ARNIE in Action: The 2013 FSAP Stress Tests for the Austrian Banking System

Martin Feldkircher, Gerhard Fenz, Robert Ferstl, Gerald Krenn, Benjamin Neudorfer, Claus Puhr, Thomas Reininger, Stefan W. Schmitz, Martin Schneider, Christoph Siebenbrunner, Michael Sigmund, Ralph Spitzer[1]

In this paper we present the main concepts and methods of the stress tests that the Oesterreichische Nationalbank conducted in 2013 in close cooperation with the IMF under the latter's Financial Sector Assessment Program (FSAP). We cover solvency and liquidity stress tests as well as, as part of our contagion analysis, the interaction of solvency with liquidity. The paper's objective is to contribute to the growing literature on applied stress testing by (i) sharing our methodological approaches, in particular innovations to cash flow-based liquidity stress testing, and by (ii) discussing the calibrations employed in what were the most extensive stress tests conducted for Austria in the past five years. Moreover we (iii) provide results at an aggregated level. The 2013 FSAP stress tests for Austria also mark the first public appearance of the OeNB's new systemic risk assessment tool, ARNIE ("Applied Risk, Network and Impact assessment Engine"). By covering recent methodological as well as operational progress, we also shed light on practical challenges. Finally, we identify the need for further work, in particular with regard to the interaction of solvency and liquidity stress testing, and contagion analysis more generally.

JEL classification: G10, G21, F23
Keywords: financial stability, stress testing, FSAP

National financial sectors are periodically subjected to comprehensive and in-depth analyses under the IMF's Financial Sector Assessment Program. For Austria, the IMF conducted an initial FSAP in 2003 and FSAP updates in 2007 and 2013. In line with past usage[2] we herewith publish the main concepts and methods of the 2013 FSAP stress tests, which we carried out in collaboration with the IMF in spring 2013.[3] The stress tests are based on common macroeconomic scenarios (see section 1) and consist of three key building blocks: a solvency stress test (described in section 2), a liquidity stress test (section 3) and an analysis of contagion effects (section 4) resulting from the interaction of solvency with liquidity and from interbank exposures. Section 5 concludes. Note that the 2013 FSAP stress-testing exercise marks the first public appearance of ARNIE (Applied Risk, Network and Impact assessment Engine), the OeNB's new computational framework for systemic risk analysis (see box 1).

1 Macroeconomic Scenarios

The OeNB's 2013 FSAP solvency stress test was conducted on the basis of three macroeconomic scenarios: (i) a baseline scenario, (ii) an adverse scenario and (iii) an adverse scenario with add-ons for a number of countries, referred to as add-on scenario in the following.

1.1 Baseline Scenario

In line with recent OeNB stress-testing exercises, our baseline scenario reflects a combination of internal forecasts for Austria and selected Central, Eastern

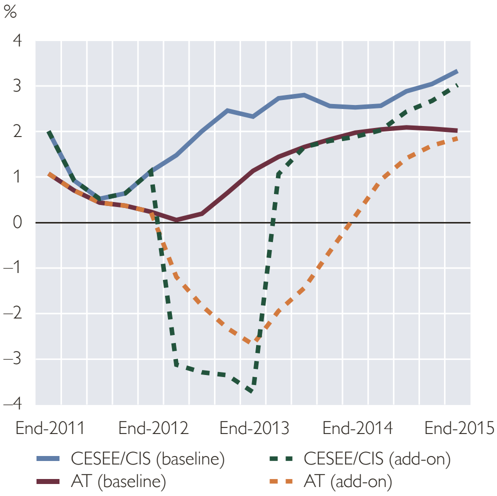
[1] *All authors: Oesterreichische Nationalbank. Opinions expressed by the authors do not necessarily reflect the official viewpoint of the OeNB or of the IMF. The authors would like to thank Michael Boss and Markus Schwaiger (both OeNB) for their continuous support, Nicolas Blancher and Laura Valderrama (both IMF) for the good collaboration during the Austrian FSAP 2013 and our referee Christian Schmieder (BIS) for a very constructive discussion. The corresponding authors are Ralph Spitzer (ralph.spitzer@oenb.at) for the solvency stress test and Stefan W. Schmitz (stefan.schmitz@oenb.at) for the liquidity stress test.*

[2] *See Boss et al. (2004, 2008) and IMF (2008).*

[3] *See IMF (2013), a Technical Note that provides more detailed results as well as the IMF's perspective on the joint stress-testing exercise.*

Chart 1

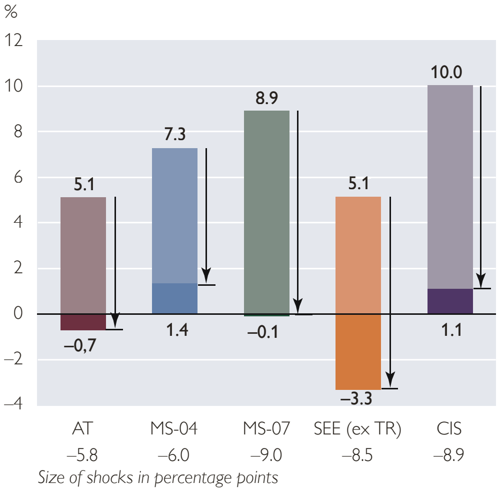
Annual GDP Growth 2013–2015 (Baseline and Add-on Scenario)



Source: IMF, OeNB.

Chart 2

Cumulated GDP Growth 2013–2015 (Baseline and Add-on Scenario)



Source: IMF, OeNB.

and Southeastern European (CESEE) countries, as well as the IMF's World Economic Outlook (October 2012). Specifically, we use GDP rates forecast for Austria at the time of the FSAP and exposure-weighted[4] average growth rates for CESEE and CIS countries (chart 1). Over the three-year time horizon, we thus expect GDP to grow by slightly more than 5% in Austria, between 5% and 9% in the different CESEE subregions, and by as much as 10% in the CIS countries (chart 2).

1.2 Adverse Scenario

Despite substantial progress in solving the European sovereign debt crisis, the main downside risk in the short to medium run stems from major debt crisis-related downturns. Therefore the adverse scenario is based on the assumption that the most distressed countries will not remain committed to continued fiscal and structural adjustment. A sudden drop in confidence is assumed to drive up interest rates and risk premia sharply. As government bond yields increase, European sovereigns run into refinancing problems, whereas banks see their core capital diminished on account of large write-downs of government bonds in their balance sheets. The fear of a collapse of large European financial institutions stresses sovereign bond markets further, creating a negative feedback loop between sovereign debt markets and financial institutions.

