from the other modules, the solvency calculation can be done on a consolidated basis, a solo entity basis or for domestic/foreign subsidiaries only.[20]

CONTAGION AND FEEDBACK ANALYSIS

Bottom-up stress tests are traditionally considered final when the first-round impact of the adverse scenario on bank capitalisation has been derived.[21] However, from the perspective of a top-down stress test, the impact assessment should not stop with the first-round effects on bank solvency. Realistically, when banks' solvency positions are hit by shocks, banks would normally be expected to react by adjusting their balance sheets and activities – often with the objective of returning to some pre-defined target balance sheet ratio. Such reactions could, for example, entail restrictions in certain activities (including new business lending), which in turn could have wider implications on real economic activity and, hence, risk amplifying the severity of the original macro-financial adverse scenario with potential "second-round" effects on bank solvency levels.

To account for such macro feedback effects, the ECB combines the top-down stress test output (for example, in the form of capital shortfalls to some pre-defined thresholds) with macroeconometric

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19 If all of the modules that are used for scenario generation and shock translation are technically integrated, a reverse-type stress test can be undertaken to rank a set of adverse scenarios, in particular by means of multiples. Multiples are simple factors applied to the initial shocks, which then feed through macro-financial models and additional satellite models into banks' balance sheets.

20 Granular information on solo entity and subsidiary level is generally not available through public data sources.

21 There are obvious and practical reasons for adopting this approach in bottom-up supervisory stress-testing exercises. Any feedback and contagion effects that might be expected to follow the first-round effects on bank solvency would be highly work intensive and complex to deal with when stress test calculations are carried out at the bank level (with or without the assistance of the micro-prudential supervisors). For example, it would require substantial efforts by supervisors to cross-check the validity of the banks' dynamic reactions to specific stresses imposed in the exercise.

models embedding banking sector variables and estimated real-financial relationships.[22]
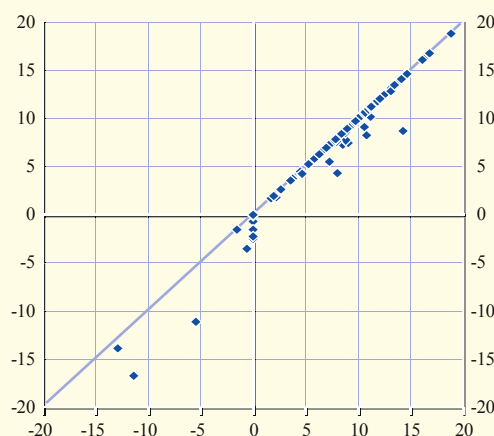
Apart from macroeconomic feedback effects, a top-down solvency stress test should also be able to account for contagion effects cascading within the financial sector itself. For example, the deterioration of the solvency situation (or even a failure) of some banks under a stress scenario could give rise to negative contagion effects on other banks in the system either through their direct bilateral linkages or, more indirectly, through confidence effects. If a bank were in a situation of severe stress, it could be assumed that it would not be able to repay its liabilities in the interbank market. If this were to occur, it could lead to a cascade of losses throughout the interbank network and could eventually lead to other banks being in distress, the effects of which would then propagate throughout the system.[23]

As an illustration, Chart 4 shows the potential capital ratio impact of such "second-round"

Chart 4 Core Tier 1 capital ratio after "first-round" adverse scenario effects and following "second-round" interbank contagion effects

(percentages)

x-axis: end-2014 CT1 capital ratio under adverse scenarios
y-axis: CT1 capital ratio ex-post interbank contagion

Source: ECB.
Note: The sample includes 80 large and medium-sized EU banks, corresponding to the sample of banks used in the EBA's EU-wide stress test, but adjusted for recent mergers and banks under resolution.

interbank contagion effects as a response to the initial "first-round" adverse scenario effects on bank solvency. The results of this particular adverse scenario configuration suggest that most banks could expect to see a further erosion of their solvency once interbank contagion effects are incorporated in the analysis.[24] This is reflected in the number of banks falling below the 45 degree line, which indicates banks for which the solvency ratio after taking into account interbank contagion effects is lower than following the first-round impact calculated in the stress test (but before accounting for contagion risk).

