How to capture macro-financial spillover effects in stress tests

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Abstract
One of the challenges of financial stability analysis and bank stress testing is how to establish scenarios with meaningful macro-financial linkages, i.e., taking into account spillover effects and other forms of contagion. We propose an approach to simulate the potential impact of spillover effects based on the “traditional” design of macroeconomic stress tests. Specifically, we examine spillover effects observed during the financial crisis and simulate their impact on banks’ liquidity and capital positions. The outcome suggests that spillover effects have a highly nonlinear impact on bank soundness, in terms of both liquidity and solvency.
I. Introduction

Stress testing has received a lot of attention in recent years, which has spurred numerous conceptual developments.\(^2\) However, overarching approaches to establish macro-financial linkages, explicitly to capture the nonlinearity of shocks (originating from spillover effects and other types of contagion), are still evolving. Such linkages have seen particularly significant growth during the past decade and are, therefore, an important dimension to be captured by meaningful empirical analysis.\(^3\) This paper uses a case study to focus on the design of stress tests which helps to capture spillover effects and demonstrate their potential impact.

The first part of the paper deals with the establishment of macro-financial scenarios that are explicitly informed by spillover effects. Scenario design for macroeconomic stress tests is typically based on an “indirect approach” (Figure 1):\(^4\) first, economic and financial variables are estimated, conditional on a macroeconomic scenario, and then the trajectories of the economic and financial variables are translated into bank solvency and liquidity\(^5\) measures on the basis of the so-called “satellite” or “auxiliary” models. Three approaches have commonly been used to predict economic and financial variables under stress:\(^6\) (i) a structural econometric model, (ii) vector autoregressive methods, and (iii) pure statistical approaches. The satellite models commonly take the form of (panel) regression models. The direct approach, on the other hand, is based on projections of the actual solvency and liquidity parameters without an explicit link to the state of economic and financial variables. While this approach could be equally meaningful in terms of the outcome of stress tests, it does not allow for detailed storytelling and can underestimate the importance of nonlinear macro-financial factors for bank-specific stress tests.

Modeling contagion effects and their impacts is typically challenging.\(^7\) By definition, spillover effects and other dynamic contagion effects are implicitly captured in past data, but not necessarily if one uses structural econometric models, which are usually perceived as being best practice. Even if potential spillover events are captured in past data, this data might not be representative for a future scenario if, for example, linkages between economies and banks have become gradually more intense over time. In this study, we focus on spillover effects originating from the recent sovereign debt crisis. Other spillover catalysts could be, for instance, a macroeconomic downturn in a major world economy or the failure of a large financial institution such as the case of Lehman Brothers.

We aim to develop a stress testing approach that captures spillover effects in detail.\(^8\) Our solution is an amended version of the indirect approach: the starting point is to establish a macroeconomic scenario, typically not informed by potential spillover effects, at least not explicitly. In the second step, the potential marginal increase of stress due to spillover effects is estimated by translating the spillover effects into reduced output paths, i.e., an adverse macroeconomic scenario. In terms of the stylized design of macroeconomic stress tests (figure 1), we thereby implicitly incorporate a quasi-feedback loop into the linear design of traditional stress tests – through a sensitivity type approach.\(^9\) The approach could also include a test for interbank bank contagion, as shown in figure 1. We build on previous IMF work to establish an explicitly iterative process, i.e., to establish a scenario informed by initial spillover effects on the basis of

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\(^2\) For work on stress testing at the IMF, for example, see Jobst et al. (2013)
\(^3\) Frank et al. (2008)
\(^4\) Jobst et al. (2013)
\(^5\) Most liquidity stress tests have typically relied on the “direct” approach.
\(^6\) Foglia (2009)
\(^7\) Jobst et al. (2013)

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**Figure 1: Stylized design of stress tests**
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At the IMF, such analyses were carried out by combining the work of Schmieder et al. (2011) and Vitek and Bayoumi (2011) as part of early warning analyses and vulnerability exercises. It should be noted that running such an approach requires close cooperation between staff running macroeconomic forecasts and staff simulating the impact of stress at the bank level (typically done by financial stability departments).

Two approaches are used to capture the spillover effects in sovereign debt markets: panel regressions and a GARCH model. The panel regressions, which are used to establish an “average” impact of spillover effects during periods of stress on advanced market (AM) and emerging market (EM) countries, respectively, suggest that increasing sovereign risk in the Euro periphery was a major driving force behind the spillover effects. As expected, risk aversion, measured through changes in the VIX and high-yield spreads, is found to increase during periods of financial stress, exhibiting a nonlinear pattern. Country-specific macroeconomic factors also matter, but to a lesser degree, and their impact does not appear to change significantly under periods of stress.