Consequently, rolling over old debt and obtaining new financing becomes increasingly difficult for all entities

[4] *We agreed with the IMF to weight GDP aggregates by the exposure of Austrian banks, for instance to define scenario severity. Specifically, we used the following country aggregates: The eight EU Member States that joined the European Union in 2004 (MS-04): Czech Republic (CZ), Estonia (EE), Hungary (HU), Latvia (LV), Lithuania (LT), Poland (PL), Slovakia (SK) and Slovenia (SI); the two EU Member States that joined in 2007 (MS-07): Bulgaria (BG) and Romania (RO); the following countries in Southeastern Europe (SEE): Albania (AL), Bosnia and Herzegovina (BA), Croatia (HR), Kosovo (RK), the former Yugoslav Republic of Macedonia (MK), Montenegro (ME), Serbia (RS), Turkey (TR); and the Commonwealth of Independent States (CIS): Armenia (AM), Azerbaijan (AZ), Belarus (BY), Georgia (GE), Kazakhstan (KZ), Kyrgyzstan (KG), Moldova (MD), Russia (RU), Tajikistan (TJ), Turkmenistan (TM), Ukraine (UA), Uzbekistan (UZ).*

with large funding requirements. Banks tighten their credit standards further and implement other supply-side restrictions to credit growth. The new European standards for capital ratios become even more binding. Depressed market sentiment leads to a further decline of valuations across asset classes. Lower equity prices trigger wealth effects in consumption and investment. European governments face an additional need for fiscal consolidation to regain the confidence of financial market participants. The shock leads to serious repercussions within the European economies, and the downturn is aggravated by feedback loops between the financial sector and the real economy and by feedback loops between financial market segments. All European countries are affected, albeit to varying degrees: The downturn is especially strong in many Southern and Southeastern European economies which are already characterized by high public debt levels, low competitiveness and weak growth prospects.

Moreover, the adverse scenario is based on the assumption that the protracted fiscal problems of the U.S.A. come to a head and lead to a sudden drop in confidence, hurting both domestic consumption and investment demand, on top of contracting foreign demand from Europe. The renewed confidence crises in Europe and the U.S.A. and the resulting demand shock cause euro area GDP and U.S. GDP to fall sharply and the 3-month EURIBOR-OIS spread to rise strongly in the first quarter of 2013. Our calibrations are driven by the standard deviations of historical quarterly year-on-year growth rates, which is broadly consistent with recent European FSAP stress-testing exercises.

This renewed stress in Europe and in the U.S.A. has global implications. In the OeNB's model for the Austrian economy, these shocks are transmitted through various channels, in particular confidence, fiscal, bank lending, interest rate, wealth and trade channels. For Austria, the adverse scenario thus results in a two-standard deviation shock to historical quarterly year-on-year growth rates at the end of the stress test horizon in Q4 2015.[5] At the same time, these shocks feed into the OeNB's GVAR (global vector autoregressive) model for emerging Europe (thoroughly documented in Feldkircher (2013)). For the CESEE/CIS subregions as weighted by the country-specific exposures of Austrian banks, the adverse scenario thus implies a deviation from baseline growth forecasts of roughly 1.5 standard deviations.

1.3 Add-on Scenario

In the add-on scenario, the overall shock to GDP growth is aggravated by additional country-specific shocks as a result of which the deviations from baseline growth forecasts are assumed to reach at least 1.5 standard deviations – i.e. the CESEE average of the adverse scenario – even in the major less-affected countries, namely Slovakia, the Czech Republic and Poland. Moreover, we assume that the downside risks are relatively more broad-based in several of those CESEE and CIS countries where Austrian banks hold significant exposures. Hence the add-on scenario is based on the assumption that the country-specific shocks for Hungary, Romania, Croatia and Ukraine are equivalent to at least 2.0 standard deviations.[6]

[5] *Based on observed historical data a shock of two standard deviations corresponds to a probability of approximately 2% to 3%.*

[6] *We treat all country-specific add-ons as idiosyncratic, without exerting contagion effects on other countries.*

2 Solvency Stress Test

The macroeconomic solvency stress test we conducted under the Austrian FSAP 2013 to assess the resilience of single banks and the banking system as a whole to shocks to capital positions broadly follows international best practices (Schmieder et al., 2011; EBA, 2011). Our solvency stress test is mainly a top-down exercise based on supervisory data for all Austrian banks on a consolidated level, including foreign subsidiaries and their CESEE and CIS exposures. In addition, the top-down results are complemented by bottom-up tests for market risk carried out by the top-5 Austrian banks,[7] which represent about 60% of total bank assets.

For the purpose of the solvency stress test, we translated the three scenarios, as described in detail in section 1, into stressed risk parameters which we apply to individual banks' exposures in specific portfolios, countries and sectors, thus establishing losses under stressed conditions that would put pressure on the banks' capital positions. The following sections delve deeper into the methodology applied: we describe how we project profits, losses and risk-weighted assets. While the scenario-driven cyclical risks are the mainstay of each macro stress test, we also provide the background of how we account for other risk factors, which we capture by including multiple sensitivity analyses.

2.1 Scope of the Solvency Stress Test

The OeNB's solvency stress test is a top-down exercise with a three-year horizon covering the entire Austrian banking system on a consolidated level, with supervisory as well as market and macroeconomic data for end-2012 serving as the starting point. We operate under a static-balance-sheet assumption where the total exposure remains constant over the stress horizon, i.e. we consider neither credit growth nor mitigating management actions.

To start with, we estimate cyclical credit risk by assessing additional losses and the reduced income-generating capacity of banks under duress in the individual scenarios. We conduct sensitivity analyses to establish the amount of additional losses that may result from (i) foreign currency lending (i.e. indirect credit risk following an appreciation of the foreign currency, in our case the Swiss franc), (ii) securitization positions, (iii) valuation losses on sovereign bond portfolios and (iv) market risk losses on trading book positions. For market risk losses, the aforementioned bottom-up approach enriches our assessment. Combining the traditional scenario-based losses with sensitivity analyses allows us to assess vulnerabilities from different angles.

2.2 Profit and Loss Projections over the Stress Horizon

To measure the resilience of the participating banks we project and analyze the evolution of several capital ratios[8] under the respective scenarios. For this purpose we need to model the evolution of the capital ratio components, namely the capital positions (the numerator) as well as risk-weighted assets (the denominator). While the calculation of risk-weighted assets follows the regulatory framework, calculating the capital positions requires assumptions about

[7] *BAWAG PSK, Erste Group Bank (EGB), Hypo Alpe Adria (HAA), Raiffeisen Zentralbank (RZB) and UniCredit Bank Austria (UCBA).*

[8] *Until the introduction of Basel III via the CRR/CRD IV, EBA's core tier 1 ratio (CT1R, see EBA (2011)), which was also used in the EU-wide stress test, remains the risk-bearing capacity measure of choice. Moreover, we calculate results for the tier 1 ratio (T1R) and the capital adequacy ratio (CAR).*

future profits and losses, the net impact of which either improves or reduces the capital positions.[9]

Operating Result before Credit Risk

Operating profit is the first buffer with which banks may absorb potential losses and should therefore reflect the (relatively) stable income from banks' core business and exclude any extraordinary income or other one-off or valuation effects. In the solvency stress test we model two main components, (i) the initial profit base[10] and (ii) the profit path,[11] i.e. the relative decline of operating profit given a certain macroeconomic scenario.

Credit Risk Losses

To project credit risk losses, we follow an expected-loss approach that is common amongst supervisors. This approach involves estimating scenario-dependent stressed risk parameters (default probabilities and loss-given defaults – PDs and LGDs) which we apply to banks' exposures[12] in order to calculate a stressed expected-loss amount, which we assume to equal credit risk impairments under stress. While the methodology for calculating stressed PDs is broadly unchanged and has been widely published,[13] we have recently refined the methodology to estimate stressed LGDs.[14]

Our stress tests are focused in particular on credit risk in CESEE and CIS. Not unlike the EU-wide stress-testing exercise, the Austrian models are estimated on a multi-country basis: Each CESEE or CIS country is modeled separately to assess the impact of national macroeconomic developments in the stress scenarios on the probabilities of default. See the following two charts for a comparison of the starting PD levels at end-2012 (chart 3) and PD peaks during the 2013–2015 stress horizon under the add-on scenario (chart 4).