3   APPLYING THE ANALYTICAL FRAMEWORK FOR POLICY ANALYSIS

The top-down stress-testing framework is a flexible tool that can be employed for many different policy analysis purposes. A number of examples are provided below of how the tool is used at the ECB.

22 See, for example, Christiano, L., Motto, R. and Rostagno M. "Financial factors in economic fluctuations", *Working Paper Series*, ECB, No 1192, May 2010; Darracq et al., op.cit. Giannone et al., op. cit.; and Angeloni, I. and Faia E. "Capital regulation and monetary policy with fragile banks", *Journal of Monetary Economics*, 2013 (forthcoming). See also Maurin, L. and Toivanen, M., "Risk, capital buffer and bank lending: a granular approach to the adjustment of euro area banks" *Working Paper Series*, ECB, No 1499, November 2012.

23 The literature on interbank contagion can roughly be divided into two broad streams: one being based on counter-factual simulations using balance sheet data and the other on market data-based contagion tools. With respect to the former approach, the main tool developed at the ECB for the purposes of stress testing is based on the paper by Halaj, G. and Kok C., "Assessing interbank contagion using simulated networks", *Computational Management Science*, Vol. 10(2), 2013, pp.157-186 and *Working Paper Series*, ECB, No 1506, January 2013. With regard to some more market data-based approaches, some recently implemented models include Gross, M. and Kok, C., "Measuring contagion potential among sovereigns and banks using a mixed cross-section GVAR", *Working Paper Series*, ECB, 2013 (forthcoming); and Gray, D. Gross, M. Paredes, J. and Sydow, M., "Modelling banking, sovereign and macro risk in a CCA Global VAR", *Working Paper Series*, IMF, 2013 (forthcoming).

24 It has to be underlined, however, that in the majority of available interbank network configurations, contagion effects tend to be rather limited. Certain network structures are more susceptible to loss propagation than others, which emphasises the fragile yet robust nature of many real-time networks.

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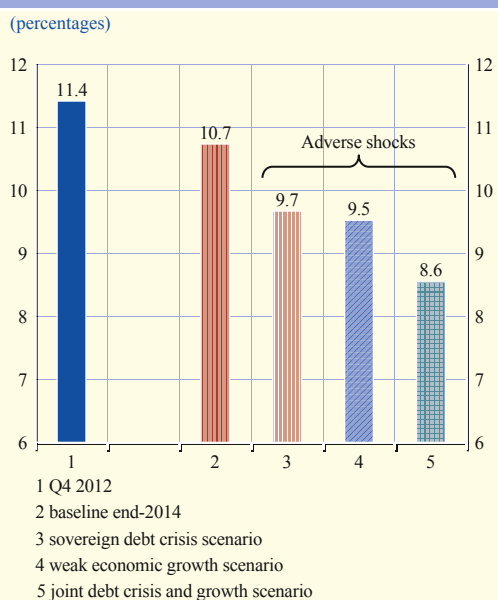## ASSESSING THE RESILIENCE OF THE BANKING SECTOR FROM A FINANCIAL STABILITY PERSPECTIVE

The top-down stress-testing framework is regularly used in forward-looking bank solvency analysis to assess the resilience of the euro area/EU banking sector to the materialisation of systemic risks identified as being particularly pertinent at a given point in time. This risk assessment work feeds naturally into the ECB's macro-prudential analysis, which is published regularly in its Financial Stability Review.

The starting point for the risk assessment analysis is typically a set of key systemic risks. The top-down stress-testing tool can help to understand the impact of these systemic risks on the banking sector and beyond. As the assessment is usually focused on gauging the impact of individual systemic risks on the financial system, scenario building blocks comprising shocks that reflect the materialisation of a specific systemic risk factor are constructed. This allows for the resilience of banks to individual risks to be assessed in a well-structured manner. Once the individual risk factor assessments have been made, joint scenarios incorporating various systemic risks can also be analysed.