GARCH models were run to obtain more granular spillover effects, such as the country-specific co-movements between peripheral European GIIPS and sovereign debt spreads and the corresponding spreads in the banks’ home countries (i.e., the 25 most systemically important financial systems, the “S-25” sample) for specific points in time. The study reveals significant differences in terms of the spillovers across countries, with a higher impact observed for most core Euro area countries (in particular, during peak periods of the crisis) than for Scandinavian countries, Switzerland, the UK and most non-European countries. The findings also show a flight-to-quality element, i.e., a negative co-movement of GIIPS spreads with German Bunds and US Treasuries.

In the second part of the paper, we illustrate how the established spillover effects would feed through to banks based on a case study for 154 large international banks from the “S-25” country sample. The impact of different degrees of spillover on banks’ solvency and liquidity positions is compared with baseline type conditions (which correspond to realized stress scenarios in recent years unlike in “normal” times). Stress at the bank level is simulated on the basis of a recently developed IMF stress testing framework for liquidity and benefits from work on solvency, which together allow running integrated solvency and liquidity scenarios.

The outcome suggests that spillover effects have a highly nonlinear impact on bank soundness, both in terms of liquidity and solvency. It is thereby shown (once more) that the design of stress scenarios is a highly crucial element of stress testing, and is sensitive with respect to the outcome of stress tests. The magnitude of the impact on bank solvency and liquidity could serve as a benchmark for other studies, while recognizing that future spillover channels could be highly different, in terms of both direction and magnitude. In this sense, our study could help to identify potential systemic vulnerabilities ex-ante, a role that stress tests have not necessarily played in the past for a number of reasons.
The paper is organized as follows. Section 2 investigates financial spillovers at the sovereign and bank level, based on panel regressions and a GARCH model framework. Section 3 provides a brief overview of the stress testing framework used to simulate the impact of spillover effects on bank liquidity and solvency. Section 4 shows the impact of different degrees of spillover based on a case study. Finally, section 5 concludes and offers some avenues for future research. The appendix shows an illustrative country example.

2. Financial spillovers from the Euro periphery to the rest of the world

2.1 Panel approach

Financial market linkages across economies have grown significantly in recent decades; linkages which were felt strongly when the financial crisis started in 2008 with the failure of Lehman Brothers, and later continued to become a sovereign debt crisis, especially in the European periphery. AM financial spillovers have been a dominant determinant of AM and EM financial soundness during the previous years. Recent studies identified three important factors for spillover effects: (i) a stress spillover catalyst – in this study, AM sovereign debt yields, (ii) risk aversion in global markets, and (iii) country-specific risk factors.

Herein, we seek to establish benchmark parameters to simulate spillover effects at the bank level. Initially, we construct a risk premium variable for our sample of 35 countries. The risk premium is the spread between 10-year domestic treasuries to US Treasuries for non-European AM countries, to German Bunds for AM countries in Europe and to the JP Morgan Emerging Markets Bond Index (EMBI) for the EM countries. The panel regressions adjust for exchange rate changes.

<table>
<thead>
<tr>
<th>Explanatory variables</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GIIPS spread</td>
<td>0.237a (0.045)</td>
<td>0.244a (0.047)</td>
<td>0.288a (0.046)</td>
<td>0.289a (0.047)</td>
<td>0.611a (0.09)</td>
<td>0.653a (0.094)</td>
</tr>
<tr>
<td>GIP spread</td>
<td>0.666a (0.242)</td>
<td>0.348 (0.238)</td>
<td>0.342 (0.229)</td>
<td>-0.070 (0.291)</td>
<td>0.025 (0.021)</td>
<td></td>
</tr>
<tr>
<td>Italy/Spain spread</td>
<td>0.015 (0.017)</td>
<td>0.015 (0.017)</td>
<td>0.031c (0.016)</td>
<td>0.030c (0.016)</td>
<td>0.053a (0.020)</td>
<td></td>
</tr>
<tr>
<td>High-yield spread</td>
<td>0.080a (0.017)</td>
<td>0.078a (0.017)</td>
<td>0.061a (0.016)</td>
<td>0.060a (0.016)</td>
<td>0.051b (0.020)</td>
<td></td>
</tr>
<tr>
<td>VIX</td>
<td>0.297b (0.131)</td>
<td>-0.632 (0.744)</td>
<td>0.256c (0.136)</td>
<td>-0.660 (0.718)</td>
<td>0.700a (0.166)</td>
<td></td>
</tr>
<tr>
<td>Openness</td>
<td>0.77</td>
<td>0.70</td>
<td>0.79</td>
<td>0.73</td>
<td>0.79</td>
<td>0.78</td>
</tr>
<tr>
<td>M2/GDP</td>
<td>415</td>
<td>415</td>
<td>435</td>
<td>435</td>
<td>454</td>
<td>454</td>
</tr>
<tr>
<td>Constant</td>
<td>25</td>
<td>25</td>
<td>23</td>
<td>23</td>
<td>26</td>
<td>26</td>
</tr>
</tbody>
</table>

R-squared (within) = 0.77, Observations = 415, T = 25

Standard errors in parentheses. a = p<0.01, b = p<0.05, c = p<0.1. Right-hand-side variables are in logs.

