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# MERCURE : A Macroprudential Stress Testing Model developed at the ACPR


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# SECRÉTARIAT GENERAL DE L'AUTORITÉ DE CONTRÔLE PRUDENTIEL ET DE RÉSOLUTION

# DIRECTION DES ÉTUDES

## MERCURE*: A MACROPRUDENTIAL STRESS TESTING MODEL DEVELOPED AT THE ACPR

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* « Modele d'Evaluation des Risques du seCteUR financiEr »

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# MERCURE : A Macroprudential Stress Testing Model developed at the ACPR

**Abstract:** The French Supervisory Authority got involved into macro stress testing exercises stress since the first Financial Stability Assessment Program ("FSAP") led by the IMF in France in 2004. Along "bottom up" exercises led at the national or international level, the ACPR has developed a "top down" stress testing model. This model was primarily focused on credit risks. Over the years, its risk coverage has substantially been extended and this article provides an update. Some risks make explicitly part of a dedicated analysis –for example the risks related to banks' retail activities. More attention is now given to contagion effects, sectorial shocks and concentration risks. Financial institutions other than banks are considered. More granular data allow for a more refined analysis.

**Keywords:** Stress Testing, Systemic Risk, Macroprudential Policy

**JEL Classification:** G21, G28

# MERCURE : Un modèle de stress test macroprudentiel développé à l'ACPR

**Résumé :** L'ACPR est impliquée dans les exercices de stress tests macroprudentiels depuis la première évaluation de la stabilité du système financier français conduite par le FMI en 2004. En complément des exercices de stress tests réalisés par les établissements financiers eux-mêmes sur une méthodologie et des scénarios proposés par le superviseur, l'ACPR a développé une gamme d'outils de stress tests construits à partir des données prudentielles collectées régulièrement auprés de ses assujettis. Ces outils étaient d'abord principalement orientés vers l'analyse du risque de crédit. Cet article fournit une mise à jour des outils depuis développés. Certains risques font partie d'une analyse dédiée : par exemple celui porté par les activités de détail. Une plus grande attention est portée aux risques de contagion, de concentrations et sectoriels. D'autres institutions que bancaires sont considérées. Des données plus granulaires appuient l'analyse.

**Keywords:** Risques systémiques, Stress Tests, Politique macro prudentielle

**JEL Classification:** G21, G28

## Introduction

The repetition of financial crisis since the early 90s led central banks, national supervisors and international organisations to make stress testing exercises a common tool for assessing the potential vulnerabilities of financial systems and their consequences on the real economy.

The French Supervisory Authority (ACPR hereafter) got involved into macro stress testing exercises stress since the first Financial Stability Assessment Program ("FSAP") led by the IMF in France in 2004.[5] Following the outbreak of the recent financial crisis in 2008, the French banks have been frequently required to assess the impact of macro shocks on their financial health using their own models. They were involved in the exercises coordinated by the EBA in 2009, 2010, 2011 and 2014 and by the IMF in 2012. The ACPR routinely complements with a top-down framework the "bottom up" exercises run by the Authority within the framework of the internationally coordinated exercises. These top down exercises are performed thanks to quantitative models developed by the ACPR and using data from usual regulatory reporting.

The goal of the top down models developed at the ACPR is threefold. First, they aim at assessing the impact of macroeconomic or idiosyncratic shocks through an easily manageable infrastructure, which is also quickly replicable, independently of the involvement of the financial institutions in the process. Second, they are used for challenging the results filed by the financial institutions when a bottom up approach is implemented. Third, they allow for spill over effects –both within the financial system and between the financial sector and the real economy. Those effects are indeed beyond the grasp of the modelling capabilities of the bottom up model developed by a private bank at the individual level.

Tiesset and Martin (2008) provide an overview of the stress-testing approach adopted by the the Commission Bancaire (the forerunner of the ACPR). This approach was based on a reduced form credit risk model. Since then, this approach has been substantially modified. A particular attention is given to the design of the macroeconomic scenarios. Additional risk categories receive dedicated analysis. Financial institutions other than banks are considered. More attention is now given to contagion effects or sectorial shocks impacting the whole French financial system. Raw data present structural breaks due to changes in the regulatory regime or in the accounting standard or in the scope of consolidation. Preliminary to the

[5] See de Bandt and Oung (2004)

quantitative analysis, considerable efforts have been exerted in order to assemble granular data set consistent over time.

In term of scenario designs, as it is done for the FSAP and EBA exercises, an adverse scenario is provided by a complete model in which macroeconomic equilibrium relationships, as well as national accounting equations and behavioural equations are accounted for. In order to complement this unique adverse scenario used for the purpose of bottom up exercises and to which individual banks will be challenged, a VAR model of the French economy is used to generate a wide range of scenarios. It helps to identify which scenarios will actually trigger the most important capital losses.

For the banking sector, the core structure of the stress testing framework is based on three different models. The first one captures the sensitivity of banks' net income to the macroeconomic environment thanks to a panel data econometric model run at the individual bank level. The other two models –developed at the banking portfolio level– project credit risk parameters accordingly to the macroeconomic scenario, with a separation between the corporate and retail portfolios.

For the insurance sector, the resilience of the life insurance sector is assessed thanks to a top down model built under the solvency I framework. The model consists of integrated balance sheet, cash flow and income statements, with special focuses on annual cash flows projections and investment policy. Some components of the balance sheet such as the life insurance premium are projected thanks to an econometric model. A top down model under the solvency 2 framework is under development.

These models are complemented by several satellite models. For credit risk in the banking portfolios, economic capital models are computed on granular data of the corporate and the retail portfolios observed over a long period at the exposure level. This allows for taking into account the compositional effects of the risk portfolio –either being well diversified or too concentrated– on the outcome of the stress test. For banks' funding risk, two models have been elaborated: one proposes a direct stress of the value of the debt issued by the banks following an increase in interest rate. Therefore, the impact of the scenario on the cost of funding is directly assessed. This is in contrast with the net income modelling of the core model for which the impact of the interest rate on the asset and the liability side are not distinguished, the maturity transformation only being stressed. Another model- more sophisticated and more complete- is based on a contagion analysis. Exploiting bilateral exposures data, banks' liquidity hoarding behaviours are incorporated in a standard iterative default cascade algorithm to compute the propagation of a common market shock through the banking system. In addition to potential solvency contagion, a market shock leads to banks liquidity hoarding that may generate problems of short-term funding for other banks. Another contagion model is used for implementing solvency stress tests. Based on a "clearing payment vector" approach, the model allows disentangling the impact of a common shock from the impact coming from the interconnections per se. The impact of idiosyncratic shocks –for example, when one institution defaults- or a global shock on common exposures can be assessed by taking into account spill-over and contagion effects. Thanks to bilateral exposure available at the individual security level, these contagion models have been applied to networks including banks, insurers or reinsurers as well.

The article is organized as follows. The first section describes the design of the stressed macroeconomic scenario. The second section thoroughly details the data used by the top down tools. This description is particular important since available data and their limitation largely explain the underlying assumptions and the quantitative methods implemented for the realisation of the stress test. The third section gives a brief overview of the workhorse of stress tests, namely solvency stress tests, for both the banking and the insurance sectors. The fourth section presents satellite models used in the analysis of the corporate bank credit risks, banks' cost of funding, systemic spill-overs between banks, insurers and reinsurers.

# I. Design of the Stress test scenarios

Two types of strategies are available in the design of stress test scenarios, either focusing on a discrete set of macro/adverse scenarios, whereby the narrative is crucial, or considering a continuum of scenarios. In both strategies, the severity of the scenarios depends on three parameters: the likelihood of their occurrence, their magnitude and the sensitivities of the financial system in case where they materialise. In the recent past exercises, a key assumption driving the impact of the scenario was whether to consider or not a static balance sheet of the financial institutions over the horizon of stress. The reaction of the financial institutions to the initial shock can substantially modify the impact a scenario might have.

## I.1 Calibration of the scenarios

Beyond the types of scenarios (1.1.1), the severity of the scenario matters (1.1.2).

### I.1.1 Types of scenarios

An important distinction is between a discrete set of macro/adverse scenarios, and a continuum of scenarios

#### *I.1.1.1 Baseline scenario, stressed scenario*

In order to assess the vulnerability of the banking and insurance sector to macroeconomic downturns, the supervisor must design a severe but possible macroeconomic scenario. The financial institutions' capital ratios in this stressed scenario are compared to their ratios in a baseline scenario deemed to reflect normal macroeconomic developments. The institution might be judged vulnerable as soon as its regulatory ratios falls below a supervisory-defined benchmark. This methodology was adopted for example by the EBA (EBA, 2014), the IMF (FSAP, 2013), the British PRA (PRA, 2014) exercises or by the Federal Reserve Board for its CCAR exercises (Fed, 2014).