For illustrative purposes, two adverse scenarios are considered: (i) a sovereign debt crisis scenario reflecting the risk of renewed tensions in euro area sovereign debt markets owing to low growth and slow implementation of reforms – materialising through an increase in long-term interest rates and declining stock prices; and (ii) an economic growth scenario reflecting bank profitability risk linked to credit losses and a weak macroeconomic environment – materialising through negative shocks to aggregate demand and aggregate supply in a number of EU countries.[25] There are strong interconnections between sovereign debt, economic activity and the banking sector and, therefore, a joint scenario combining the adverse economic growth shocks and the sovereign debt shocks is also considered.

An obvious measure by which to gauge the resilience of the banking sector to such adverse circumstances is the level of capitalisation after having translated the scenarios through the various modules of the framework. The capital ratio after stress provides information on the ability of the banks to withstand adversity without becoming insolvent. In this vein, Chart 5 illustrates the impact, two years ahead, on the EU average CT1 capital ratio under the adverse scenarios described above and under a baseline (based on the European Commission's spring 2013 economic forecast). It is observed that both a reintensification of the sovereign debt crisis and a marked deterioration in economic growth could entail some reduction in average solvency ratios across the EU banking sector with the CT1 ratios dropping around one

Chart 5 EU average core Tier I capital ratio under the baseline and adverse scenarios

(percentages)

1 Q4 2012
2 baseline end-2014
3 sovereign debt crisis scenario
4 weak economic growth scenario
5 joint debt crisis and growth scenario

Source: ECB.
Note: The sample includes 80 large and medium-sized EU banks, corresponding to the sample of banks used in the EBA's EU-wide stress test, but adjusted for recent mergers and banks under resolution.

25 For a more detailed description of scenarios reflecting those risks, see, for example, the *Financial Stability Reviews*, ECB, December 2012 and May 2013.

percentage point below the baseline at the end of 2014 in both scenarios. If instead the shocks underlying the two scenarios are combined to form a joint scenario (see the green bar in Chart 5), the adverse impact on average solvency ratios is amplified, with the EU average CT1 ratio falling to 8.6% (i.e. more than two percentage points below the baseline).

Owing to the high starting levels of EU banks' capitalisation (with the EU average CT1 capital ratio at the end of 2012 standing at 11.4%), even after imposing substantial stress, EU banks on average appear to be fairly robust and remain well above regulatory minimums. However, the average development of EU banks' solvency positions may mask substantial variation across individual banks and across EU Member States. From a financial stability (and micro-prudential) perspective, it is necessary to pay particular attention to those banks that appear weakest under stress.

The projection of bank solvency positions using the stress-testing framework is a complex process involving several modelling steps (as described above). Therefore, to better understand what is driving the outcome of the solvency analysis, it is useful to decompose the difference between the starting capital ratios and the end-of-horizon capital ratios into the main contributing factors. This is illustrated in Chart 6, which shows the key factors behind the projected CT1 capital ratio reduction between 2012 and 2014 under the three adverse scenarios, as well as under the baseline. It is observed that pre-provision profit accumulation, which tends to lessen the negative impact on solvency of loan losses and changes in risk-weighted assets, is generally lower under the adverse scenarios compared with the baseline.[26] The sovereign debt crisis scenario, in particular, implies

Chart 6 Main contributing factors to EU average core Tier 1 capital ratio under the adverse scenarios

(percentages)