Table 1: Panel regressions, 2006 Q1–2012 Q2 (dependent variable: sovereign spreads of 35 sample jurisdictions) (quarterly data)

Explanatory variables include: GIIPS spread, GIP spread, Italy/Spain spread, High-yield spread, VIX, Openness, M2/GDP, Constant. The sample of jurisdictions includes Australia, Austria, Belgium, Brazil, Canada, China, Denmark, Finland, France, Germany, Greece, Hong Kong SAR, Hungary, India, Ireland, Italy, Japan, Korea, Luxembourg, Malta, Mexico, Netherlands, Norway, Poland, Portugal, Russia, Singapore, Slovenia, Spain, Sweden, Switzerland, Turkey, the UK and the US.

Recent studies identified three important factors for spillover effects: (i) a stress spillover catalyst – in this study, AM sovereign debt yields, (ii) risk aversion in global markets, and (iii) country-specific risk factors.

Herein, we seek to establish benchmark parameters to simulate spillover effects at the bank level. Initially, we construct a risk premium variable for our sample of 35 countries. The risk premium is the spread between 10-year domestic treasuries to US Treasuries for non-European AM countries, to German Bunds for AM countries in Europe and to the JP Morgan Emerging Markets Bond Index (EMBI) for the EM countries.

On the basis of random effects panel regressions, the sovereign spreads are regressed on three sets of peripheral spreads: average spreads for the European peripheral countries (GIIPS), (ii) for Greece, Ireland and Portugal (GIP), and (iii) for Italy and Spain (IT-ES). Risk aversion is identified by two variables: high-yield spreads and the VIX. The former is the difference between yields to maturity of Moody’s Aaa-rated and Baa1-rated US corporate

20 Caceres and Unsal (2011)
21 The sample of jurisdictions includes Australia, Austria, Belgium, Brazil, Canada, China (mainland), Cyprus, Denmark, Finland, France, Germany, Greece, Hong Kong SAR, Hungary, India, Ireland, Italy, Japan, Korea, Luxembourg, Malta, Mexico, Netherlands, Norway, Poland, Portugal, Russia, Singapore, Slovenia, Spain, Sweden, Switzerland, Turkey, the UK and the US.
22 The panel regressions adjust for exchange rate changes.
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bonds. The latter is the implied volatility for S&P 500 index options. Trade openness, liquidity (proxied by M2 to GDP and the level of reserves to GDP), inflation rates, GDP growth, the current account, the level of public debt and deficits to GDP ratios are used as macroeconomic control variables to capture country-specific cyclical effects. The regressions are estimated for two time periods on the basis of quarterly data: 2006–12 and 2008–12. The choice of the two sample periods is meant to capture the impact of the systemic stress. The results (displayed in tables 1 and 2) present various model specifications considered useful to identify drivers of spillover stress and their actual impact, respectively. Using the sovereign debt spreads of the 35 sample countries as the dependent variable, table 1 shows the outcome for 2006–12 and 2008–12. The choice of the two sample periods is meant to capture the impact of the systemic stress. The results (displayed in tables 1 and 2) present various model specifications considered useful to identify drivers of spillover stress and their actual impact, respectively. Using the sovereign debt spreads of the 35 sample countries as the dependent variable, table 1 shows the outcome for 2006–12 and 2008–12. The results confirm previous studies in that all three factors, i.e., a catalyst, risk aversion and country-specific factors, are actually important to explain financial stress (measured in terms of sovereign spreads), at least for the recent financial crisis:

- Increasing sovereign risk in the Euro periphery was found to be a catalyst for spillover effects
- The global perception of risk magnifies stress conditions, as do expected future interest rates
- Country-specific macroeconomic factors also matter, but to a lesser degree
- While the impact of country-specific factors does not appear to change significantly under stress, the impact of the former two factors is higher during 2008–12, i.e., in the period covering only the crisis years (compared with the full sample period)

For the longer sample period (i.e., 2006–12), a one percentage point change in Euro periphery sovereign spreads (i.e., GIIPS and GIP) translates into a 0.2–0.3 percentage point change of sovereign debt spreads in the 35 sample countries (table 1). Global risk aversion (measured by changes in high-yield spreads) has an even higher impact — a 1 percentage point change in high-yield spreads translates into a circa 0.6 percentage point change in sovereign spreads. As global risk aversion and high-yield spreads are highly correlated during episodes of stress, the joint impact on the peripheral spreads is exacerbated — which is illustrated in a comparison of the coefficients in tables 1 and 2. The transmission of risk premium shocks from Italy and Spain to the countries in the sample is more pronounced than for the GIPs.