To design consistent baseline and stressed scenarios for its own stress tests exercises, the ACPR relies on Mascotte, the neo-keynesian macroeconometric model developed by the forecasting directorate of the Banque de France (see Baghli et al., 2004). Macroeconomic variables are thus derived from a complete model in which macroeconomic equilibrium relationships, as well as national accounting equations and behavioural equations are accounted for. The stressed scenario is obtained as the output of various exogenous shocks applied simultaneously to the model. Therefore, the macroeconomic consistency of the scenario is guaranteed by the use of a macro econometric model. The choice of the exogenous shocks is driven by the potential imbalances or macro vulnerability put forward by a macro analysis. For illustration, high public debt or deviation of the housing prices from their long term equilibrium might lead to consider a strong increase in interest rates and a large decrease in housing prices over the horizon of the stress testing exercise. As only a very limited number of stressed scenarios will be considered, the narrative underlying each scenario is crucial.

#### *I.1.1.2 A continuum of scenarios*

Comparing the capital ratio in the baseline and in one stressed scenario yields a unique measure of the banking sector's vulnerability, conditional on a unique macroeconomic scenario. It is possible to derive complementary metrics of systemic vulnerability by repeating the exercise over multiple macroeconomic scenarios.[6] To do so, the ACPR has developed a simple VAR representation of the French economy (see box 1). This model yields a distribution of potential paths for the French economy. It is then possible to simulate the capital ratios of French banks across these scenarios. This gives a distribution of capital ratios. It enables computing various percentiles of capital losses for the whole banking sectors. These percentiles are useful statistics to draw a financial stability assessment. It helps assessing macroeconomic vulnerability over various types of macroeconomic shocks, differing by their magnitude and likelihood. There is indeed no reason for this vulnerability to be linear in either the magnitude or the likelihood of the downturn. This tool can also yield a direct measure of financial stability. In such a reverse stress testing approach, once the distribution of capital ratios is known, we can detect the scenarios in which the ratio breaks the regulatory minimum. The probability of these scenarios is a measure of macroeconomic vulnerability: the higher the probability, the weaker the financial system in case of a macroeconomic downturn.

Extending this approach to measure insurance vulnerabilities is quite difficult as the vulnerabilities of the insurance sector and banking sector differ significantly. The insurance sector is less concerned with credit risk and funding risk while these are prominent risks regarding the banking business. On the opposite, insurers are affected by insurance shocks inherent to their line of business (shocks on mortality or claims for instance). It is mainly affected by financial variables movements while real economy activity and the capital position of the banks are more intertwined. This substantial difference between the two sectors is due to their business models and the composition of their balance sheets. In contrast to banks, insurers do not engage in substantial lending activities - characterized by probabilities of default heavily depending on the position in the economic cycle - and their assets typically largely consist of financial assets (bonds, equities, real estate, derivatives …). This implies that an economic scenario generator focused on financial variables is needed to test insurance companies' vulnerabilities related to market risks. Such a model can be developed with 'standalone' approach or in conjunction with the macro econometric model in order to generate financial scenarios conditionally to a consistent macroeconomic path. Similarly to the VAR model for banks, this generator will provide the distribution of capital ratios or other interesting risks measures that are valuable for financial stability analysis.

[6] In order to value their balance sheet, insurers rely on similar tools to generate economic scenarios, but they concentrate on the relationships between financial yields.

**Box 1 – A simple VAR representation of the French economy**

We calibrate a VAR representation of the French economy thanks to data over the period 1990 onwards, on a quarterly basis. We consider six macroeconomic variables: real GDP growth, the unemployment rate, the CPI growth rate, real estate prices (in growth rate), and long and short term interest rates, in this order. We take the first or second differences of the variables in order to deal with non stationarity and estimate a VAR model with four lags[7]. We can use the model to anticipate the distribution of the reaction of these variables – used in top-down models – in case of various shocks. As an example, figure 1 displays the cumulative reaction of selected variables to a positive unitary shock to real estate price growth rate. The model allows accounting for all variables of the top-down model in a consistent way, their reactions accounting for the others'. [8]

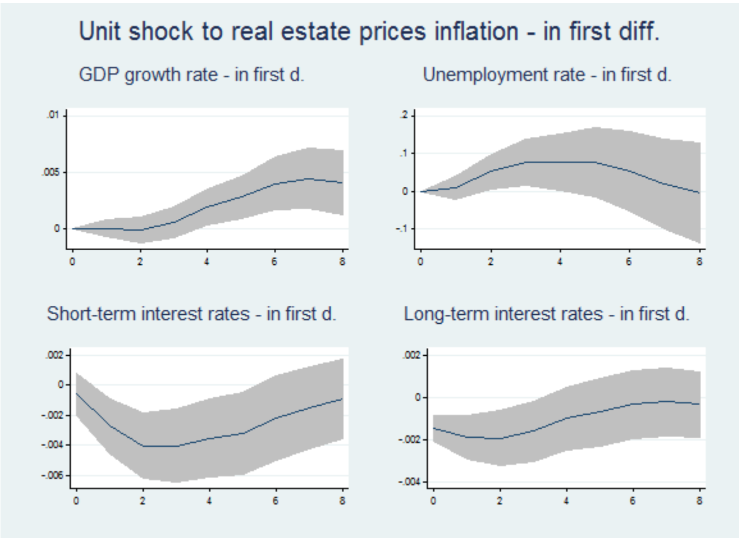


Figure 1 – A shock to real estate prices on the French economy

*Note: the figure displays thet impulse response functions (IRF) of four variables (respectively,GDP, unemployment, short-term and long-term interest rates) to a unit shock to real estate prices inflation. All variables are considered as the first difference of the growth rate and the VAR model is estimated with 4 lags. We present the IRF over eight quarters after the shock.*

### I.1.2 Gauging the severity of a scenario

[7] The estimation suffers from omitted variable bias since we do not consider a VECM framework. When tested, this framework has yielded integration relations that are difficultly interpretable economically.

[8] The approach may be generalized in order to distinguish normal times vs crisis periods, using Markov Switching VARs (see de Bandt and Malik, 2010).

The severity of a stress test exercise can be summarized by its expected capital shortfall. It thus depends on three parameters: the likelihood of the scenario, the magnitude of the scenario and the sensibility of the financial system to macroeconomic downturns. The definition of the macroeconomic scenario sets the first two parameters. Its design is thus key to the credibility of the exercise, especially in the approach where a baseline scenario is compared to a unique stressed scenario. To measure its strength, it is first necessary to compare its magnitude to past episodes of macroeconomic distress. To compare a scenario across different institutions (e.g. banks with different business models or banks and insurance companies) it is necessary to identify the salient macroeconomic vulnerability for each institution and compare the magnitude and likelihood of the relevant shocks.

To compare a scenario across structurally different countries, it is useful to correct the magnitude of the shock by considering either the countries' respective average growth or volatility. Table 1 does so, taking as example the 2014 Fed and EBA/ECB stress test exercises for selected countries. We report the traditional severity measure, GDP deviation from baseline over the stress test horizon. We also compute two alternative indicators. The first indicator applies the shocks in the GDP growth rates observed in the adverse scenario to the average growth rate computed over 1998-2013. In other words, it is the shock to long-term growth induced by the stress scenario. It controls for the influence of the baseline scenario, which may dampen the impact of a sizeable shock to the economy. Doing so, we note the German scenario, which looked roughly comparable to the USA (severe) one with the traditional measure, is clearly more severe from this new perspective. The second indicator normalizes GDP shocks by the volatility over 1998-2013. It corrects for the volatility differences across countries. This is a decreasing indicator in the probability of the shock. The intuition here is that a given GDP shock is more severe if applied to an economy with lower GDP volatility. From this point of view, the German scenario is less severe than the USA (severe) scenario, which is now as severe as the French one.

The severity of insurance scenarios mainly depends on the distress of financial variables which are usually less central to banking scenarios. This increases the complexity of a plausible scenario for the insurance sector since the sensibility of insurers' capital depends on two additional parameters: the likelihood and the magnitude of the shocks on financial variables *in response* to a macroeconomic distress.

**Table 1 – Comparing stress tests severity across countries.**

| | 3-year GDP deviation (level) | Correction #1 - average growth rate | Correction #2 - volatility |
|---|---|---|---|
| **France** | -6 | -0,59 | -2,34 |
| **Germany** | -7,6 | -1,31 | -1,95 |
| **Italy** | -6,1 | -1,62 | -1,89 |
| **USA - severe** | -7,8 | -0,47 | -2,34 |
| **USA - adverse** | -5 | 0,46 | -1,50 |

*Note*: In the first column, we present the 3-year GDP level deviation of the adverse scenario from the central scenario for selected countries (in the 2014 EBA/ECB exercise and for the 2014 Fed exercise). The second and third columns propose alternative severity measures. The first correction controls for the assumptions of the baseline scenario by computing the average annual growth rate in the adverse scenario applying the GDP growth rate shocks to the average growth rate over 1998-2013. This indicator is the shock to long-term growth induced by the stress scenario. The second correction normalizes GDP shocks by the volatility over 1998-2013. The lower the indicator, the less likely is the shock.