- baseline
- weak economic growth scenario
- sovereign debt crisis scenario
- joint debt crisis and growth scenario
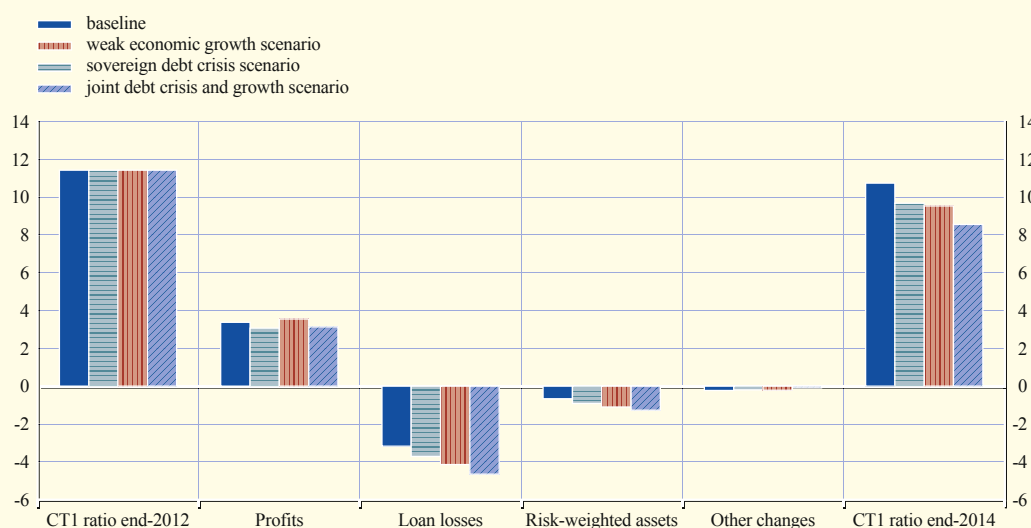
Source: ECB.

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26 Under the weak economic growth scenario, pre-provision profits are on average higher than under the baseline. This, at first, somewhat surprising finding is owing to the fact that lower taxes and dividends are paid under the economic growth scenario compared with the baseline. In pre-tax terms, profits are, however, lower under the weak economic growth scenario.

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lower profit accumulation owing largely to higher funding costs and marked-to-market valuation losses on trading book exposures. At the same time, the weak economic growth scenario results in considerably stronger loan losses owing to the impact of the weakening economic activity under this scenario. Finally, the joint scenario results in even lower profits and higher loan losses than the two separate scenarios.

INPUT INTO MACROECONOMIC AND MONETARY POLICY ANALYSIS

With its forward-looking focus, the solvency assessment tool can also be usefully employed as an input in macroeconomic and monetary policy analysis. Given the predominant role of banks in the euro area financial system and as a result their importance in the transmission of the monetary policy stance to the real economy, forward-looking assessments of bank solvency can provide valuable guidance for monetary policy analysis.[27]

The solvency analysis framework is, for instance, used in the context of the regular staff macroeconomic projection exercises to provide information on potential credit supply restrictions as a result of capital constraints that arise over the forecast horizon. Specifically, a given macroeconomic projection can be fed through the satellite models and balance sheet calculations of the stress-testing framework to derive projections of banks' loss absorption capacity n-years ahead. The resulting capital projections can then be held against a pre-defined capital ratio threshold to derive capital shortfalls that in turn can be used to calculate loan restrictions (or other balance sheet adjustments), which ultimately should have a dampening impact on projected real economic activity.

Furthermore, the stress-testing framework can provide a useful yardstick for the implications of monetary policy measures (standard and non-standard). For example, the solvency impact assessment based on an adverse scenario including constraints on banks' access to funding can inform the policy-maker about the impact on the banking sector and beyond if such quantity constraints were not to be accommodated by monetary policy action.

In a similar vein, the framework is also suitable for analysing the impact of key monetary policy measures. By exploiting the forward-looking nature of the stress-testing tool, if stress test output is linked to a macroeconomic model, the impact on the banking sector and the macroeconomy of, for example, extraordinary central bank liquidity measures and prior assumptions about their use by banks can be assessed. This is particularly useful in a crisis context where unprecedented measures may often be needed, but owing to their extraordinary nature, their impact is generally less well known.