Credit Risk-Weighted Assets

Apart from capital, which is influenced by the net result after tax and dividends, risk-weighted assets are the other main driver of the capital ratio. We account for the evolution of credit risk-weighted assets of IRB portfolios[15] using historical (realized) risk-weighted

[9] *We take account of tax effects as well as dividends in all three scenarios.*

[10] *For IFRS/FINREP reporters, we define operating profit as follows: Net interest income (including dividend income) + fee and commission income (net) + trading result + investments in associates + other operating result – administration costs – depreciations. For other banks, we use a similar definition based on the local GAAP accounting scheme. As operating profit usually exhibits some volatility, we use an exponential smoothing procedure based on quarterly data over the last five years to establish the stable income from banks' core business.*

[11] *The profit path models the reduced income generation capacity of banks under stress along two dimensions: On the one hand the operating result is reduced by defaulting exposures which no longer earn interest. On the other hand foreign income is reduced by foregone income due to unfavorable exchange rate movements for cross-border operations.*

[12] *We exclude (typically) nongranular portfolios from the calculation: sovereign exposures are accounted for in a separate sensitivity analysis and interbank exposures drive the contagion analysis results.*

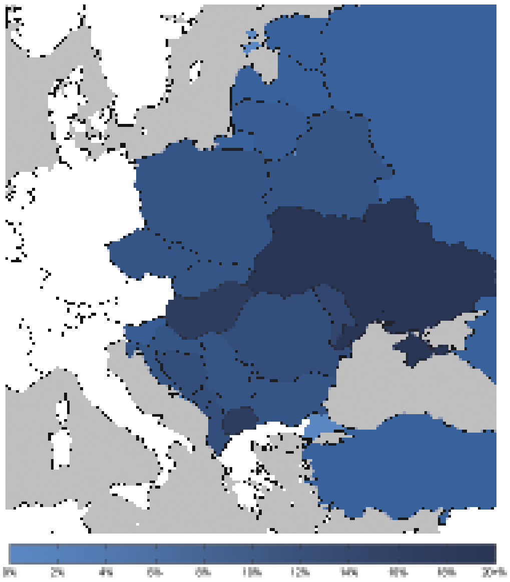
[13] *See Kerbl and Sigmund (2011) for the current model.*

[14] *We estimate LGD using two inputs: (i) collateral information and (ii) an estimate of the LGD for the uncollateralized part of the exposure. We stress the two separately before computing the effective LGD. Real estate collateral is subjected to country-specific haircuts which we estimate for CESEE and CIS countries based on the historic GDP sensitivity of house prices. The LGD for the uncollateralized part is also country-specific and based on the 2012 edition of the World Bank's Doing Business statistics.*

[15] *Currently only credit risk-weighted assets for internal ratings-based portfolios are modeled endogenously. Portfolios in the standardized approach and other risk-weighted asset risk categories (e.g. market and operational risk) are kept constant. Risk-weighted assets for securitization exposures are considered separately in a sensitivity analysis.*

Chart 3

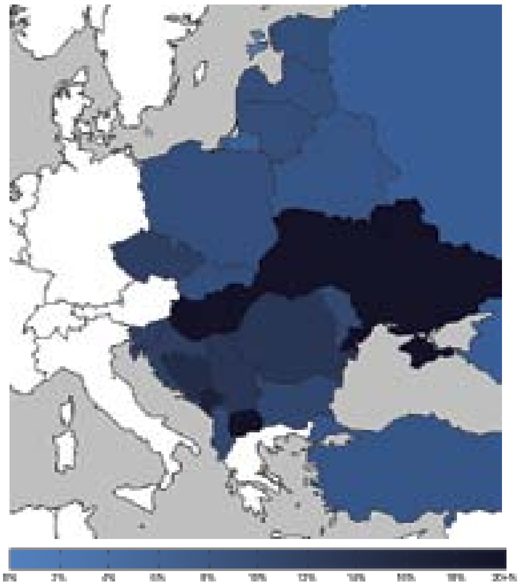
Aggregate Probabilities of Default, End-2012



Source: OeNB.

Chart 4

Maximum Aggregate Probabilities of Default under the Add-on Scenario



Source: OeNB.

assets at the starting point and apply relative changes as reflected by stressed risk parameters according to the Basel II formula.[16] In order to match the respective regulatory approach of each individual bank/portfolio, we treat Foundation IRB and Advanced IRB portfolios separately. Furthermore, risk parameter shifts are smoothed over time to mimic the through-the-cycle nature of regulatory parameters as opposed to the point-in-time approach used for projecting credit risk losses.

2.3 Results of the Solvency Stress Test

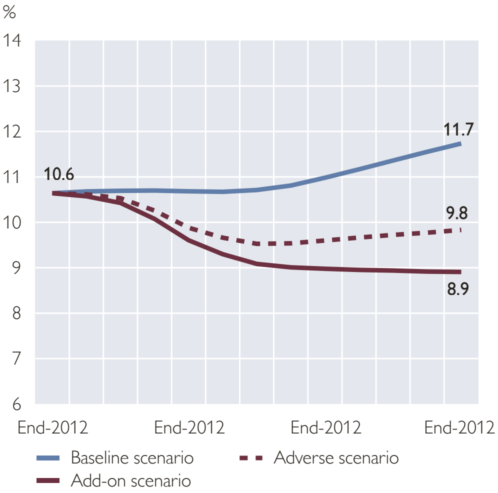
Chart 5 shows that the aggregate Austrian banking system entered the latest OeNB stress test with a core tier 1 ratio of 10.6% at the end of 2012. In the baseline scenario, the banking system managed to improve this ratio to 11.7% by the end of 2015. In the adverse scenario, the core tier 1 ratio went down to 9.8% by end-2015 and dropped to 8.9% under the add-on scenario. The result of the baseline scenario is mainly driven by (i) the profitability of the system – operating profit before risk exceeds credit risk provisions throughout the horizon of the baseline scenario. Moreover, (ii) the static-balance-sheet assumption leads to a reduction in risk-weighted assets (driven by IRB banks) of 9%.

The result under the assumptions of the adverse scenario is mainly driven by (i) a decline in operating profit before risk and (ii) an increase in credit risk provisions that peak at the end of 2013 (+57% from end-2012, substantially above historic highs even at the height of the financial crisis). The Austrian banking system rises from its trough in mid-2014 as measured by the core tier 1 ratio but without returning to the starting level by end-2015. The result of the add-on scenario is mainly driven

[16] *See BCBS (2004, 2005).*

Chart 5

EBA Core Tier 1 Ratio of the Austrian Banking System 2013–2015 (All Three Scenarios)



Source: OeNB.

by (i) a further decline in operating profit before risk and (ii) an increase in credit risk provisions that also peak at the end of 2013, albeit at significantly higher levels. Moreover, credit-risk weighted assets (of IRB banks) peak in mid-2014 with an increase of almost 10% from the initial end-2012 value. The impact at year-end 2015, however, is still negligible with +3%, not least due to the fact that IRB banks' performing portfolios decrease due to the constant-balance-sheet assumption. Still, the additional blow to vulnerable CESEE and CIS economies takes its toll in particular on the largest Austrian banks. Nevertheless, the three internationally active banks remain comfortably above the thresholds agreed with the IMF.