Some significant vulnerabilities (e.g. low yield environment) of insurance sector to market risk are difficult to connect with a particular macroeconomic scenario due to either a lack of historical events or an unclear causality link between macroeconomic and financial environment. The academic and experimental literature focusing on these links is rather scarce and it does not explore the capital sensitivity to macroeconomic events, see e.g. Kiesenbauer (2012) for impact on lapse rates or Lee and al. (2013) for some link evidence between premiums and macroeconomic environment.

### 1.2. Static *vs* Balance Sheet assumptions

Banks' balance sheets may be supposed static in top-down stress-testing exercises, as well as in bottom-up ones. Basically, it means that, over the stress test horizon, banks' balance sheet structure remains unchanged: there is no credit growth, and maturing assets and liabilities are replaced by new assets and liabilities, whose features (amount, maturity) are exactly the same.

Under this assumption, banks' mitigating actions are not factored in the exercise. Such an approach provides supervisors with insights on whether banks are capitalised enough given their current balance sheet. Since no deleveraging from the banks, no portfolio reallocation to riskless assets, no capital management are envisaged, the static balance sheet assumption might be considered as the worst case scenario for the reaction functions of the financial institutions. Moreover, relaxing this assumption will lead the financial institutions to be less strict in implementing the stress test and will make difficult for the supervisors to enforce a sufficient level of severity.

The static balance sheet assumption is quite common when dealing with bottom-up banks' stress testing. For instance, previous EU-wide stress testing exercises led by the EBA made use of this assumption. We then also make use of this assumption especially when challenging banks' bottom-up outcomes with our top-down models.[9] Nevertheless, if banks do not only suffer from macroeconomic shocks but adjust to them, then the static balance sheet assumption could misestimate the impact of these shocks on the banking system. Deleveraging might trigger a credit rationing pushing households and businesses more towards a default.

It is however an empirical challenge to estimate the banks' reaction to economic shocks since a proper identification of supply and demand effect is needed. Following Hancock and Wilcox (1993, 1994) seminal papers on partial adjustment of banks' capital ratios, many papers have investigated empirically the determinants of movements in the capital ratio. These papers often include macroeconomic variables as a determinant of variations in capital ratios (see for example Berrospide and Edge (2010), which include for example stock market volatility). This is also a common feature of credit equations, which test empirically the determinants of credit supply. Berrospide and Edge (2010) find real GDP growth is a significant determinant of credit.

Departing from the empirical macroeconomic literature, a recent strand of literature assesses the impact of higher capital requirement on credit distribution using sharp identification strategies. Aiyar et al (2014) contrast the credit distribution of the resident foreign branches with the credit distribution of the UK-own banks. The latter are subject to time-varying, bank-specific minimum capital requirements set by the national regulator. Jimenez et al (2012) exploits successive dynamic provisioning requirements imposed to Spanish banks by the Bank of Spain over the years 2000s and that are a function of the provisioning rate accordingly to a close formula. Behn et al. (2013) compare the credit granted to firms borrowing from several banks which are under different Basel II regulatory regimes. Fraisse et al. (2013). exploit a unique supervisory dataset providing information on capital requirements at the exposure level for the six largest French banking groups between 2008 and 2011 and compare how lending varies depending on the capital requirements charged by banks at the exposure level. This literature might help to calibrate DSGE models taking into account second round effects (see Darracq-Parie et al., 2013). More simply and taking a preliminary step an equation relating credit growth to solvency ratio equation could be added to the VAR models described above.

[9] Our methodology allows to perform solvency stress tests with dynamic balance sheet as well.

As for the insurance sector, in the vast majority of the stress testing exercises, only an instantaneous stress test is envisaged. This consists in measuring the immediate impact of instantaneous shocks either directly on balance sheet items or indirectly on underlying assumptions required for valuation purpose. Consequently, direct management actions in response to the shock are not factored in such situations. However, the valuation principles for insurance's liabilities (technical provisions) allow considering specific future management actions (e.g. profit sharing policy, change in strategic asset allocation …) which significantly absorb the effects of an immediate shock. This ability to manage negative events over longer time horizons is specific to insurance sector in contrast to the banking sector and the range of available actions is very heterogeneous among insurance industries. Note that a desirable feature of such stress test is the identification of insurance participants with less ability to manage specific risk or with a poor risk management policy.

In sum, the static balance sheet assumption allows for a homogeneous treatment of financial institutions engaged in the stress testing exercise. From a level playing field perspective, such an assumption makes sure that the same rules apply for all, thereby allowing comparability. Indeed, under the dynamic assumption (the alternative), several opposite effects are at stake, which can lead to very heterogeneous outcomes. A deleveraging process is likely to have both a positive effect on banks' solvency positions via a decrease in risk weighted assets and a negative effect via a drop in the volume of activity, which implies lower net interest incomes. Overall, one might end up with very different situations depending on several individual factors as the balance sheet structure or the structure of the profit and loss account.

# II. DATA

Top down models draw heavily on prudential reporting collected by the ACPR in order to perform micro prudential risk analysis. Data sources differ greatly in their level of granularity and they are key drivers of the methodological choices of the modelling approaches. This section thoroughly describes the data used for inputs to the top down models. It distinguishes between data available for the banking (II.1.) and the insurance sector (II.2).

## II.1 Data used for modelling the banking sector

Data for the banking sector include reporting data for banks, the corporate sector, at the retail level (from credit registers) and the wholesale level (data on large exposures), as well as data on housing loans.

### II.1.1 Data at individual banks' level

The observation of homogeneous regulatory data over a long period of time is challenging due to the frequent breaks in the prudential regulation and the accounting frameworks in the recent years. The ACPR's top down credit model relies on long term series of credit losses and banks revenues, built thanks to the use of reporting based on different scopes and standards. On a consolidated basis the common standardized reporting framework issued by the European Banking Authority (EBA) for the Capital Requirements Directive –aka the "COREP" – and the standardized reporting framework issued by the EBA for financial reporting data –aka the "FINREP" – are used. On a solo basis the French prudential reporting "Base de données des Agents Financiers" –aka the "BAFI" – and the "Système Unifié de Reporting Financier" – aka the "SURFI" –are used.

COREP and FINREP contains highly detailed data on credit, including the breakdown by category of exposure, the level of provisions, the regulatory credit parameters (probability of default and loss given defaults). The information are limited to a period starting in 2008 with the transition from the Basel 1 to the Basel 2 regulatory framework. These data are reported on a consolidated basis, including exposures that are not located in France. They are complemented by BAFI (accounting reporting until March 2010 and available since 1993), and SURFI (accounting reporting since June 2010) provided on a solo basis. As opposed to COREP, the recourse to accounting reports as BAFI, SURFI and, in some cases, FINREP allows for the calibration of the models on long-term data. In the case of the modeling of banks' return on assets as for the modeling of mortgage defaults, a combination of these different data sets is made. The variables are built by keeping the same definition over the estimation period studied thanks to the good documentation of the reports. The data observed since 1993 notably contain the different components of the profit and losses account.

### II.1.2 Banks exposures on the domestic corporate sector

Part of the analysis on corporate risks relies on a large dataset of bank-firm linkages available at the Bank of France: the Credit National Register ("Centrale des Risques"). The aim of this register is to collect data on bank exposures to residents on a monthly basis to monitor and control solvency risk. More specifically, credit institutions are required to report each of their commitments or risk exposures (e.g., credit claims) on a company as defined by a legal unit and referenced by a national identification number (SIREN) as soon as they reach a total of

EUR 25,000. These statements cover the funds made available or drawn credits, the bank's commitments on credit lines and guarantees, and specific operations (medium and long-term lease with purchase option, factoring, securitized loans, etc.). Recipients are single businesses, corporations, sole-proprietorship engaged in professional activities. They may be registered in France or abroad. Reporting financial intermediaries include all resident credit institutions, investment firms, and other public institutions on a solo basis. This data set can be matched with firm-level accounting and rating information, also available from the Bank of France on a yearly basis ("FIBEN" for "Fichier Bancaire des Entreprises"). Accounting information follows the tax forms that firms have to fill in and provides extremely detailed information on the balance sheet and the income statement. In principle, firm's financial statements are collected in so far as its turnover exceeds EUR 0.75 million. Credit ratings are awarded by a special unit at the Bank of France, which is in charge of maintaining the credit national register. The register covers a vast number of firms: when restricting to 12-month fiscal years and closing date at the end of December the database covers more than 160,000 firms in their legal unit form for 2014. ACPR's tops down tools making use of these datasets are based on an observation period starting in 2000.