USING THE TOP-DOWN FRAMEWORK TO CROSS-CHECK BOTTOM-UP STRESS TEST RESULTS

Accompanying a bottom-up stress test with a top-down review has become common practice in recent years, and the ECB has recently been involved in several such exercises at both the EU and national levels. The idea behind a cross-check of bottom-up stress test results using top-down tools is that because a top-down cross-check is carried out at a centralised level without involving the banks being stressed, it can provide a more impartial (even though possibly less precise[28]) assessment of the solvency needs of individual banks. From a supervisory point of view, bottom-up stress test results produced by the banks will inevitably have to be viewed through a critical lens

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27 See also the article entitled "Assessing the financing conditions of the euro area private sector during the sovereign debt crisis", *Monthly Bulletin*, ECB, August 2012.
28 Owing to the fact that typically less granular bank level data are available to the top-down stress tester.

owing to the misalignment of incentives (i.e. the banks will have a natural tendency to produce stress test results that will have minimal pecuniary implications). The top-down review can help make the supervisory assessment of bottom-up results more objective.[29]

Depending on data availability, the top-down cross-check of bottom-up results can be focused either on the individual drivers of a solvency analysis or on the overall capital shortfall given a pre-defined capital ratio threshold.[30]

In general, data needs for stress-testing exercises exceed those for the standard supervisory monitoring of banks. This is because the modelling of bank-specific balance sheet and profit and loss items in a stress-testing exercise requires a very granular set of data. This level of detail varies depending on the type of stress test conducted, i.e. a bottom-up exercise (modelling, for instance, the default risk of individual consumer loans of a specific bank) requires far more data than a top-down exercise (modelling, for example, the aggregated portfolio of consumer credit loans of an individual bank in a specific country).

In terms of parties involved, it is useful to include all relevant stakeholders from the very beginning of a stress-testing exercise that includes a bottom-up and a top-down component. This allows for a streamlining of the needs of both processes. Typically, the bottom-up stress test involves either: i) individual banks, which receive instructions from their supervisory agency; or ii) in the case of EU-IMF financial assistance programmes, an independent consultancy firm assigned the task of running a bottom-up stress test using bank-internal data, or a national supervisor. The top-down stress test is run either: i) by the supervisor (national or supranational); ii) a non-supervisory international organisation (such as the European Commission, ECB and IMF); or iii) an independent consultancy firm.

The top-down review of bottom-up results usually involves the key milestones set out in Table 1 below.

The process of cross-checking bottom-up and top-down results begins in general after the finalisation of the interim bottom-up results, which are usually shared with all relevant parties in the form of granular data output accompanied by a detailed report explaining all relevant methodological

Table 1 The process of cross-checking bottom-up and top-down stress test results

1. Definition of the general perimeters of the exercise and broad methodological guidance;
2. Definition of data templates, data collection and asset quality review;
3. Interim bottom-up and top-down stress test results;
4. Comparison of interim bottom-up and top-down results as part of a due diligence process;
5. Revision of bottom-up results and production of final results;
6. Endorsement of final results by all relevant stakeholders;
7. Publication of results.

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29 Obviously, for the cross-check to be meaningful, bottom-up and top-down stress tests should use the same sample of banks.
30 For banks with very complex business models (e.g. a bank with large trading activities including derivative positions and hedging), it can be difficult to provide a top-down estimate of the overall capital shortfall under a given stress scenario: some of the required data inputs would need to be very granular, leading to an excessively resource-intensive process. In such cases, it is therefore often more meaningful to review individual capital shortfall drivers, such as loan losses or net interest income, instead of the overall capital shortfall outcome.

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Table 2 The main analytical steps for cross-checking bottom-up and top-down stress test results

1. Clarification of starting point data discrepancies between bottom-up and top-down data owing to the aggregation/consolidation of bottom-up information;
2. Outlier detection for bottom-up starting point data and baseline/adverse forecasts via statistical analysis using historical data or banking system aggregates as a reference;
3. Comparison of model-driven bottom-up and top-down results;
4. Comparison of non-model-based assumptions (e.g. staff expenses, treatment of operational risk, fee and commission income);
5. Plausibility checks of bank-specific business plans and banking system results.

assumptions and models. Practically, the cross-check features a qualitative and quantitative review of the various stress-test components. For each bank in the sample, as well as the aggregate system, the main steps that need to be taken are set out in Table 2 above.