At the same time, this rather benign aggregate outcome masks the significant dispersion of results we observe among the almost 600 consolidated Austrian banks included in the exercise. Besides the known problem banks, banks with low initial capitalization ratios and low historical profitability perform poorly. The latter are, however, mostly smaller banks, as chart 6 shows. While even under the most severe stress test scenario almost half of the consolidated Austrian banks remain in the group with a capitalization ratio above 14%, these banks constitute less than 10% of the Austrian banking system in terms of assets. At the other end of the distribution, a nonnegligible number of banks fail the stress test under the add-on scenario. Yet the assets of these banks – which are mostly the known problem banks – make up less than 7% of the entire banking system.

Overall, the solvency stress test results indicate an improvement of head-

Chart 6

EBA Core Tier 1 Ratio Pattern of the Austrian Banking System End-2015 (Add-on scenario)

Source: OeNB.

line figures in line with international trends, but also the persistence of pockets of vulnerability in individual institutions as well as significant downside risks for the aggregate system. Amid the challenging European economic environment and the associated risks, Austrian banks should respond to the outside pressure emanating from regulators, supervisors, investors and rating agencies alike by strengthening their capital positions to improve their risk-bearing capacity.

Box 1

ARNIE, the OeNB's New Computational Framework for Systemic Risk Assessment[1]

The OeNB started to perform stress tests about a decade ago. Our first integrated tool – the Matlab-based Systemic Risk Monitor (SRM) – was put into operation in 2006. The SRM was a one-period model which accounted for market risk, credit risk and interbank contagion within a consistent framework. In order to address the longer time horizons required for solvency stress testing, we soon developed a second tool, which shared some components with the SRM but also used other data sources. However, it remained without a multi-period contagion mechanism. Over time, we implemented additional models in Matlab or added other Excel-based tools to generate exogenous input to the OeNB tools.

As the integration of various models became overly complex and burdensome the need to develop a new, integrated yet flexible tool arose. The result of this endeavor is ARNIE, the "Applied Risk, Network and Impact assessment Engine," which incorporates the OeNB's earlier developments and our experience with them but is based on a completely new code. While ARNIE can be used for stress testing it was conceived as a broader, bank-centric financial stability and impact assessment toolkit. This broader focus was driven – amongst others – by the recent rise to prominence of macroprudential regulation, as well as the abundance of policy-related questions with a view to the aggregate impact of the microprudential reregulation of banks. Hence, ARNIE does not only integrate and replace the existing tools to allow for traditional stress tests and network/contagion analysis, but in fact significantly broadens the horizon. It is based on the design principles of modularity, data abstraction, data aggregation and scalability.

***Modularity:** The modular design of ARNIE allows us to switch individual functionalities/modules on or off as needed and even to replace individual modules with others, depending on the current objective.*

***Data abstraction:** Instead of directly importing data from the Austrian supervisory databases, ARNIE draws on a generic data pool which is populated from various data sources through separate data extraction functions. ARNIE itself uses only data from the data pool and is therefore completely shielded from reporting systems or other information infrastructures.*

***Data aggregation:** ARNIE addresses an important tradeoff between data granularity and performance. Aggregation takes place at two points: Before calculations, ARNIE aggregates data from the data pool into customizable cubes. For example, credit risk data (exposure, collateral information and the risk parameters PD and LGD) are stored along six dimensions, which allows us to model shocks to specific countries and sectors and will, when implemented, allow us to model credit growth and rating migrations. When it comes to reporting, the data can be aggregated again for presentation purposes.*

***Scalability:** ARNIE can handle very large amounts of data, from a single-digit number of banks to large banking populations such as the entire Austrian banking industry (about 600 consolidated banks) or even larger populations, without excessive burdens on resources. The tool (in fact, each module) can run in a consolidated or an unconsolidated mode, which allows us to produce a consolidated view of banking groups and assess the impact on specific subsidiaries.*

[1] *Extensive ARNIE documentation is forthcoming in early to mid-2014 and is available on request.*

With regard to stress testing, ARNIE was designed to run traditional point forecast-type calculations as well as Monte Carlo simulations. For macroeconomic stress tests, we typically design two to three scenarios, which are then translated into risk parameter shifts. For Monte Carlo simulations, we process a multitude of automatically generated scenarios to arrive at a distribution of results which will include more extreme realizations and provide the impact of tail events. To generate such scenarios, we have recently implemented a forecast error model which estimates a variance/covariance matrix for IMF WEO forecasts using Bayesian inference. Draws are then sampled from the posterior predictive distribution and applied to the current baseline forecast.

The second step after scenario generation – the translation into risk parameters – currently still relies on a separate infrastructure for model estimation and selection, from which estimated models are imported into ARNIE via the data pool. Moreover, ARNIE also contains a module for analyzing interbank exposure contagion. We have switched from the more common Eisenberg/Noe algorithm to a Furfine-type default cascade model (see section 4.2), and further methodological work on the contagion model is planned.

All in all, ARNIE passed its first litmus test, the stress-testing exercise of the 2013 Austrian FSAP, quite well. We were able to react quickly to new requirements by the IMF and our management alike. Further work will focus on both refining existing models to widen the scope of existing analyses and developing new models to provide analytical capabilities for assessing relevant macroprudential policy.

2.4 Sensitivity Analyses

Beyond the risk emanating from cyclical credit risk, the solvency position of banks may come under stress from various other risks. To account for those risks we conduct a number of additional sensitivity analyses which are independent from the macroeconomic scenarios.

Foreign Currency Lending Sensitivity

One of the main risks facing the Austrian banking system is the significant stock of foreign currency loans. As we cover cyclical credit risk under the main scenarios we model the indirect credit risk stemming from an appreciation of the foreign currencies and its impact on borrowers' ability to service their debt. We calculate two separate sensitivity analyses, covering (i) foreign currency loans taken out by CESEE or CIS borrowers and (ii) the foreign currency loan portfolios of Austrian banks, as the two differ substantially with regard to their loan characteristics. Moreover, we focus on loans denominated in Swiss francs in particular, as the overwhelming majority of foreign currency loans taken out in Austria are denominated in this currency. For CESEE we also focus on the Swiss franc, mainly because our econometric models do not produce reliable results for other foreign currencies.

Foreign currency loans taken out by CESEE or CIS borrowers are mostly installment loans, i.e. we can directly observe the additional impact of exchange rate fluctuations on the impairments for foreign currency loans in comparison to local currency loans. As we observe that the relationship between foreign currency appreciation and the credit risk underlying foreign currency loans is not linear[17] we use nonlinear (exponential and quadratic)[18] functional forms to fit the data and account for

[17] *For small appreciations the credit risk only increases slightly whereas large appreciations have a disproportionate impact.*

[18] *In addition, we used different estimation criteria for fitting the curves: quadratic errors, absolute errors and robust (Huber-type) estimation. Altogether, we end up with 15 different models. For the final calculation we used an average over these models.*

the losses as CESEE/CIS foreign currency sensitivity.