### II.1.3 Contagion and concentration risk

Contagion models and the analysis of concentration risks (in term of country or industry) make an intensive use of the large exposure report. French credit institutions are required to report all the large exposures that they may have to either other credit institutions or even a country or a company (Large Exposure Report, CEBS, 2009) as soon as the exposures amount to more than 10% of its capital or more than 300 million of Euros. A "large exposure" is an item of the asset side or off-balance sheet that is exposed to "counterparty" risk. A "counterparty" is defined as a set of individual counterparties that have strong financial or economic links. A strong financial link exists as soon as one individual counterpart is a subsidiary of another one. A strong economic link exists as soon as the default of one individual counterpart is likely to occur with the default of the other individual counterpart. The exposure to a counterparty –set of individual counterparts strongly connected– is the sum of all risks on any individual counterparts of this specific counterparty. The credit institution identifies a counterparty by providing its name, a public identification code if possible (for instance, national identification number such as SIREN, for domestic counterparty), a bank-internal identification code, its address, its industrial sector, its rating, its probability of default, etc. The risks are then breakdown into four main classes. The first class consists in (debt or equity) securities and loans. The second class gathers derivatives. The third class is composed of off-balance sheet instruments such as guarantee commitments given, guarantee commitments received and funding commitments. The last class is formed by the net trading portfolio position. Except for the last class, the classes are designed in a credit risk perspective. Banks are due to report their large exposures on a quarterly basis. Largest banks report at each quarter a few hundreds large exposures while smallest bank may report none. Counterparties are mainly sovereign, financial institutions, large international industrial groups (such as oil and gas, car, shipping… industries). Data are available starting from 2001.

#### II.1.4 Housing loans to French households

The French credit national register does not cover loans granted to households. In order to fill the gap at this level of granularity, the ACPR collected granular data set at the loan level from various entities with different business models. The database covers a large variety of clienteles, which range from households borrowing on the regular housing loans market to low-income borrowers using regulated loans providing financial assistance. The database provides information about loans characteristics (amount, maturity, type of interest rate, type of loans, regulated or not, loan-to-value and loan-to-income ratios, date of origination) and also on borrowers characteristics (such as the age of the borrower, its marital status, its profession and personal savings). The database provides also borrowers' internal ratings at the loan's origination including a potential default status. The dataset retains housing loans which destination is to finance home ownership or buy to let investments. These data set cover approximately 50% of the French market for housing loans over the 2001-2013 period.

### II.2 Data used for modelling the insurance sector

As the French supervisor responsible for the insurance market, ACPR is the recipient for insurance prudential reporting from all insurance undertakings. Four major categories of enterprises are subject to ACPR insurance supervision: insurance and reinsurance organizations (a little bit more than 300 undertakings), mutual insurers (approximately 600 undertakings) and provident institutions (approximately 50 undertakings). The main databases are based on the existing regulatory system (Solvency I) and are reported on a solo basis (i.e. not consolidated). A second source of data stems from data collections on behalf of to the European insurance supervisor (EIOPA). They are generally at a group level, concern only most important of the European insurance market and can be regular reporting or ad-hoc surveys. Finally, many French undertakings and groups have already began to report some data under the new regulatory framework, Solvency II, which will come into force at the 1st of January 2016, with first mandatory reporting due to June 2016.

### II.2.1 Solvency I reporting

Under current regulation, reporting entities must submit to the authority sets of quarterly and annual data. A centralised database was built only recently, therefore data quality is uneven. Quarterly reports, available from the 4th quarter of 2001, consist of tables on quarterly flows, outstanding investments and asset-liability simulations. The annual report, generally available from 1996, contains accounting tables on P&L (with detailed information on technical result), balance sheets (including off-balance sheet information and a very detailed asset reporting), the reinsurance policy, prudential information (solvency requirements, eligible assets and a small liquidity stress test). The detailed statement of investments ("TCEP" standing for, "tableau complémentaire à l'état détaillé des placements") reports every single asset, along with a high level of details on issuers, amounts and securities. A look through approach is applied (UCITS are broken down in the underlying assets included in the UCITS). The ACPR is also enriching the TCEP tables with financial information extracted from Bloomberg or Moody's.

Furthermore, in reaction to the recent financial crisis, ACPR has launched weekly and monthly data collections in order to monitor closely and timely lapse risk and sovereign risk. Finally, ACPR has also been collecting annually since 2006 data on benefits paid by life insurers to policyholders at a very detailed level (version of contract).

### II.2.2 EIOPA and Solvency II reporting

Since 2011, EIOPA has been asking National Supervisory Authorities (NSA) to collect quarterly "fast tracks" for the 30 main insurance (and reinsurance) groups in Europe. Therefore, ACPR receives reporting for 6 French groups at a consolidated level, concerning assets, liabilities, P&L data and solvency ratios. ACPR has also received from main French insurance groups some occasional data collection, on the use of derivatives for instance.

While the first regulatory reporting under Solvency II will only be collected in 2016, ACPR has already been collecting on an annual basis the most important tables since 2013 in order to prepare undertakings to new reporting standards. When in force, Solvency II reporting will be on a solo and on a group basis, quarterly for part of the information and annually for the rest, for financial stability and for micro supervision purposes. Reported data will give balance sheet information, detailed data on assets, technical provisions, own funds and capital requirements. European groups with total assets beyond 12 billions will be concerned by the additional Financial Stability reporting. This will consist in shorter reporting timelines, more information given on a quarterly basis and some additional data requirements. In addition to the bulk of the harmonised SII reporting, NSAs will collect a few tables designed at the national level on matters specific to their national markets and not covered by the European reporting, such as minimum guaranteed rate for life insurance contracts for instance.

## III. Solvency stress tests

On the banking side, the core structure of the internal stress testing framework relies on three main blocks. The first block projects the revenues and losses of the banks through the horizon of the stress testing exercise. The two other blocks projects the RWA of the Basel 2 corporate and retail credit portfolios. On the insurance side, the main tool projects the stylised balance sheet of an insurer representative of the French solo life insurance entities within the solvency 1 framework. This projection is calibrated thanks to an econometric modelling of the life insurance premiums growth. Solvency II Top Down tools are under development.

### III.1 Solvency stress tests in the banking sector

#### III.1.1 Framework structure for the banking sector (overall framework)

The core structure of the ACPR's internal stress testing framework is based on 3 models, which aim to estimate the evolution of banks' solvency ratios given a stressed macroeconomic scenario:

- The ROA ("Return On Assets") model captures the sensitivity of banks' net income to the macroeconomic environment through a pure econometric modelling approach;
- Two credit risk models which aim at assessing the evolution of banks' RWA[10] stemming from a deterioration of the credit quality of both corporate and French retail credit portfolios. The corporate credit stress testing model is based on the Merton framework, which is also at the root of the Basel II ASRF model. The retail stress testing model is mainly based on an econometric modelling approach, whose purpose is to forecast the share of non-performing loans in the credit retail portfolios.

[10] The retail credit risk model has also an effect on solvency ratios' numerator.

### III.1.2 Return on assets

The econometric model[11] captures the sensitivity of banks' net income to macroeconomic conditions and banks' specific variables. Banks' net income is projected using the estimated model and the different scenarios. Projected reserves or losses are taken into account to predict banks' solvency ratios.

Fixed effects regressions are performed at the bank level.[12] Estimations are weighted according to banks' size. Extreme values are treated using a Jackknife procedure.

The following specification is used

$$\pi_{i,t} = \phi_1 \pi_{i,t-1} + X_t \beta + Z_{i,t} \theta + \alpha_i + \varepsilon_{i,t},$$

where $\pi_{i,t}$ represents banks' return on assets. $X_t$ and $Z_{i,t}$ are respectively macroeconomic and banks' specific variables. $\alpha_i$ represents bank fixed effects $i$ is a subscript for the i$^{th}$ bank, $t$ for the t$^{th}$ time period.

$X_t$ includes GDP growth, inflation, the slope of the yield curve, and the volatility of the stock market index. A higher GDP growth may cause a higher loan distribution (increased demand) and indirectly higher revenues from financial markets, due to higher stock market returns (Coffinet and Lin, 2010). An inflation rate that is fully anticipated may raise profits as banks may appropriately adjust interest rates in order to increase revenues, depending on the competiveness in the sector (e.g. the market power of the banks). The interest rate spread corresponds to the difference between the French 10 year's government bond yield and the 3 month Euro interbank offered rate (Euribor). Its impact notably depends on the balance sheet structure, the ability to proceed to a repricing. It is important to note that banks can use derivative instruments to mitigate interest rate exposure which may limit the impact of interest rate changes. Higher stock market volatility may increase banks' trading opportunities, yield higher non-interest income and profitability. On the contrary, losses on trading income may be large when stock market is significantly stressed. The volatility of the SBF 250 is introduced in the model. $Z_{i,t}$ includes bank characteristics : the ratio of net non-interest income to total asset, the ratio of equity to total assets, the bank size. Revenue diversification enhances bank profitability via higher margins from non-interest businesses

[11] See Coffinet and Lin (2010) who developed a model for stress testing French banks' profitability.