The first step on this list is usually the most time-consuming part of a top-down review of bottom-up stress test results and therefore requires sufficient time buffers to be allocated to it at the planning stage. While steps two to four usually examine individual stress test drivers (e.g. loan losses), step five goes a bit further by combining all stress test drivers to give a broad picture of an individual bank and the national banking systems. This also allows for a plausibility check of bank-specific business plans, which are often provided along with the baseline projections. Plausibility checks should cover the aspect of balance sheet changes in terms of volumes and related prices. Once all of the bottom-up cross-checks have been completed, an endorsement of the results can be brought forward.

Chart 7 provides an illustration of potential discrepancies between bottom-up and top-down stress test results comparing individual risk drivers. It can be observed that, while the overall solvency effects between the two exercises on aggregate do not substantially differ, there are

Chart 7 Cumulative contribution of different risk drivers to the evolution of aggregate core Tier 1 capital under the adverse scenario from the end of 2012 to the end of 2014

(percentages)

1 bottom-up
2 top-down
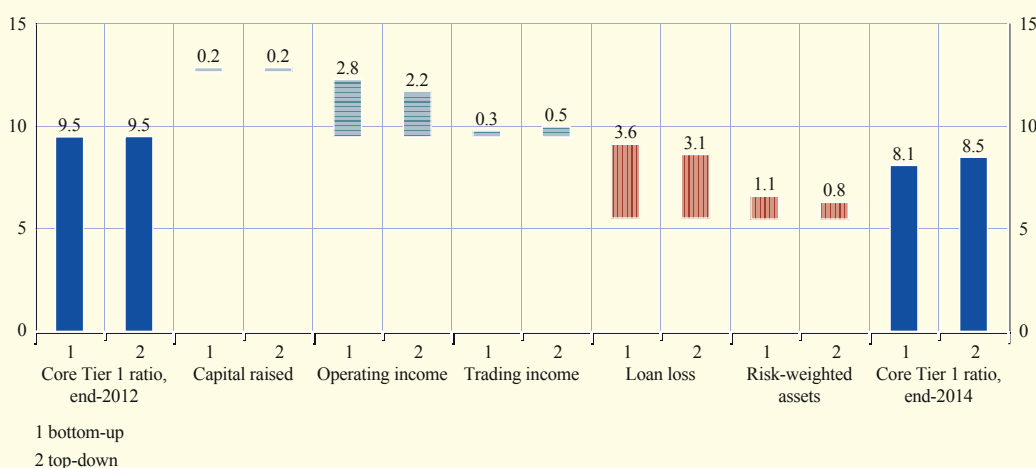
Source: ECB.
Note: The light blue and brown bars refer to positive and negative contributions, respectively.

marked differences for certain sub-components (e.g. operating income and loan losses). Such an outcome suggests that further qualitative checks are needed with regard to these sub-components. Furthermore, while the chart illustrates aggregate banking sector results, at bank level the differences between bottom-up and top-down results may be more striking and warrant particular quality checking efforts for specific banks.

ASSESSMENT OF MACRO-PRUDENTIAL POLICIES

The advent of new and largely untested macro-prudential powers in the EU – both at the national level and at the supranational level in the context of the SSM – poses considerable analytical challenges for the formulation, calibration and assessment of relevant macro-prudential policy instruments (MPIs). Assessing both the qualitative and quantitative impact of a specific MPI is essential for a policy-maker attempting to determine the size/strength of the policy response. To this end, tools are needed that can: (i) mimic the functioning of the propagation channels of macro-prudential policy impulses; and (ii) provide information about the relative impact of various MPIs or a combination of those.