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### Table 2: Panel regressions, 2008 Q1–2012 Q2 (dependent variable: sovereign spreads of 35 sample countries) (quarterly data)

<table>
<thead>
<tr>
<th>Explanatory variables</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GIIPS spread</td>
<td>0.492a (0.105)</td>
<td>0.463a (0.106)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIP spread</td>
<td>0.511a (0.090)</td>
<td>0.479a (0.090)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Italy/Spain spread</td>
<td></td>
<td></td>
<td>1.002a (0.173)</td>
<td>0.998a (0.175)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High-yield spread</td>
<td>1.042a (0.299)</td>
<td>1.033a (0.279)</td>
<td>0.813a (0.301)</td>
<td>0.517 (0.397)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VIX</td>
<td>0.823b (0.322)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Openness</td>
<td>0.018 (0.021)</td>
<td>0.017 (0.021)</td>
<td>0.034c (0.019)</td>
<td>0.033c (0.019)</td>
<td>0.033 (0.027)</td>
<td>0.032 (0.027)</td>
</tr>
<tr>
<td>M2/GDP</td>
<td>0.078a (0.020)</td>
<td>0.075a (0.020)</td>
<td>0.057a (0.018)</td>
<td>0.056a (0.018)</td>
<td>0.045c (0.025)</td>
<td>0.043c (0.025)</td>
</tr>
<tr>
<td>Constant</td>
<td>-0.133 (0.222)</td>
<td>-2.418b (1.084)</td>
<td>-0.216 (0.222)</td>
<td>-2.459b (1.022)</td>
<td>-2.508 (1.026)</td>
<td>-1.117 (1.307)</td>
</tr>
<tr>
<td>R-squared (within)</td>
<td>0.93</td>
<td>0.78</td>
<td>0.91</td>
<td>0.78</td>
<td>0.91</td>
<td>0.85</td>
</tr>
<tr>
<td>Observations</td>
<td>321</td>
<td>321</td>
<td>357</td>
<td>357</td>
<td>341</td>
<td>341</td>
</tr>
<tr>
<td>T</td>
<td>18</td>
<td>18</td>
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<td>18</td>
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</tbody>
</table>

Standard errors in parentheses. a = p<0.01, b = p<0.05, c = p<0.1. Right-hand-side variables are in logs.

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23 Measured in terms of the R-squared and the actual coefficients.
Depending on the model specification, the availability of domestic liquidity and trade openness also contribute to some degree to spillovers.\textsuperscript{24}

The outcome for the crisis period only (covering the years from 2008–12, table 2) indicates that the coefficients for all three major drivers, i.e., European periphery shocks, global risk aversion as well as the slope of the US yield curve are higher than for the period including the pre-crisis years (table 1). A 1% shock to Euro periphery spreads translates into a 0.5 percentage point increase in the risk premium of the 35 sample countries if the shock originates in the GIPs and a one percentage point increase in spreads if it originates in Italy and Spain.

Hence, it seems that the size of the peripheral European country determines the size of spillovers, as expected. Moreover, global risk aversion shocks also translate almost one-to-one into spreads.

\textsuperscript{24} For robustness check, a separate set of regressions was run to estimate the impact of expectations of higher interest rates, represented by the slope of the US Treasury yield curve on the global risk premium. Results indicate that a steepening of the curve implies higher costs of borrowing for the periphery countries.
2.2 DCC GARCH approach

The panel regression approach provided the average spillover effect on countries’ sovereign spreads. Below, we complement the above by estimating country-specific daily co-movements in order to differentiate more between countries and produce the range of the potential spillover impacts observed over time. We use a multivariate GARCH framework for the estimation, which allows for heteroskedasticity of the data and a time-varying correlation in the conditional variance. Specifically, the Dynamic Conditional Correlation (DCC) specification by Engle (2002) is adopted, which provides a generalization of the Constant Conditional Correlation (CCC) model by Bollerslev.

As before, for the European AMs, we measure the risk premium of 10-year instruments as the difference between the average GIIPS spread as well as those of the domestic treasuries to German Bunds. For the non-European countries, the spread to the 10-year US Treasury bonds is calculated, and for EM countries, we use the EMBI Global spread and the HSBC Asian US Dollar spread for Asian jurisdictions.

As expected, our findings suggest that the spread between GIIPS to German Bunds exhibits a higher degree of co-movement with the risk premiums for European countries than non-European countries (figures 2-5). In particular, implied DCC GARCH correlations with the GIIPS spread were as high as 0.7–0.8 for Austria, Belgium, France and the Netherlands during episodes of systemic stress (figure 2, panels A and B). In contrast, the GIIPS co-movement with the UK spread to German Bunds is relatively low and oscillates between 0 and 0.2, while the model implied correlation with the Swiss spreads reaches a maximum of 0.4 (figure 2, panel C). The results also show that the spreads of the Scandinavian countries, namely Denmark, Norway, Sweden and Finland (with higher average levels though),27 on average exhibit a lower co-movement with the GIIPS spread than their continental European peers (figure 2, panel D). The outcome also suggests a constant level of stress, with some easing toward the end of the observation period, a finding that also applies to the non-European sovereigns.