[12] We also perform instrumental variables method to correct for a potential bias due to the presence of the autoregressive term and the potential endogeneity of some banks' specific variable such as capitalization. Our conclusions remain unchanged.

and lower cost income ratios (Elsas et al., 2010) even if these activities can be associated with higher risk taking and consequently higher revenue fluctuations. The ratio of net non-interest income over total asset proxies of revenue diversification. In the Modigliani and Miller framework, funding sources have no effect on asset cash flows. However in the presence of market failures, the capital structure is not neutral. Higher capital may notably diminish the moral hazard between shareholders and debtholders. Higher levels of capital increase the banks' incentives to monitor their borrowers because shareholders will collect a larger share of assets payoffs and lose more in case of failure. The ratio of equity over total asset is used to control for capitalization. Large banks are generally better diversified but also more complex. Two dummy variables that are constructed according to the first and fourth quartiles of the total assets are included in the model.

### III.1.3 Models for stress testing Risk Weighted Assets

#### *III.1.3.1 Stress-testing banks' corporate credit portfolio*

The following framework, aiming at performing a stress test on French banks corporate exposures, allows us to assess the impact of a macro-economic scenario on the amount of RWA associated to these portfolios. The main steps of this framework are:

- Firstly, an econometric model relates a given macro-economic scenario to the evolution of the default rates of US and EU corporates. The default rate is derived from S&P transition matrices.[13]
- Second, the projected default rates are used to stress both regulatory PDs and rating migrations.

The model is applied to the 8 main French banking groups, which represent more than 90% of the French banking system.

The S&P CreditPro database, which contains issuer ratings history for 15800 obligors since 1981, of which more than 2000 ended in default is used in order to relate PD to the economic cycle. The obligors are mainly large corporate institutions – sovereigns and municipals are excluded – and pools include both US- and non-US industrials, utilities, insurance companies, banks and other financial institutions, real estate companies.

[13] The French banking sector is exposed to geographically diversified large corporates. The French credit national register collects the exposure of the firms operating in France.

Besides, our framework basically requires information on the structure of banks' portfolios by types of rating. They are available from banks' Prudential Common Reporting (COREP). This information is actually combined with mappings – provided by onsite-inspections division – that convert the internal rating system of each bank into the S&P rating scale.

The link between the projected default rates and credit migrations is made through the Merton's framework on which is also based the Basel II Asymptotic Single Risk factor (ASRF)[14]. Within this framework, the probability of transition from rating class *i* to rating class *j* is given (in our case a 8x8 transition matrix) by the following formula:

$$P_{ijt} = \Phi\left[\frac{\Phi^{-1}(\overline{P}_{i8} + \ldots + \overline{P}_{ij}) + \sqrt{\rho}\, Z_t}{\sqrt{1-\rho}}\right] - P_{i8t} - \ldots - P_{i,j+1,t}$$

This approach, which aims at representing transition matrices by a single parameter, was firstly studied by Belkin, Suchower and Wagner (1998). They follow the CreditMetrics framework proposed by Gupton, Finger and Bhatia (1997).

Within this framework, many strategies can be used to calibrate the model. Our strategy involves several steps.

First, a scale measuring the state of the economy is computed with $\lambda_t = \frac{\widehat{DR}_t - \overline{DR}}{DR_{crisis} - \overline{DR}}$ where $\widehat{DR}_t$ is the default rate projected at t, $\overline{DR}$ is the average default rate over the sample period and $DR_{crisis}$ is the default rate reached during the worst crisis observed over the period of observation.

Secondly the macroeconomic systemic risk is measured as:

$$Z_t = (Z_{100\%\,crisis} - Z_{0\%\,crisis})\lambda_t + Z_{0\%\,crisis}$$

Where $Z_{0\%\,crisis}$ is calibrated by minimizing the Euclidian norm between the observed transition matrix over the entire period and the transition matrix given by the ASRF model. To calibrate $Z_{100\%\,crisis}$ the same strategy except is implemented except that the transition matrix is computed only over periods of recession.

Finally, the uniform correlation factor $\rho$ between all obligators is estimated in order to obtain the best fit of historical data by the model. That is, the total distance is minimized over the entire sample between empirical transition matrices and matrices stressed by our model.

[14] Vasicek, o. "Limiting Loan Loss Probability Distribution", KMV Corporation

### III.1.3.2 Stress-testing banks' retail portfolio

As for the corporate exposure, the stress test on French retail exposures (« retail stress test ») is performed in two stages:

- Firstly, an econometric model relates a given macro-economic scenario to the evolution of the non-performing loans (NPL ratio) of the retail households' credit. The NPL ratio is the dependent variable of a panel data econometric model run at the bank level.
- Second, the impact in terms of solvency are assessed after « stressing » some parameters (namely probabilities of default – "PD" - and provisions), based on the results of the former econometric estimation.

In order to form a representative sample of the activity of credit lending to retail customers in France, a portfolio of retail banks is selected based on criteria of absolute size and relative size of their respective credit portfolios. The resulting sample is comprised of 101 retail banks currently in business. Adjustments have been made to the sample in the event of withdrawals of approval, mergers or acquisitions during the period under review. The selected banks consist essentially in subsidiaries or/and so-called "regional banks" of 7 major French banking groups (BNP Paribas, Groupe Crédit Agricole, Société Générale, Groupe Crédit Mutuel, Groupe BPCE, La Banque Postale, HSBC France). The selected sample covers almost 90% of the loans to individuals and more than 95% of loans to individual entrepreneurs. It is worth noting that the vast majority of loan exposures (90%) consist of loans to individuals.

Series of default rates for retail customers at a bank level are not available over a long period in France. As for prudential data (COREP), which includes probabilities of default as per Basel 2 definition, they are available only from march 2008 onwards. Therefore, it was considered more appropriate to model the NPL ratio of the retail credit portfolio, i.e. the amount of NPL divided by the total amount of loans. This ratio will then serve as inputs for the projections of loan impairment charges (impacting the numerator of the *CET1* solvency ratio) and also for the projections of the regulatory PD (impacting the denominator of the ratio, through the RWA).

Projections of the default rate over the simulation horizon are based on panel data econometric methods (with banks as individuals, and a quarterly frequency). The estimation is based on a dynamic fixed-effects model:

$$y_{i,t} = \alpha + y_{i,t-1}\beta + Z_t\delta + \mu_i + \varepsilon_{i,t}$$

Where $y_{i,t}$ is the dependant variable calculated as the logistic of the NPL ratio. $y_{i,t-1}$, is introduded as the explanatory variable with a one quarter lag, $Z_t$ is the following set of macroeconomic variables: year-on-year French GDP growth ; French unemployment rate (according to the ILO measure) ; long-term interest rates (10-year OAT rates) and a one-year lag on the year-on-year growth of real estate prices. $\mu_i$ is the fixed effect associated to individual $i$ banks in the 101 sample, $\varepsilon_{i,t}$ is the regression residual and $t$ is the quarterly periods of 21 years (from March 1993 to December 2013, i.e. 84 time periods).

The variation in PD induced by the "stressed" economic conditions is assumed to be the same as the variation in the NPL ratio as derived from the econometric model. This "sensitivity stress-test" on PD is applied to each class of risk within the five sub-portfolios[15] that make up the retail credit portfolio classified under the *Internal Ratings-Based approach* ("IRB"). For the sake of simplicity, it is assumed here that retail exposures granted to foreign customers and classified under the IRB approach are of the same risk profile as the ones from the French retail portfolio[16].

Stressed LGD in the retail credit portfolio is driven by the initial level of the LGD and the cumulative growth of real estate prices. This growth is adjusted of the share of exposures with a positive LGD in order to limit the impact of compositional effects.[17] Indeed, a proportion of the mortgages might have an exposure at default below the stressed collateral thus leading to a zero LGD. As for the PD, this stress on LGD is applied to each class of risk within the five IRB sub-portfolios.

The impact on the numerator comes from the regulatory adjustment for IRB provision excesses or shortfalls (resulting from the difference between the total amount of provisions and expected losses). In case of IRB provision shortfall, (i.e. if the new amount of provisions,

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[15] Namely: Retail – secured by real estate SME, Retail – secured by real estate non-SME, Retail – Qualifying revolving, Retail – Other SME and Retail – Other non-SME.

[16] It should be noted that loans to foreign customers represent about 10% of the amounts of retail exposures classified as IRB.

[17] This share is estimated thanks to granular data from mortgage portfolios representative of the French market.

once adjusted for the new impairment losses, is lower that the "stressed" EL), half of the difference is deducted from the CET1.

As for the corporate model, the impact on the denominator is obtained after having converted the PD into *through-the-cycle* PD as per Basel prudential requirements, the "stressed PD" and "stressed LGD" are used to estimate "stressed" RWA and EL parameters for each of the classes of the aforementioned sub-portfolios making up the IRB retail credit portfolio. Furthermore, the relative variation of provisions due to "stressed" economic conditions is 150% risk-weighted for retail exposures classified under the Standard approach[18].