For the foreign currency loans of domestic borrowers, we need to apply an indirect method as most Austrian foreign currency loans are bullet loans. We model debtors' disposable income after debt servicing as a function of exchange rate changes. As debt servicing exceeds disposable income we introduce hypothetical provisioning requirements which we then distribute equally over the loan's remaining maturity, thus accounting for the share of additional impairments allotted to the scenario horizon as domestic foreign currency sensitivity.

Market Risk Sensitivity for the Trading Book

To analyze market risk sensitivity, we ask the top-5 banks to provide results based on a given set of stressed market risk parameters. With regard to the methodology we follow the approach in EBA's 2011 EU-wide stress test,[19] while the risk parameters are recalibrated in cooperation with the IMF.

Securitization Exposures Sensitivity

For the credit risk sensitivity of securitization positions, we follow the methodology of EBA's EU-wide stress test 2011 as well. The approach excludes securitization positions from the traditional, expected loss-based calculation of credit risk losses. Instead, stress is applied through an increase in risk-weighted assets.[20]

Sovereign Exposures Sensitivity

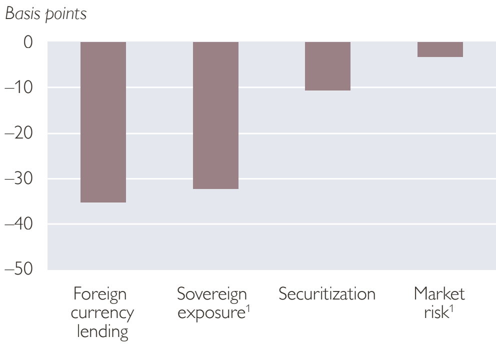
For sensitivity analyses covering the risk emanating from banks' holding of sovereign bonds, we calculate the impact of valuation losses based on historically observed yield changes provided by the IMF. We apply these haircuts to market values of banks' entire sovereign bond portfolios independent of their accounting treatment.[21]

2.5 Results of the Sensitivity Analyses

Despite the fact that sensitivity analyses cover risks that we do not cover in the "core run" of our solvency stress tests we compute their impact based on assumptions loosely based on or inspired by the main macroeconomic scenarios. Losses and increases in risk-weighted assets (with respect to securitization exposure) are then evenly spread across the three-year stress test horizon, fully

Chart 7

Maximum Impact of the Sensitivity Analyses on the EBA Core Tier 1 Ratio of the Austrian Banking System



Source: IMF, OeNB.

[1] Due to the granularity of the available data, the results for the sensitivity of the Austrian banking system to sovereign exposure and market risk reflect only the impact of the top 5 banks.

[19] See EBA (2011).

[20] Due to criticism regarding the disproportionate impact of the rating migrations under the adverse scenario, we base the sensitivity analysis on the baseline calibration. See EBA (2011).

[21] Gains/losses for bonds not valued at fair value are marked to market as well, and gains and losses are allowed to offset each other.

accounting for tax effects. We investigate the impact of each sensitivity analysis in terms of (i) absolute impact and (ii) the change in the core tier 1 ratio at the end of the observation period end-2015.

Chart 7 shows the maximum impact of each of the four sensitivity analyses we observe. The impact is never that high that the overall assessment of the solvency stress test would need to be revised. However, it becomes evident that foreign currency lending denominated in Swiss francs – with losses arising almost evenly domestically and at cross-border subsidiaries – and severe stress in the market of sovereign debt pose substantially more risk than banks' securitization exposures or their market risk in the trading book.

3 Liquidity Stress Test

While the objective of a solvency stress test is to assess the resilience of banks to shocks to their capital position, the objective of a liquidity stress test is to assess the ability of banks to meet their payment obligations on time at reasonable costs.[22] A liquidity stress test therefore considers the timing of cash inflows and outflows and the evolution of unencumbered liquid assets (the counterbalancing capacity) which can be used to generate cash to cover unexpected net outflows. A bank fails the solvency stress test if its capital ratio falls below a certain threshold, while it fails the liquidity stress test if the cumulated counterbalancing capacity is not sufficient to cover its cumulated net funding gap. The following sections delve deeper into those assumptions and the methodology applied.

3.1 Liquidity Stress Test Framework

The OeNB's liquidity stress test covers the largest 29 domestic banks on a consolidated/subconsolidated level[23] over three different time horizons: 30, 90 and 360 days. Specifically, we analyze cash-flow data including securities flows (i.e. changes in banks' counterbalancing capacity)[24] that banks report on a weekly basis as a combination of contractual and behavioral cash flows, together with their counterbalancing capacity across six currencies and five maturity buckets. For each of those dimensions, banks report figures for roughly 15 line items,[25] or up to around 1 200 data points per bank each week, which add up to a detailed picture of their liquidity positions and their reliance on behavioral components, e.g. expected funding on the unsecured money market.

3.2 Liquidity Risk Scenarios

Similarly to a solvency stress test, a liquidity stress test uses risk parameters which convey the impact of the (macroeconomic) scenarios. Here, the scenarios have to be translated into stressed risk parameters: stressed run-off and roll-

[22] *Again, we broadly follow best practices; see the cash-flow-based approach in Schmieder et al. (2012) and BCBS (2013a, b).*

[23] *Our sample covers about 80% of the Austria banking system.*

[24] *A cash-flow template contains data on banks' contractual and behavioral cash-flows in various maturity buckets and currencies; ideally, it also captures contractual and behavioral securities flows. In contrast, implied cash-flow approaches generate cash-flows from stock data. The former contains more information on banks' liquidity risk exposure and liquidity risk-bearing capacity.*

[25] *Inflows encompass, for example, receivables from unsecured money market lending, reverse repos, maturing foreign currency swaps, expected new issuance; similarly outflows contain the mirror flows; the counterbalancing capacity contains various asset categories as well as expected inflows due to parent bank support. Inflows, outflows and securities flows are interlinked via repos, reverse repos, paper in own portfolio maturing and expected financial re-investment. The structure of the template ensures that all material cash and securities flows are captured.*

over rates for the cash-flows and stressed haircuts for the counterbalancing capacity. Contrary to the econometric approach in solvency stress tests that links the scenarios to risk factors, the lack of time series forces us to perform this translation based on expert judgment. We address model uncertainty by covering a matrix of liquidity risk scenarios which is anchored in the macroeconomic scenarios and informed by a detailed analysis of past evidence, including experience from the recent crisis.[26] To address scenario uncertainty, we construct 15 embedded scenarios for each of the three time horizons. The results can be summarized in matrices (see chart 8) across two dimensions with increasing severity: Horizontally scenario severity increases, vertically the usability of the counterbalancing capacity is gradually reduced to reflect decreasing reliance on central bank bail-outs. Those scenarios are then tested for each currency.