Co-movements of the GIIPS spread with Australian and Canadian spreads (relative to US Treasury bonds) are rather low, with implied correlations up to 0.2 (figure 3). Looking at the Asian jurisdictions, Hong Kong SAR, Japan and Singapore show a somewhat higher correlation, with the GIIPS spread of up to 0.3 and with one jump to 0.4. In terms of EM countries, results suggest that mainland China’s co-movement with the GIIPS spread is rather subdued compared with the other EMs: Brazil, Mexico, Russia and Turkey (figure 4). Out of this EM sample, Turkey has the highest implied correlation with the GIIPS during episodes of system stress, up to 0.6.

Since the onset of sovereign debt crisis in 2009, the average GIIPS interest rates exhibit a negative correlation with both the German Bund and US Treasury interest rates (figure 5).

Figure 3: Estimated GARCH correlations – GIIPS with non-European countries
Source: Bloomberg and authors’ calculations

These econometric techniques allow us to analyze the daily co-movement of the GIIPS spreads and the sovereign bond spreads of our sample of AMs and EMs. The GIIPS spreads are included in the model as a conditioning variable, as is the VIX. The methodology is, therefore, closely aligned to that of the panel regression.

We choose as the sample period daily data from 2007 to end of August 2012, with a view to covering the full crisis period.

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26 Given the high volatility movements during the recent financial crisis, the assumption of constant conditional correlation among the variables in the CCC model is not very realistic, especially in times of stress, where correlations can rapidly change. Therefore, the DCC model is a better choice since correlations vary with time.
27 Finland is the only Euro-area country within the sample that seems to explain the higher level of correlations.
Since 2009, the implied correlation has turned negative for both countries, with lows of -0.4 (US) and -0.6 (Germany), indicating a sudden flight to safety, in line with other recent studies.\textsuperscript{28}

3. Liquidity and solvency stress testing

The area of stress testing has seen a number of advances during recent years. Our study uses a recently developed IMF liquidity stress testing framework to run integrated solvency and liquidity stress tests. The liquidity stress testing framework presented in Schmieder et al.\textsuperscript{29} was developed in the context of recent financial sector assessment programs (FSAPs)\textsuperscript{30} and International Monetary Fund (IMF) technical assistance, extending the seminal work of Čihák,\textsuperscript{31} and drawing upon work at the Austrian National Bank (OeNB).\textsuperscript{32}

In this study, the focus is on scenario design, namely building integrated scenarios for solvency and liquidity risks that take into account spillover effects and feedback loops.\textsuperscript{33} The central question becomes how the findings established in section 2 can be used to inform bank-level stress tests.

Nevertheless, while we attempt to condense a wealth of information and assumptions to establish integrated scenarios, this should not, in any sense, give a false sense of precision. Instead, we recommend running a whole range of scenarios that can build upon the ones established in the study, with varying

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure4}
\caption{Estimated GARCH correlations – GIIPS with EM countries and Korea}
\textit{Source: Bloomberg and authors’ calculations}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure5}
\caption{Estimated GARCH correlations – GIIPS with Germany and the US}
\textit{Source: Bloomberg and authors’ calculations}
\textit{Note: Unlike the other GARCH models, the average GIIPS interest rates are taken and not the GIIPS spread to German Bunds.}
\end{figure}

\textsuperscript{28} IMF (2011)
\textsuperscript{29} Schmieder et al. (2012).

\textsuperscript{30} Examples include Chile, Germany, India, Spain, Turkey and the UK.
\textsuperscript{31} Čihák (2007).
\textsuperscript{32} It is complemented by a previously developed solvency stress testing tool by Schmieder et al. (2011). While developing the solvency and liquidity stress testing frameworks, four key facts were accounted for, which constitute key challenges of contemporaneous financial stability analysis: the availability of data varies widely, and lack of data is common; both solvency and liquidity risks have various dimensions, which require multidimensional analysis, thereby integrating risks; designing and calibrating scenarios is challenging, even more so for liquidity risk than for solvency risk (mainly as liquidity crises are relatively rare and originate from different sources); and communication of stress test results is an integral part of the exercise. The answers to these multiple dimensions are Excel-based balance sheet type frameworks.\textsuperscript{33} The exercise thereby reflects key principles for liquidity stress testing put forward by the Basel Committee in the aftermath of the first wave of shocks following the default of Lehman Brothers (BCBS, 2008).
degrees of severity. Reverse stress tests can also be included. This is an important way forward to obtain a better understanding of key solvency and liquidity risks faced by banks, and to gain a more comprehensive view of their respective risk tolerance.

3.1 Liquidity stress testing approach
We apply an implied cash-flow approach to simulate the impact of a bank-run type stress scenario. The banks’ liabilities are broken down into demand and term deposits, short-term wholesale funding (including bank and secured funding), derivatives funding, as well as long-term funding, such as senior debt or subordinated debt. On the asset side, we include a range of potentially liquid asset positions, such as cash, government, trading and investment (both available-for-sale and held-to-maturity) securities, loans and advances to banks and reverse repos and cash collateral. Given European periphery banks’ increasing collateral use of pools of loans (such as covered bonds) for liquidity, we also include a crude definition of banks’ loan level as a portion of their total assets.