### III.2 Insurance

In contrast to banking exercises, insurance bottom-up stress tests mainly consist of the immediate impact of instantaneous shocks on insurers' and reinsurers' balance sheets. Indeed, participants assess the new assets and liabilities values, and associated solvency ratios, in the post shock environment, defined by the new values assumed for stressed variables while non-stressed variables remain unchanged. These assumptions are commonly used for EU-wide stress testing exercises led by the EIOPA (see for instance the 2014 EIOPA exercise).

Since insurers are long term investors, persistent adverse macroeconomic situations may rather destabilize insurance sector over a long term horizon. In particular, a prolonged low interest rate environment is a key risk for traditional life insurers as it is causing a gradual erosion of their wealth and profitability. Moreover, life insurance sector may be exposed to massive lapse events in case of sudden and sustained interest rates hikes that interests paid by life insurers to policyholders may not be able to meet. A multi period stress test exercise is necessary in order to assess this effect.

To measure long term resilience of insurance sector, the ACPR has conducted both top-down and bottom-up exercises under Solvency I and II frameworks with different assumptions in terms of future lapses and premiums. This requires constructing beforehand appropriate long term macroeconomic scenarios with an explicit link with premium and lapse payments.

[18] Retail exposures (as measured in terms of EAD) under the standard approach account for approximately 20% of the retail portfolio of French banks.

### III.2.1 Top down satellite models

The current ACPR life insurance model, developed under “solvency I” regulation, aims at measuring the impact of different shocks on life insurers’ wealth, profitability and solvency ratio. The scenarios used in these exercises may combine shocks on financial variables (market conditions), on inflows and outflows (lapses and premiums) or insurance variables (margins). For instance, the impact of ten years of low interest rates can be assessed with this model under various assumptions of premium and lapses.

The assessment is based on data as of end-December N-1 and the risk-horizon is 10 years. The model applies to French solo life insurance entities at the individual level. It was calibrated on the data of the ten most important undertakings on the French life insurance market collected on a quarterly or annual basis by ACPR. Some additional assumptions were also defined using expert judgment, for instance regarding non-observable investment patterns or profit sharing policies used by institutions. The model consists of integrated balance sheet, cash flow and income statements, with special focuses on annual cash flows projections and investment policy. First, inflows (premiums, matured investments and net financial income) and outflows (benefits including surrenders, fees) are projected to determine whether the life insurer needs to sell some assets to meet the cash outflows. Then, new end of year assets’ market value is computed taking into account (i) the yearly variations of market prices that were given in the assumptions, (ii) the new investments that were made during the year (since insurers are supposed not to wait for the end of year to invest the cash flows they receive throughout the year), (iii) the bonds which have matured during the year and (iv) the amount of assets that the insurer has to sell at the end of year to meet its obligations, which was determined in the first step. The book value of insurers’ assets is computed simultaneously, also by asset class (sovereign bonds, bank bonds, other bonds, shares, real estate, loans and deposits), so that it is possible to keep track of the evolution of unrealized gains and losses. Finally, the rest of the balance sheet is projected, which consists mainly of the evolution of mathematical provisions (depending on new premiums and surrenders, margins on payments and deposit margins and revaluation of life insurance contract). The life insurer’s P&L is estimated recovering net financial income and fees included in the first step calculation of projected cash flows. Margins, participating provisions (PPB and PRE) and the French capitalization reserve variations and revaluations are deduced from the projected balance sheet. Taxes are added.

This model is quite sensitive to the rate of benefits paid to policyholders, which is difficult to predict. In the model, this interest rate is computed on a yearly basis following a target interest rate specific to each life insurer, depending on long term interest rates, on historical rates paid to policyholders and on realised financial incomes. This target rate is adapted so that legal and regulation constraints on benefit sharing are always respected. Because of the Solvency I framework, the simulated solvency ratios are also very sensitive to the life insurer’s balance sheet size, with a mechanistic effect of improvement when provisions decrease. However, it may reflect some situations when premiums growth penalizes life insurers’ profitability.

### III.2.2 Empirical analysis for life insurance premiums

This econometric model aims to assess the impact of the evolution in the macroeconomic environment on the collection of life insurance premiums. It can be used to project gross premiums one or two quarters ahead, for direct stress testing (reaction of premium growth to interest rates shocks for instance) or to calibrate other stress test models (to relate the macroeconomic scenario to the figures of premiums growth used as an input in the above described Solvency I model).

The aggregate gross inflows in life insurance are projected thanks to an econometric model exploiting aggregated data collected by the ACPR over a relative long period on a quarterly basis (1997-2012). The interest rate gap (defined as the difference between TEC10 and Euribor-3 months), the return in the French stock market index and the variations in the taxes affecting life insurance products (taxes specific to life insurance and taxes affecting simultaneously life insurance and other financial products) captures the effects of the macroeconomic environment on insurance life premiums. An increase in the interest rate gap is associated with a higher growth in gross premiums. Indeed life insurance products are becoming more competitive as compared to banking saving accounts. Stock index growth is positively correlated with life premiums growth. This may stem from the share of unit-linked products in life insurance premiums, from the wealth effect due to the equity market and from a positive financial environment favorable to both equities and life insurance. Finally, an increase in taxes on life insurance income is related to a lesser growth in life insurance premiums. The existing model is currently being extended to feature a new equation on aggregate lapses and also estimates of premiums and lapses on individual data.

### **III.2.3** Solvency II Top Down tools under development

This subsection briefly presents the overall approach considered by the ACPR to develop suitable model under Solvency II regulatory framework aiming to:

- backtest the main results given by insurers participating to bottom up stress tests exercises,
- give a picture of solvency position and eventually assess the risk profile of several synthetic insurers taken as representative reference of French insurance market.

At the time of drafting this paper, these tools are currently under development and our main objective is to provide reliable flexible model to conduct top down analysis at national level with our own stress tests methodology.

As the Solvency II framework is not yet finalized, there is a lack of relevant data regarding assets, liabilities and capital valuation with a fine degree of granularity. At this time, Solvency II data were only collected during the previous public stress test exercises, quantitative impact studies and during the EIOPA 2012 long term guaranteed assessment. Furthermore, ACPR has launched in 2013 a Solvency II preparatory exercise on the French market which provides useful results to feed our model.

Regarding asset portfolios, insurance data are collected from the TCEP database which contains a higher degree of details on investment insurers. This database is also completed with additional features of these securities available in public financial portals like Bloomberg and in the FINREP prudential database in case where information is not publicly available. This data collection can be considered as a reliable substitute to the future Solvency II reporting dedicated to the detailed list of assets.

At a first step, these tools will contain three main modules able to reassess the value and main characteristics of insurance asset portfolios, estimate the technical provisions related to tradition life insurance products and compute the Solvency Capital Requirement (SCR).
First, valuation techniques to assess simple securities (bonds, equities, property …) after one shock for any insurer are implemented. As the main issue in Solvency II valuation purpose is related to assess best estimate liabilities and their absorbing capacities, one need to precisely assess the market value of assets to deduce effects on liability side and valuate capital related

to market risk. Modelling technical provisions for individual undertakings is extremely complex due to the strong heterogeneity of insurance guarantees, management actions and dynamic policyholder's behavior. For this purpose, some representative liability portfolios with simple valuation techniques to measures the effect of systematic shocks should be considered first. The third module consists simply in standard formula SCR calculation model

## IV. Satellite models on the risks of individual financial institutions

In addition to the core structure, satellite models have been developed in order to run an in-depth analysis of some key risks for the French banking sector. They cover the credit risk of the corporates operating in France, the housing loans granted to French households, the large corporate to which French banks are exposed, the funding risks of the French banks. All those models exploit granular data available at the level of the exposure.

### IV.1 Stress testing credit risk in fine-grained business loans portfolios

This section presents the macroeconomic credit risk stress testing model for granular loans portfolios.

To estimate the impact of macroeconomic risk factors on the probability of default an econometric model belonging to the class of generalized linear mixed models (GLMM) is used. It combines both fixed and random effects for observable and unobservable factors as in Frey and McNeil (2003) and McNeil and Wendin (2007). More precisely, the following model is estimated:

$$P(Y_{ti} = 1 | \gamma_t) = \Phi(x'_{ti}\,\mu_r + g'_t\,m_r + z'\gamma_t)$$

Where $\Phi$ stands for the standard normal cumulative distribution, $Y_{ti}$ is a dummy equating one when the counterparty $i$ is in default at time $t$, $x_{ti}$ is vector defining the rating of borrower $i$ at time $t$ (and potentially others exogenous firms specific characteristics), $\mu_r$ is the vector of parameters controlling the effect of rating on the transition to default status, $g_t$ is a vector of observable macroeconomic variables, $m_r$ is a vector of parameters capturing the sensibility of each borrower $i$ to macroeconomic conditions, $\gamma_t$ is a vector of unobserved factors and $z$ is the design matrix of random effects.