Stressing Inflows and Outflows

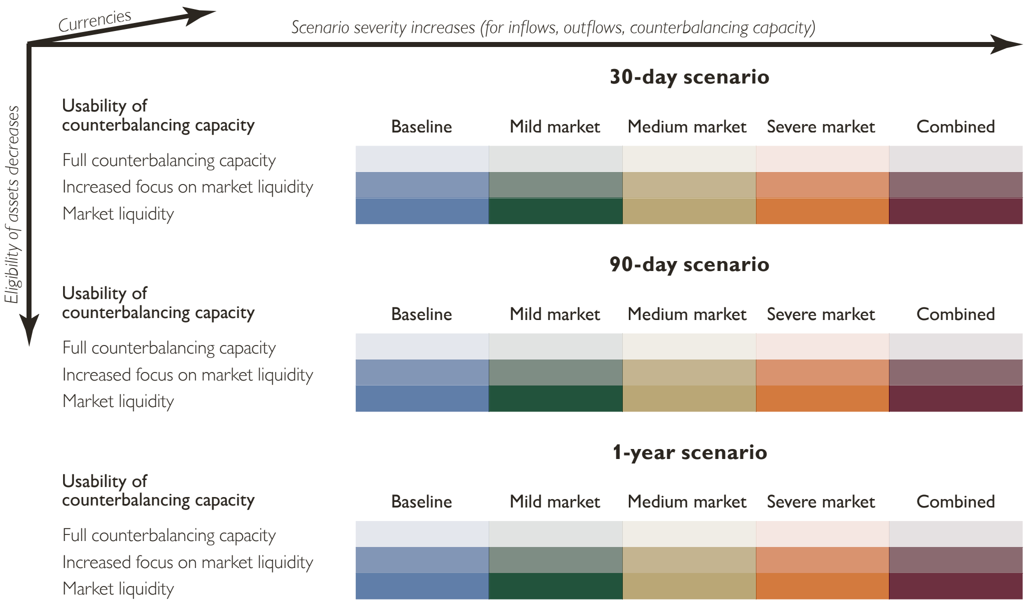
In addition to the baseline scenario (i.e. business-as-usual liquidity positions as reported) we construct a mild, a medium and a severe market scenario. This is complemented by a combined scenario which adds an idiosyncratic (bank-specific) shock to the severe market scenario.

The scenarios for the 30-day stress test horizon

For the mild market scenario, we assume that unsecured interbank markets close for all banks, and that all foreign currency swap markets close as well. Given the exposure of some Austrian banks to funding liquidity risk in U.S. dollars and Swiss francs, the scenario is not really mild, but in our hierarchy of

Chart 8

Overview of the Liquidity Stress Test Scenarios



Source: OeNB.

[26] *See BCBS (2013a, b), Schmieder et al. (2012) and the data and literature cited therein.*

embedded scenarios it is the mildest. In addition, the medium market scenario assumes that the expected issuance of short-term and long-term secured and unsecured debt is reduced by 50%. In addition, we stress liquidity commitments to banks (increase of 50%) and nonbanks (increase of 50%). In the severe market scenario, issuance markets dry up completely and draw-downs of committed lines to banks and nonbanks double. The combined scenario, finally, adds an idiosyncratic shock to the severe market scenario. It consists of a reduction of expected rollover rates of wholesale deposits to 90% and of retail deposits to 95% over the 30-day period.[27]

The scenarios for the 90-day stress test horizon

The mild, medium and severe market scenarios for the 90-day stress test horizon are equivalent to those in the 30-day horizon, except that strained market conditions persist three times as long. Thus, the degree of severity is higher over the longer scenarios. However, in the severe market scenario banks are allowed to react to the liquidity shock. Re-investment of maturing paper in own portfolios is reduced to 50% and banks utilize their liquidity buffer to cover stressed net outflows.[28] The combined scenario adds an idiosyncratic shock to the severe market scenario. It consists of a reduction of expected rollover rates of wholesale deposits to 80% and of retail deposits to 90% over the 90-day period. Re-investment of maturing paper in own portfolios is reduced by 100%.

The scenarios for the 12-month stress test horizon

The baseline, mild and medium market scenarios over 12 months are similar to their 30-day and 90-day equivalents, except that the scenario horizon is longer and that banks are allowed to scale back re-investments of maturing paper in own portfolios by 50% due to the length of the stress. The severe market scenario and the combined scenario assume a broad deposit outflow calibrated to the experience of periphery countries during the sovereign debt crisis.[29] The severe market scenario also incorporates an additional solvency/liquidity link (the interaction between a bank's expected future solvency and its access to funding markets, see section 3.4).

Stressing the Counterbalancing Capacity

Modeling banks' central bank dependency

The operational frameworks that the Eurosystem and other central banks (i.e. Bank of England, U.S. Federal Reserve Bank, Swiss National Bank) use to implement monetary policy ensure generous access to central bank liquidity for banks through combinations of full allotment and/or asset purchasing programs, broadened eligibility criteria, and long-term funding programs. However, the liquidity stress test aims at ensuring that banks internalize the negative externality associated with individual banks' liquidity problems and at avoiding the moral hazard problem

[27] *See Schmieder et al. (2012), table 3.*

[28] *Under a 90-day combined stress, the relaxation of this objective is reasonable; the counterbalancing capacity is maintained to absorb liquidity shocks and should thus be allowed to decrease if liquidity stress prevails for more than a very short period.*

[29] *This translates into a reduction of rollover rates by 4% for retail deposits and 6% for nonbank wholesale deposits for the severe scenario, and by 5% and 10% for the combined scenario.*

associated with implicit liquidity guarantees provided by central banks.[30] Thus, we foresee three distinct, but embedded approaches to testing the usability of the counterbalancing capacity:

For the "full counterbalancing capacity" approach, we assume that all liquid assets, even less liquid assets,[31] can be used to generate cash. However, committed liquidity lines and liquidity injections from parent banks are excluded. For the "increasing focus on market liquidity" approach, we exclude the less liquid assets, and for the "market liquidity" approach we shut out all nonstandard central bank operations.[32]

Taking into account market risk and market liquidity risk

We use haircuts to proxy the impact of both price effects and market liquidity effects on the counterbalancing capacity. The baseline and the mild market scenario utilize the haircuts that banks report in the weekly liquidity template (apart from the adjustment necessary to reflect the different approaches to banks' central bank dependency). The 30-day medium market scenario assumes a 5% haircut (on top of the reported haircuts) for unencumbered collateral deposited at central banks. This haircut doubles under the 90-day medium market scenario. For the severe market scenario and the combined scenario, we distinguish between collateral deposited with the OeNB and with other central banks. The former is stressed on the components of the tradable portfolio[33] ranging from 1% (asset class 1/credit quality step 1)[34] to 100% (asset class 5/credit quality step 5). Nontradable assets are subject to credit migration across credit quality steps according to the output of the macro-to-PD shifts of the solvency stress test. Haircuts increase accordingly. Collateral deposited at non-Eurosystem central banks receive a haircut of 10%. For other components of the counterbalancing capacity (not deposited at central banks) the additional haircuts range from 1% (AAA-rated bonds) to 10% (A-rated bonds). Other components receive haircuts between 15% and 100% (committed lines, liquidity support from the parent banks). The calibration is based on the empirical studies of the behavior of various funding markets.[35] The 90-day severe market scenario and the 90-day combined scenario apply a factor of 1.5 to all haircuts in the respective 30-day scenarios. The haircuts for nontradable assets deposited at the OeNB are based on a 90-day rather than the 30-day PD shift.