With respect to the macro-prudential propagation channels, while some attempts have already been made to model macro-prudential policy in both dynamic general equilibrium models[31] and static general equilibrium frameworks,[32] the importance of different propagation channels and the way they are intertwined has yet to be explored.[33]

The ECB's stress-testing framework is a complementary tool to existing general equilibrium models that could provide valuable information about the relative impact of various MPIs, or a combination of these, on individual banks' capital shortages. Exploring the framework's granular information about banks' balance sheet structures can provide an immediate quantitative assessment of the direct (or "first round") impact of a given MPI on banks in the cross-section. The outcome of such an exercise can be used as an input into other macro models in order to quantify possible risks arising from macro feedback effects or contagion. In particular, the stress-testing framework may act as a platform to calibrate an optimal macro-prudential policy response to a specific shock or a combination of shocks embedded in a scenario, thus providing policy-makers with concrete answers on how to shield the financial system against specific risks, should they materialise. For instance, the optimal level of the capital buffer can be estimated by simulating the banking system's response to a macroeconomic scenario from the perspective of minimising second-round feedback effects.

Moreover, owing to the granular information on banks' exposures, sectoral capital requirements and/or risk weights may be calibrated in order to find an optimal macro-prudential policy response

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31 See, for example, Kannan, P., Rabanal, P. and Scott, A., "Monetary and macroprudential policy rules in a model with house price booms", *Working Paper Series*, No WP/09/251, International Monetary Fund, November 2009; Darracq et al., op.cit.; Angelini, P., Neri, S. and Panetta, F., "Monetary and macroprudential rules", *Banca d'Italia Working Papers*, No 801, 2011; Beau, D., Clerc, L. and Mojon, B., "Macroprudential policy and the conduct of monetary policy", *Working Paper Series*, No 390, Banque de France, July 2012; Lambertini, L., Mendicino, C. and Punzi, M.T., "Leaning against boom-bust cycles in credit and housing prices", *Journal of Economic Dynamics and Control*, forthcoming; and Angeloni and Faia, op. cit.

32 See, for example, Goodhart, C.A.E., Kashyap, A.K., Tsomocos, D.P. and Vardoulakis, A.P., "Financial regulation in general equilibrium", *NBER Working Papers*, No 17909, 2012.

33 While some attempts have already been made to include more than one policy instrument in a general equilibrium framework (e.g. Goodhart et al., op. cit.), most research has so far concentrated on analysing the impact of a single macro-prudential instrument. This makes it challenging to assess the impact of a combination of the instruments in a general equilibrium set-up. Moreover, as macro-prudential policy-making is largely uncharted territory and its theoretical underpinnings are relatively less explored than say monetary policy theory, it is, therefore, prudent to apply a range of tools/models when carrying out impact assessments. For a review of the recent literature, see also the special feature A entitled "Exploring the nexus between macro-prudential and monetary policies" in the May 2013 Financial Stability Review.

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to a specific sectoral shock, such as a negative house price shock or an increase in probabilities of default of a specific corporate sector. As far as liquidity-based MPIs are concerned, the framework can in principle also provide information on an optimal level for the liquidity coverage and the net stable funding ratio, for example given an adverse scenario involving pervasively tight liquidity conditions in funding markets. Furthermore, different levels of loan-to-value and loan-to-income ratios, the setting of which will remain in the domain of local authorities, can be reflected in the differentiation of LGD and PD parameters within the framework, respectively.

This notwithstanding, the use of the stress-testing framework for macro-prudential purposes poses several analytical challenges. Notably, it is important to keep in mind that the stress-testing tool is only a partial equilibrium framework and therefore needs to be combined with other analytical tools in order to capture the full dynamic effects of a given MPI. However, as the stress-testing tool embeds elements of both the time dimension and cross-section of systemic risks that MPIs are supposed to address, it provides a useful complement to other modelling frameworks employed in macro-prudential policy analysis.

4 CONCLUSION

Top-down macro stress testing has become an important tool for solvency impact assessments. This article has described the current set-up for forward-looking solvency assessments at the ECB and highlighted some of its main uses for policy analysis. Macro stress testing is an effective tool for gauging in a dynamic manner the resilience and soundness of the banking sector, which is crucial for making informed policy decisions from a micro- and macro-prudential perspective, as well as for monetary policy purposes. Nevertheless, it is important to emphasise that stress test results will always be surrounded by uncertainties and should thus be complemented with other tools and expert judgement in order to achieve a comprehensive assessment of the financial sector.