This approach allows considering a multifactor framework that may help capturing the dependency structure across exposures by adding new latent factors that are linked to observable characteristics of the borrower, such as its size, location, sector or other observable characteristics depending on the nature of the loan. In particular our model takes into account default correlation both between and within clusters. Extending the Merton-Vasicek model, on which the calculus of the regulatory capital is based, is motivated by the recent findings in the credit risk literature (see for instance Lucas, Koopman and Schwaab, 2012) who demonstrates that relying on a single common factor capturing the business cycle leads to underestimating default correlation and thus portfolio losses.

Within this framework, at least three approaches can be used to include the macroeconomic scenario and perform a stress test. The first approach considers a conventional single factor model and integrates directly the macro-variables in the GLMM model. In this case we interpret the factor as a frailty indicator as is usually done in the literature. The second approach considers a multi-factor framework and introduces additional latent factors related to macroeconomic variables. Finally, another approach is to consider the impact of macroeconomic factors on the estimated values of latent factors through a second satellite model.

Once the credit risk parameters are estimated the associated regulatory and economic capital are computed. The computation of the economic capital is done by simulating the factors and taking a quantile (at the 99.9% confidence level) of the resulting loss distribution. Using the methodology described in Tasche (2009) the marginal capital can also be determined i.e. the contribution of each segment to the economic capital to identify risk concentration and potential vulnerabilities.

The tool can be used for measuring sectoral risk. Table 2 gives a numerical example in the case where industry fixed effects capture the dependency structure. On average, multifactor capital ratio appears to be lower than single factor capital ratio. This can be interpreted as a strong diversification effect due to the industry. Some industries are shown to consume more economic capital than others. In some sectors and for some banks, the economic capital can be lower for some banks than the regulatory capital. This is the case for example one bank in the manufacturing sector.

**Table 2: Distribution of the ratios of regulatory capital to economic capital by industry across banking groups and industries (Excerpt from Dietsch et al. (2013)).**

| | Regulatory capital requirements over capital requirements given by a multifactor model | | | Regulatory capital requirements over capital requirements given by a single factor model | | |
|---|---|---|---|---|---|---|
| | min | mean | max | min | mean | max |
| agriculture | 0,9 | 6,8 | 8,6 | 1,6 | 2,0 | 2,7 |
| construction & real estate | 2 | 11,4 | 14,3 | 1,3 | 1,7 | 2 |
| manufacturing | 0,9 | 4,8 | 6,5 | 1,3 | 1,7 | 1,9 |
| retail | 3,9 | 13,6 | 14,4 | 1,4 | 1,9 | 2 |
| wholesale | 2,3 | 8,7 | 13,9 | 1,3 | 1,7 | 2 |
| transport | 1,4 | 9,3 | 9,1 | 1,5 | 2,0 | 2,8 |
| service to business | 1,9 | 19,8 | 26 | 1,6 | 2,1 | 2,8 |
| services to households | 1,4 | 9,0 | 10,5 | 1,4 | 1,9 | 2,6 |

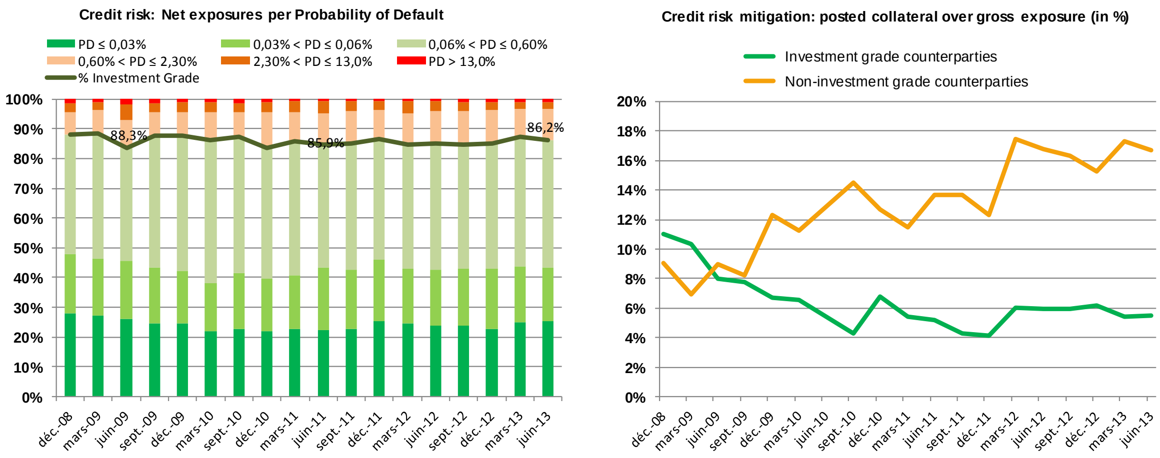
Source: ACP-BDF, Directorate Research

Note: regulatory capital ratios are computed as the weighted average of requirements computed using the "other retail" Basel 2 IRBF formula when the loan amount is lower than € 1 million and accordingly to the "corporate" formula when it is higher. Weights are the respective amounts of the two borrowers populations.

## IV.2 Large corporate exposures

Large corporate exposures being specific in many ways raised the need for a dedicated risk assessment. Figure 2 presents some key elements regarding large corporate exposures: the evolution of banks' credit risk considering probability of default of their counterparties and the levels of posted collateral for credit risk mitigation purposes. They represent a substantial proportion of banks' assets and, therefore, of their capital and they concentrate risk through few counterparties with low granularity. In this context, a stress test is performed on large corporate banks' exposures. It is highly inspired from the corporate credit risk stress testing model presented in the previous section. The evolution of default probabilities is simulated according to different adverse scenarios to derive the impact on RWA for credit risk. These results can then be confronted to the total corporate portfolio RWA stress test impact to measure the banks' relative sensitivity to large corporate exposures throughout the banking corporate business. In a stress testing perspective and disconnected from a macroeconomic scenario, idiosyncratic shocks –such as the default of the largest counterparty- can also be applied.

Figure 2: Large Corporate Exposures - Probability of Default and credit risk mitigation




Source : ACPR, Large Exposure Reporting

## IV.3 Stress testing banks' cost of funding

### *Stress testing costs of funding*

When a bank gets new wholesale funds, the price paid to creditors depends both on an interest rate component and on the bank's credit spread – Euribor 3m + 100 bps for example. The stress test framework presented hereafter deals with the second component, whose level evolves according to systemic factors, like market conditions, and an idiosyncratic factor which is the institution's credit quality. The scope of the stress test encompasses all debt securities whose maturity is shorter than the stress horizon. All securities whose maturity date is beyond the end of the stress scenario have no impact whatsoever on banks' P&L accounts. Losses estimation differs according to accounting portfolios: when a bond is under the fair value regime, losses associated with all its future cash-flows are factored in the stress (method 1 is implemented); otherwise losses arising from the stress are recognised at the pace of its coupons payments (method 2 is implemented). A large share of debt securities issuances is public, so that features of these securities are available in financial portals like Bloomberg. This allows applying the following methodologies at a very granular level. In order to include the small part of debt that is not publicly available, the outcome is subsequently scale to the appropriate basis thanks to the FINREP prudential database. Relying on public and prudential information, this framework can be applied to all banking groups.

The stress is carried out under several assumptions:

- Banks are not able to pass-through extra costs of funding on their customers, due to strong competition in commercial activities.
- Losses arising from higher costs of funding cannot be offset, even partially, by any gains on both non-derivative and derivative liabilities other than bonds that would result from changes in banks' own credit spread. This assumption is in line with the CRR-CRD4 regulation (CRR Art. 33) which rules out fair-value adjustments on own debt (CRR Art.33 (1) (b) and (c)) - except for bonds (CRR Art. 33 (3)) - from own funds (but partially actually because this provision is supposed to be phased-in until end-2017 (CRR Art. 481)).
- Banks' balance sheets are static,[19] i.e. the liabilities mix and maturing profile are constant.
- For the purpose of the stress test, losses may arise from new debt issuances only, i.e. any adjustments on bonds issued prior to the beginning of the stress due to changes in banks' credit spread are not factored in this exercise.
- The maturity date of callable bonds is set to the first date of call. It is noteworthy this assumption is quite conservative and our framework allows to withdraw it.
- All incurred losses are frontloaded in the first fiscal year of the stress test.