3.3 Results of the Liquidity Stress Test

Looking at the aggregate across all currencies, the funding structure of Austrian banks appears resilient. For instance, under the medium scenario across all currencies – according to the

[30] *BCBS (2013a).*

[31] *Less liquid assets include assets such as BBB corporate bonds, credit claims or other pledgeable assets.*

[32] *To assess the impact of the scenario under the assumption of a discontinuation of nonstandard central bank measures we increase the haircuts on unencumbered eligible assets deposited with the Eurosystem to 100% for the following types of assets: nonmarketable assets, securities with ratings below A-, unsecured issuances by banks and financial corporates, as well as asset-backed securities.*

[33] *According to the Eurosystem eligibility criteria for marketable assets (www.ecb.europa.eu/paym/coll/standards/marketable/html/index.en.html)*

[34] *According to the Eurosystem haircut schedule (ECAF) (www.ecb.europa.eu/press/pr/date/2013/html/pr130718_annex.pdf)*

[35] *See Schmieder et al. (2012) and BCBS (2013a, b) and the data and literature cited therein.*

IMF comparable with other recent European FSAPs – assuming total closure of the unsecured interbank and foreign currency swap markets, and with substantial haircuts in the counterbalancing capacity,[36] the total liquidity shortfall based on the cumulated counterbalancing capacity amounts to only 0.1% (30-day horizon), 0.3% (90-day horizon) and 0.2% (1-year scenario) of total liabilities of the 29 banks in the sample.[37]

While the liquidity situation of the system has improved substantially since 2008, some banks are lagging behind in their adjustment process in particular with regard to foreign currency funding. While the situation across banks has continuously improved for U.S. dollar liquidity, the picture is less reassuring for the Swiss franc. Only about half of the banks in the sample show a high resilience to Swiss franc liquidity shocks. Given the fact that there are maturity structure limits to reducing the asset portfolios denominated in Swiss francs, it is important that these banks lengthen their average Swiss franc funding tenors to a period of up to two years, diversify into repo markets, and increase their Swiss franc liquidity buffers.

3.4 Linking Solvency to Liquidity

Up to the recent FSAP stress tests, we ran solvency and liquidity stress tests as two entirely separate exercises without any mutual impact. In reality there are important interactions between banks' solvency and liquidity positions. In the 2013 round of stress tests we therefore implemented links to capture some of these effects. As the calibration of such interactions is not straightforward this area merits further work, at both national and international levels.[38]

In principle, solvency and liquidity can interact in two directions: The solvency position can influence the liquidity position (e.g. defaulting assets reduce inflows), and the liquidity position can influence solvency (e.g. via funding costs). In the liquidity stress test only the former was implemented (see below). The latter is investigated in the contagion analysis (see chapter 5).

We modeled the impact of solvency stress results on the liquidity stress test via multiple channels: (i) the rating migrations in the solvency stress test are mapped on credit claims deposited by banks as collateral at the central bank, which reduce their counterbalancing capacity; (ii) assets which default in the solvency stress test reduce cash inflows; (iii) the solvency position of a bank impacts its access to funding markets.

First, the migration of credit claims pledged to the central bank across credit quality steps (and, thus, haircut categories) has to be derived from detailed bank-level collateral data. We assume that loan volumes are identically distributed across the respective PDs in each credit quality step. An increase in PDs shifts the PD range for each credit quality step upward. The weighted sum across each bank's credit claim migration across credit quality steps is again weighted by the bank's share of non-marketable assets in its entire volume of collateral deposited with the central bank. We apply the composite haircut

[36] *See IMF (2013).*

[37] *Despite the longer horizon the liquidity gap in the 1-year scenario is marginally lower than in the 90-day scenario due to the ability to access funding markets by the better capitalized banks and the embedded banks' behavioral reactions.*

[38] *See Puhr and Schmitz (2013).*

to the respective lines in the liquidity stress test to derive the decreased liquidity generation capacity.

Second, the calibration of reduced cash inflows due to defaulting assets' impact is a direct output of the solvency stress test (for loans and advances) rescaled to the appropriate liquidity stress-test time horizon. The calibration for nonfinancial bonds is more demanding, as banks do not report the composition of their own-portfolio assets. We approximate it by the share of banks' reported holdings of nonfinancial bonds in their stock of highly liquid assets and the migration of loans to nonfinancials across PD buckets.

Third, modeling the interaction between a bank's expected future solvency and its access to funding markets is inspired by the dynamics observed in the asset-backed commercial paper market during the post-Lehman financial market turmoil. We assume that, initially, issuance markets (secured/unsecured as well as short-term and long-term) are closed for all banks. After the first quarter, uncertainty is reduced and investors are able to distinguish between stable and less stable banks. The calibration is based on the results of the solvency stress test at *t+1* year, i.e. implicitly investors are forward-looking and use similar models to assess expected future solvency as the solvency stress test and arrive at similar conclusions. An empirical basis for the calibration is, however, work in progress.[39]

4 Contagion Analysis

In addition to the solvency and the liquidity stress tests, we perform a contagion analysis to deepen the link between solvency and liquidity while at the same time accounting for losses from interbank exposures. Due to reporting data limits for cash-flow data, the contagion analysis horizon is constrained to one year. With regard to severity, the liquidity stress scenario in the contagion analysis is similar to the 12-month medium market scenario, including the interaction between a bank's expected future solvency and its access to funding markets (see 3.4 above).

4.1 Linking Liquidity to Solvency

For the link between liquidity and solvency, we focus on two channels: (i) a cost-of-funding shock and (ii) asset fire-sale losses. Both influence solvency via profit or loss effects. We model the cost-of-funding shock as a market shock that affects both retail and wholesale deposits as well as new issuances[40] and apply the aggregate impact to the stressed cash flows. In addition, some pass-through to new loans is possible. As such, the impact of the cost-of-funding shock is driven by the maturity mismatch and the spread shock on existing assets rather than by pass-through constraints. Even if banks were able to pass through most of the funding shock, the volume of loans where banks can adjust the pricing is much lower than that of liabilities due to banks' maturity transformation.

With the asset fire-sale losses we capture contagion through common exposures via price and market liquidity impacts on banks' counterbalancing capacity and their profit or loss. Fire-

[39] *An important channel from solvency to liquidity which the approach disregards is the impact of a bank's solvency position and its access to unsecured interbank markets. Already the standard market liquidity stress scenario assumes a complete dry-up of the unsecured interbank market and, thus, preempts the potential impact of this channel.*

[40] *New issuances, however, play a minor role, as most banks are assumed to be shut out of issuance markets anyhow.*

sale shocks are calibrated based on the haircuts in the stress test plus the solvency shock that feeds into haircuts via the migration matrix of credit claims deposited as collateral with the central bank. Unlike the cost-of-funding shock, which is a market shock, the losses due to asset fire sales are bank-specific. If a bank does not have a cumulated net funding gap over the stress horizon, it does not have to sell liquid assets and, hence, does not face any losses from asset fire sales. This is also true if there are enough cash reserves to cover the gap.