3.2 Solvency stress testing approach
We use rules of thumb for solvency stress testing as proposed by Hardy and Schmieder and thereby, a simplified solvency test. Credit losses, banks’ pre-impairment income and the trajectories of risk-weighted assets (RWAs) for a two-year horizon were simulated based on GDP trajectories, with and without spillover effects. The capital shortfall was measured against a tier 1 capital ratio (tier 1 capital/risk-weighted assets) of 6%, below which a bank is considered undercapitalized.

4. Integration of the financial spillover analysis with the stress testing approach
Our integrated approach to simulate stress at the bank level is illustratively shown in figure 6:

1. **Scenario design:** We use the GDP trajectories of a specific macroeconomic scenario, the WEO baseline scenario for 2013-14 as of April 2012 and add the spillover stress component.

2. **Spillover analysis:** The outcome of the spillover analysis (see above), measured through a widening of sovereign spreads, worsens the macroeconomic scenario, and is used as a sensitivity analysis. The translation of the spillover effects into the revised macroeconomic trajectories is based on recent IMF work.

3. **Soundness of banks:** The scenario is translated into bank-level stress parameters to simulate both the banks’ solvency and liquidity positions, drawing on work by Hardy and Schmieder and Schmieder et al. respectively.

We use bank-level data from Bankscope (from end of June 2012) for large systematically important banks (SiBs). In total, our sample includes 154 large banks from the following 26 jurisdictions: Austria, Australia, Belgium, Brazil, Canada, Switzerland, mainland China, Germany, Denmark, Finland, France, the UK, Hong Kong SAR, India, Japan, Korea, Luxembourg, Mexico, the Netherlands, Norway, Poland, Russia, Sweden, Singapore, Turkey and the US.

Our sample comprises almost the full EBA sample for the European banks (except for the banks in the GIIPS countries) and includes the largest banks in the non-European countries. In total, it captures US$84t of bank assets (i.e., about 50% of the assets held by banks worldwide), US$39t non-bank deposits and around US$7t of government securities held by banks.

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34 The work by Taleb et al. (2012) and Schmieder and Hardy (2013) for example, could be useful to consider in this context.
35 Hardy and Schmieder (2013).
36 However, it should be noted that the evidence is based on a comprehensive set of data from 16,000 banks during the past 15 years (as available).
37 Please note that this specific choice is meant for illustration only - through a similar level as used for the European stress tests conducted in 2010 and 2011, for example.
38 Hardy and Schmieder (2013), Schmieder et al. (2012)
4.1 Scenarios
We refer to four different scenarios: the April 2012 World Economic Outlook (WEO) baseline scenario for 2013–14 (scenario 1); and three spillover scenarios (referred to as scenarios 2.x) conditional on scenario 1 — scenarios that banks could potentially face, where increasing degrees of spillovers affect the general growth trend.

Specifically, scenario 1 is adjusted for an increase of GIIPS spreads by 100 (scenario 2a), 200 (2b) and 300 (2c) basis points, respectively. We further distinguish between the spillover impact observed during periods of substantial financial stress (using the panel regression for 2008–12 and the GARCH model for 2010–12) and during periods of less significant stress (using the panel regression for 2006–12 and the GARCH model for 2008–12), i.e., refer to a total of six spillover scenarios (2a/1, 2a/2, 2b/1, 2b/2, 2c/1, 2c/2).

For the banks’ solvency, we simulate their tier 1 capital ratios by end of 2014, on the basis of the evolution of the main solvency dimensions (banks’ income and losses). For liquidity, we determine the impact of a worst-case idiosyncratic shock to the bank’s liquidity profile on top of the impact on liquidity resulting from the macroeconomic/spillover scenarios.

4.2 Impact on bank solvency
As outlined above, we use the outcome of the 2012 Spillover Report by IMF, which simulates the impact of a 300 basis point increase in peripheral countries’ spreads (including a lower yield increase for core countries) on European countries’ GDP paths on the basis of the IMF G-35 model.39

We applied our scenarios to a stylized Austrian bank.40 In the first step, we simulated an increase in the Austrian sovereign debt spread using the evidence established in section 2. A 100 basis point shock of GIIPS spreads (scenario 2a) resulted in an increase of Austrian spreads by 24 basis points for less significant spillover stress (scenario 2a/1) and 50 basis points (2a/2) for more substantial spillover stress. When measured in relation to the April 2012 WEO baseline scenario for Austria, suggesting real GDP growth rates of 1.8% (2013) and 2.2% (2014), spillover analysis carried out at the IMF (2012) would predict a drop of real GDP growth by about 0.45 percentage points for scenario 2a/1 (less significant spillover stress), whereby the GDP trajectory becomes 1.4% (2013) and 1.8% (2014). For a period with more significant spillover (scenario 2a/2), the impact is about twice (0.9 percentage points), whereby the GDP trajectory is 0.9% (2013) and 1.3% (2014). For a 200 basis point shock (scenario 2b), growth drops by 1.7 percentage points and for 300 basis

39 Vitek and Bayoumi (2011)
40 Data for this scenario analysis can be obtained from the authors.

Figure 6: Overview of the concept to simulate stress at the bank level
How to capture macro-financial spillover effects in stress tests

points (scenario 2c) by 2.6 percentage points (per year) under substantial spillover conditions.