However, depending on the accounting framework under which the respective assets are treated, fair value accounting can lead to solvency effects even if the bank does not have to sell the respective asset. To account – at least partially – for these effects, the model assumes a theoretical loss due to asset fire sales under the assumption that all assets are subject to fair value accounting and that banks sell their counterbalancing capacity assets (except cash) proportionally to their cumulated net funding gap. As such, banks with less liquid assets face higher fire sale losses.[41]

4.2 Modeling Contagion

Contagion is modeled using a Furfine rather than the Eisenberg/Noe model,[42] which we used to apply at the OeNB. We chose to switch to the former due to methodological concerns about the implicit LGD of the latter, which might yield inadequate (i.e. very low) values and therefore low contagion losses. The Furfine contagion model works as follows: any bank that falls below a given threshold is assumed to default on all its interbank obligations with the same exogenous LGD for all borrowers. For the purpose of the FSAP stress test, we set the capital threshold to the regulatory minimum of 8% (capital adequacy ratio) and the LGD to 100%, which can be read as very conservative assumptions.

In the OeNB implementation, we measure the capital adequacy ratio at the consolidated level (as is usually the case for solvency stress tests), while contagion losses are computed at the unconsolidated level. If a consolidated group falls below the default threshold, all unconsolidated entities of the group are considered to be in default. Unconsolidated losses are then computed by netting unconsolidated exposures (excluding intra-group exposures) bilaterally and deducting collateral without haircuts. These losses are then consolidated to arrive at the consolidated capital adequacy ratio impact.

5 Conclusions

In this paper we present the main concepts and methods used in the Austrian 2013 FSAP stress test. We cover solvency and liquidity stress tests as well as, as part of our contagion analysis, the interaction of solvency with liquidity. The mechanics of solvency stress testing, following a balance sheet framework (Schmieder et al., 2011), are by and large well established. The main challenges lie in producing consistent results: striking the right balance between bank profitability and losses in both baseline and adverse scenarios on the one hand while keeping the economic and regulatory perspective on the other is not trivial. This is exacerbated by two additional challenges: (i) Results rely heavily on valid starting points, and data quality and consistency

[41] *For a discussion of the literature on asset fire sales and its implications in our model see Puhr and Schmitz (2013).*

[42] *See Furfine (2003) and Eisenberg and Noe (2001), respectively.*

issues pose a serious threat to the validity of results. At the same time (ii) banks have established a reputation for managing their earnings and optimizing their risk-weighted assets, both of which substantially impact econometric models that link scenarios to risk factors. On a more positive note, our experiences combining fully-fledged scenarios with sensitivity analyses are positive: This approach allows us to incorporate estimates for specific risks which cannot be consistently captured in a macroeconomic scenario, and the results thus produced are easy to communicate. Thus, this approach should enable us to address at least some of the aforementioned problems.

With regard to liquidity stress testing we face somewhat different issues. While there is no commonly agreed approach yet – see Schmieder et al. (2012) – the starting point for our analysis is the OeNB's extensive cash-flow reporting framework, which is an asset. However, we still need to address the lack of established econometric models that link scenarios with risk factor shifts (run-off rates, haircuts, etc.). To address model and scenario uncertainty, we opt for a rather large number of scenarios to uncover pockets of vulnerability in banks' balance sheets. As part of the Austrian FSAP 2013, we work for the first time on a thorough, formal link between solvency and liquidity stress (see Puhr and Schmitz (2013) for further details). While the importance of incorporating these feedback effects is beyond controversy, the implementation is not straightforward. In our models, the greatest issues lie in the different data dimensions for solvency and liquidity stress testing: Whereas solvency looks at countries and sectors, liquidity deals with cash flows across product types, maturities and currencies. Mapping those cash flows into the solvency world (and vice versa) is a major challenge which underlines the need for microdata-based regulatory reporting. For tail events, firm econometric foundations to model the interaction between banks' solvency, funding liquidity and market reactions are, moreover, still restricted to an abstract academic world. Nevertheless, we believe that those feedback channels are at least as important as traditional interbank contagion, but that they have received far less attention so far. More work is needed here.

Finally, the collaboration with the IMF provided us with an outside view on the stress-testing framework of the OeNB and with ample feedback for advancing our theoretical as well as practical approach to stress testing. See IMF (2013) for the Fund's perspective on the stress-testing exercise for Austria's 2013 FSAP. Moreover, the launch of our new systemic risk assessment tool, ARNIE, enabled us to enhance the calculations of the solvency stress test as well as the contagion analysis. While some features like modularity or the data abstraction layer will play out their strengths over time, the new data structure and the reporting routines provided an immediate payoff. Compared with our previous mix of tools and models, having a single framework in place that allows for adjustments and reporting in a consistent fashion was invaluable. We are confident that ARNIE will enable us to delve deeper into the assessment of macroprudential risks in the future.

References

BCBS. 2004. International Convergence of Capital Measurement and Capital Standards. A Revised Framework.

BCBS. 2005. An Explanatory Note on the Basel II IRB Risk Weight Functions.

BCBS. 2013a. Liquidity stress-testing: a survey of theory, empirics and current industry and supervisory practices. WP 24.

BCBS. 2013b. Literature review of factors relating to liquidity stress. WP 25.

Boss, M., G. Krenn, M. S. Schwaiger and W. Wegschaider. 2004. Stress Testing the Austrian Banking System. In: Österreichisches Bank Archiv 52(11). 841–856.

Boss, M., G. Krenn, C. Puhr and M. Summer. 2006. Systemic Risk Monitor: A Model for Systemic Risk Analysis and Stress Testing of Banking Systems. In: OeNB Financial Stability Report 11. 83–95.

Boss, M., G. Fenz, G. Krenn, J. Pann, C. Puhr, T. Scheiber, S. W. Schmitz, M. Schneider and E. Ubl. 2008. Stress Tests for the Austrian FSAP Update 2007: Methodology, Scenarios and Results. In: OeNB Financial Stability Report 15. 68–92.

Eisenberg, L. and T. Noe. 2001. Systemic Risk in Financial Systems. In: Management Science 47(2). 236–249.

Elsinger, H., A. Lehar and M. Summer. 2006. Risk Assessment for Banking Systems. In: Management Science 52(9). 1301–1314.

EBA. 2011. 2011 EU-Wide Stress Test: Methodological Note.

Feldkircher, M. 2013. A Global Macro Model for Emerging Europe. OeNB Working Paper 185.

Furfine, C. 2003. Interbank Exposures: Quantifying the Risk of Contagion. In: Journal of Money, Credit and Banking 35(1). 111–128.

IMF. 2008. Austria: Financial Sector Assessment Program, Technical Note – Stress Testing and Short-Term Vulnerabilities.

IMF. 2013. Austria: Financial Sector Assessment Program, Technical Note – Stress Testing the Banking Sector.

Kerbl, S. and M. Sigmund. 2011. What Drives Aggregate Credit Risk. In: OeNB Financial Stability Report 22. 72–87.

Puhr, C. and S. W. Schmitz. 2013. A View From The Top – The Interaction Between Solvency And Liquidity Stress. In: Journal of Risk Management in Financial Institutions (forthcoming).

Schmieder, C., C. Puhr and M. Hasan. 2011. Next generation balance sheet stress testing. IMF Working Paper 11/83.

Schmieder, C., H. Hesse, B. Neudorfer, C. Puhr and S. W. Schmitz. 2012. Next generation system-wide liquidity stress testing. IMF Working Paper 12/03.