We then use the satellite models by Hardy and Schmieder to determine banks’ loan impairment levels and pre-impairment income for 2013 and 2014.\(^41\),\(^42\) For a stylized bank with loss impairment rates of 0.5% and a pre-impairment return on capital of 10% in 2012,\(^43\) loan impairment rates are simulated to decrease slightly under the baseline scenario and mild spillover conditions, while they would increase (nonlinearly) under increasing levels of spillover stress. The same pattern holds for pre-impairment income. This input is used to simulate the bank’s capital, RWAs\(^44\) and capital ratio. Again, the same pattern holds, with a decrease of the stylized banks’ capital ratio to 7.5% under the most severe scenario, which is above the hurdle rate in terms of tier 1 capital to pass the stress test (6%).

The outcome of this solvency stress test applied to the 154 banks presented in figure 6 shows that the large international banks would be in a position to digest the baseline scenario plus some level of spillover stress, while additional stress in the Euro area periphery results would have a highly nonlinear impact on potential capital needs. The nonlinearity results from two factors: the nonlinearity in the satellite models for loan impairment rates and pre-impairment income and the effect of the kick-in of capital needs for banks that fall below the hurdle rate.

4.3 Impact on bank liquidity

For the liquidity stress test, we simulate the impact of stress on both banks’ market liquidity (i.e., their ability to fire sale assets) and funding liquidity (i.e., the potential outflow of funding).\(^45\) Again, we assume that the bank is affected by the shock in its home country.\(^46\) The link between the level of stress and bank liquidity is established on the basis of empirical work of Schmieder et al.\(^47\) We link the GDP trajectories, implied by the changes of sovereign spreads, to funding shocks experienced by the most affected banks during the Lehman crisis. In other words, we simulate highly adverse idiosyncratic liquidity shocks conditional upon macroeconomic conditions.

\(^41\) Hardy and Schmieder (2013)
\(^42\) For simplification, we assume that banks are affected according to their domestic scenarios, i.e., that their business is predominantly based in their home country.
\(^43\) In a few cases, the latest available figures were from 2011.
\(^44\) The RWAs are simulated based on work by Schmieder et al. (2011), assuming point-in-time credit risk parameters.
\(^45\) Unlike for the solvency scenario, we do not simulate stress for a specific point in time; rather, the simulated stress conditions reflect a worst-case situation resulting from the general macroeconomic conditions as well as an idiosyncratic shock to the bank conditional.
\(^46\) In other words, it is assumed that all of its assets are based in the home country, which is a crude simplification.
\(^47\) Schmieder et al. (2012)
In line with (very limited) empirical evidence, we expect the relationship between the shock and the potential adverse impact on the bank level to be highly nonlinear (table 3). Under a worst-case scenario, banks would experience a shock equal to a Lehman Brothers type scenario, the severe stress scenario (this shock level represents how the stress at the time of the Lehman Brothers' event affected the banks that were most severely hit, i.e., overlays a market shock with an idiosyncratic liquidity shock). The stress level relative to the one experienced by banks at the time of the Lehman Brothers crisis is established via the cumulative GDP trajectory under stress compared with the long-term average. For the example of the Austrian bank discussed above, the stress level is at 0.65, i.e., the benchmark funding stress parameters (for the severe stress scenario) in table 3 have to be multiplied by 0.65.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Moderate stress scenario</th>
<th>Medium stress scenario</th>
<th>Severe stress scenario</th>
<th>Very severe stress scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquidity outflows</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer deposits (term)</td>
<td>2.5%</td>
<td>5%</td>
<td>10%</td>
<td>20%</td>
</tr>
<tr>
<td>Customer deposits (demand)</td>
<td>5%</td>
<td>10%</td>
<td>20%</td>
<td>40%</td>
</tr>
<tr>
<td>Wholesale funding</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Short-term (secured)</td>
<td>5%</td>
<td>10%</td>
<td>20%</td>
<td>40%</td>
</tr>
<tr>
<td>Short-term (unsecured)</td>
<td>25%</td>
<td>50%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Contingent liabilities</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liquid inflows</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Haircut for cash</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Haircut for Government securities</td>
<td>1%</td>
<td>2%</td>
<td>5%</td>
<td>10%</td>
</tr>
<tr>
<td>Haircut for trading assets</td>
<td>3%</td>
<td>6%</td>
<td>30%</td>
<td>100%</td>
</tr>
<tr>
<td>Proxies, specific assets</td>
<td>Equities: 3 Bonds: 3</td>
<td>Equities: 4-6 Bonds: 3-8</td>
<td>Equities: 10-15 Bonds (only LCR eligible ones): 5-10</td>
<td>Not liquid</td>
</tr>
<tr>
<td>Haircut for other securities</td>
<td>10%</td>
<td>30%</td>
<td>75%</td>
<td>100%</td>
</tr>
<tr>
<td>Proxies, specific assets</td>
<td>Equities: 10 Bonds: 10</td>
<td>Equities: 25 Bonds: 20 (some not liquid)</td>
<td>Equities: 30 Bonds: (only LCR eligible ones): 20-30</td>
<td>100%</td>
</tr>
<tr>
<td>Percent of liquid assets</td>
<td>10% (or actual figure)</td>
<td>20% (or actual figure plus 10 ppt)</td>
<td>30% (or actual figures plus 20 ppt)</td>
<td>40% (or actual figures plus 30 ppt)</td>
</tr>
</tbody>
</table>

1/ The Lehman type scenario would correspond to a scenario encountered by banks that were hit severely during the 30-day period after the Lehman collapse, i.e., a stress situation within a stress period rather than an average. The scenario has been put together based on expert judgment, using evidence as available.
2/ The haircut highly depends on the specific features of the government debt held (rating, maturity, market depth) and can be higher or lower. The figures displayed herein are meant for high-quality investment grade bonds, taking into account recent market conditions. The same applies for the remainder of the liquid assets. For the securities in the trading book, it is assumed that they are liquidated earlier, resulting in lower haircuts.
3/ A haircut of 100% means that the asset is illiquid, i.e., the marker has closed.
4/ The figures account for a downgrade of the bank, which triggers margin calls and higher collateral requirements generally. Please note that the unencumbered portion applies to a gradually narrower definition of liquid assets.

Table 3: Benchmark stress scenarios
Source: Schmieder et al. (2012)
The funding available for the specific banks under the European Central Bank’s Long Term Refinancing Operations is inferred from country-level data and used as a cushion for the relevant European banks.

Figure 8 shows the outcome of this liquidity stress test. Under the baseline scenario, all banks have sufficient liquidity, as expected. Adding spillover stress triggers a nonlinear increase in liquidity needs (which occur in case the liquidity needs exceed the available liquidity generated via fire sales), and more substantial spillover stress makes the stress highly nonlinear. Measured against tier 1 capital rather than total assets, the substantial spillover stress leads to a maximum liquidity shortfall of 20% for the entire bank sample for scenario 2c/2 (300 basis points spread shock, significant spillover stress) and close to 6% for scenario 2b/2 (200 basis points spread shock), compared with 0.3% and 1% if measured against total assets.48

5. Conclusion
This study attempted to contribute to an important challenge faced by current financial stability analysis, namely to capture spillover effects and other types of contagion that ultimately determine macro-financial stress at the bank level.

By integrating recent IMF work on financial spillover analysis and stress testing, we use a novel framework that allows some light to be shed on the potential impact of spillover effects on bank-level solvency and liquidity. Nevertheless, we recognize that significant additional effort and evidence is needed to make the modeling of dynamic macro-financial linkages more robust, not least owing to the many potential channels of spillover and contagion, the fact that the use of crude data available for stress tests is subject to uncertainty, and other factors that contribute to uncertainty (such as mixed evidence for the use of market data).

The outcome of the stress tests suggests that spillover effects observed for the sovereign debt markets in recent years have a highly nonlinear impact on bank soundness, in terms of both liquidity and solvency. This implies (once more) that the design of stress scenarios is a crucial element of stress testing, and is very sensitive with respect to the outcome of stress tests.

48 We did not explicitly model a central bank response as the lender of last resort (LOLR) to mitigate the estimated liquidity shortfall. In reality and as seen during the crisis period, central banks would provide large liquidity support to solvent banks subject to an appropriate haircut.
References

Appendix A

<table>
<thead>
<tr>
<th>Factor</th>
<th>Ambiguity</th>
<th>Certainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sovereign risk</td>
<td>CDS spread</td>
<td>Average of Euro periphery sovereign spreads to German Bunds</td>
</tr>
<tr>
<td></td>
<td>GIIPS spread</td>
<td>Average of Greece, Ireland and Portugal sovereign spreads to German Bunds</td>
</tr>
<tr>
<td>Risk aversion</td>
<td>High-yield spread</td>
<td>Difference between yields to maturity of AAA-rated and BAA-rated corporate US bonds</td>
</tr>
<tr>
<td>Macroeconomic environment</td>
<td>Openness</td>
<td>Sum of imports and exports to GDP ratio</td>
</tr>
<tr>
<td></td>
<td>M2/GDP</td>
<td>Broad money to GDP ratio</td>
</tr>
</tbody>
</table>

Main explanatory variables
Source: Authors