*Under the fair value regime*, losses equal to the price difference between maturing and issued debt securities issued over the stress test. The principle of this modelling is fairly simple: starting from a spread term structure and a transition matrix, a bond *i*, whose maturity is T, is priced by discounting the future cash-flows, i.e.:

$$V_{i,t} = \sum_{k=t}^{T} \frac{CF_{i,k}}{(1 + r_{k,t} + s_{i,k,t})^k}$$

Where $CF_{i,t}$ stands for the expected cash-flow, $r_t$ for the risk-free interest rate and $s_{i,t}$ for the bond's credit spread at the date *t*. The whole operation is usually represented by all the cash-flows following the valuation date. The curves used for the pricing are those of the valuation date. This framework does not factor in the variety of cash-flows, namely coupons, accrued coupons, repayments of nominal and so on. Assuming a continuous-paid coupon discounted at a constant spread over time, but depending on the bond's maturity and a flat interest rates curve, the previous equation becomes:

[19] This assumption was made by the IMF for its FSAP Fr in 2012, was also present in the methodology of the EBA EU-wide stress-test exercise in 2011 and 2014.

$$V_{i,t} = c\frac{1-\frac{1}{(1+r_t+s_{i,t})^T}}{\ln(1+r_t+s_{i,t})}\frac{1}{(1+r_t+s_{i,t})^T}$$

Where $s_{i,t}$ is an average spread and $r_t$ an average risk-free interest rate. Where the par-spread is set to: $c = \ln(1+r_t+s_{i,0})$. Within this framework, the losses function may be easily expressed as: $L = \mathrm{V}_{\mathrm{i},0} - \mathrm{V}_{\mathrm{i,t}} = 1 - \mathrm{V}_{\mathrm{i,t}}$

*When debt securities are not under the fair value regime*, losses are due to the higher coupons of the renewed debt over the stress test. This method is very close to the EBA methodology developed for the EU-wide stress testing exercise. Basically, the idea is to record extra costs of coupons of new debt securities. The main difference comparing with the method 1 is that the lost value created at the very beginning of the operation is progressively recorded over time, whereas in the first method all the lost value is booked in the same year. In this framework, the impact on banks solvency is smoothed.

***Extension to interbank market operations***

Information related to interbank market is scarce compared to debt securities. However, funding shocks may be larger for this type of funding source during periods of stress. Extra costs of funding on those operations are assessed by extrapolating the outcomes of the stress on debt securities. Information provided by the supervisory reporting FINREP on the scheduling of both debt securities and credit institutions deposits was exploited in the past. This information is now provided by new ECB reporting (“Short Term Exercice reporting”).

## V. Contagion Models and financial interlinkages

In addition to the satellite models described above aiming at spotting the vulnerability of individual institutions subject to a common shock, a large range of contagion models have been developed in order to assess the amplifications of the common shock that might be due to financial interlinkages. These empirical models share a common methodology that allows disentangling the impact due to a common shock from the one due to the existence of bilateral exposures. The French banking sector, the European banking sector, the French banking and insurance sector, the network of French insurers and their reinsurers have been put to stress. Thanks to long time series of bilateral exposures, it has also been possible to develop systemic measures based on the evolution of the French banking sector over the years.

### V.1 Methodology, Shocks and Indicators

As illustrated by the last financial crisis, financial distress might propagate and amplify through financial inter linkages. The solvency and funding stress tests detailed above can be complemented by first measuring the importance of these financial interlinkages and second running contagion stress tests. The methodology disentangles the impacts of a common shock or an idiosyncratic shock from the impacts coming from the propagation of the shock through the interconnections of the system. It has been applied to various networks involving banks - French or European-, insurers or reinsurers.

#### V.1.1 Methodology

Two main types of contagion stress-tests are carried out. The first type envisages an idiosyncratic and exogenous shock leading to the default of one specific institution and measures the impact of this default on the rest of the system. For this type of shock, there might be as many scenarios as institutions. The second type considers a shock external to the system e.g. affecting a component of the balance sheet different from intra financial assets such as sovereign exposures or market risk exposures. This shock can be calibrated in a deterministic approach or a stochastic approach. In a deterministic perspective, the value of the shock is scenario-based. It might rely on macroeconomics forecasts. The banking asset values are derived from sensitivity to the macroeconomics variable. For instance, the loss on the retail portfolio can be computed from an unemployment rate, a GDP growth, etc. In that perspective, the results are non-probabilistic: they are informative on what may happen conditionally to a scenario without providing any insight on the likelihood of such scenario. In a stochastic approach, the aim is to build a joint distribution of the value of the external assets of all banks. One way is to write the value of assets as function of factors of which distribution is known (when factors are observed) or can be estimated (when factors are latent). The distribution of assets is then derived from the distributions of the underlying factors. In contrast with deterministic shocks, using stochastic shocks provides information on the likelihood of contagion as well as on its magnitude.

The contagion mechanisms include solvency and liquidity features. For the solvency contagion, $Ax_i$ stands for the external asset of institution $i$, $L_i^*$ its nominal debt, $L_i$ the value of its debt, $K_i$ its capital, $\gamma_{i,j}L_j$ the value of the exposures of institution of institution $i$ on institution $j$ based on lending (and debt securities), and $\pi_{i,j}K_j$ the value of the exposures of institution of institution $i$ on institution $j$ based on equity. Merton's structural model implies that:

$$\begin{cases} L_i = \min( Ax_i + \sum_j \gamma_{i,j} L_j + \sum_j \pi_{i,j} K_j \,;\, L_i^*) \\ K_i = \max( Ax_i + \sum_j \gamma_{i,j} L_j + \sum_j \pi_{i,j} K_j - L_i^*; 0) \end{cases}$$

Gourieroux et al. (2012) shows that this 2n-system has a unique solution. The coefficients $\gamma_{i,j}$ and $\pi_{i,j}$ are calibrated on regulatory reports (namely Large Exposures and TCEP). Shocks are defined as input value for the external assets. The outputs are the value of the debt and the value of equity.

The liquidity contagion is adding liquidity hoarding behaviour in top of the solvency contagion. Banks are assumed to cut down short-term interbank exposures when their solvency ratios become low. When facing a fall of its short-term funding, a bank covers with its cash (issuance of new debt is forbidden). If there is no enough cash, the bank is in default for liquidity difficulties.

### V.1.2 Idiosyncratic shock: illustration for the European banking sector

The methodology described above was applied exploiting data collection of bilateral exposures made by the ESRB working group on interconnectedness. Data are from December 2011. Idiosyncratic shocks consisting in the failure of one (and only one) of the banks in the European network[20] (here composed of the 53 major European banks) were implemented. Then contagion, through interbank exposures, may cause other defaults into the system. Figure 3 shows the impact of idiosyncratic default on the rest of the banks. The system-wide capital loss rises nonlinearly after the 40th scenario. This suggests that approximately 13 banks stand out as more systemically important, in the sense that their default would trigger significantly larger losses for other banks in the system

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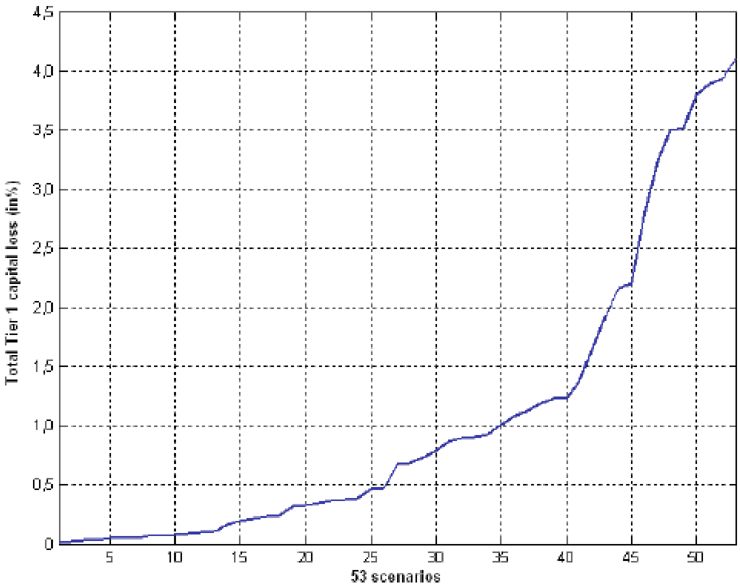
Figure 3: Idiosyncratic shock considering solvency contagion mechanisms (excerpt from Alves et al. (2013))




*Note:The vertical axis shows the total tier 1 capital loss over initial Tier 1 capital. The horizontal axis shows the 53 scenarios (53 bank defaults), in ascending order of severity of the resulting system-wide loss. LGD ares set at 100%.. For illustration, a loss lower than 1,5% occurs in 40 scenarios.*

### V.1.3 Global shock: illustration for the French banking sector

Rather than idiosyncratic shocks, a global shock impacting the external assets (e.g. outside the interbank assets) of the banks can be envisaged. Large Exposures data are used to create macro-prudential indicators thanks to an automated network stress test mechanism. Systemic indicators are computed along three dimensions: (i) interconnectedness contribution to capital, (ii) systemic importance and (iii) systemic fragility.

Large Exposures data are compiled over the years for 15 institutions,[21] whose assets represent more than 90% of the overall banking sector between 2002 and 2014. Solvency contagion is modelled following Gouriéroux et al. (2012), as explained above. Returns on external assets are broken down into two components, a systematic and an idiosyncratic one. The systematic factors are built using Principal Component Analysis on the returns of the banking "external" assets. The sensitivity of each institution to these factors is estimated thanks to an OLS regression. Residuals are the idiosyncratic components of each institution's returns. Time series of both systematic and idiosyncratic components are then computed. Their statistical distribution is fit by Gaussian laws with a reliable quality of fit. The values for external assets are randomly drawn in these distributions. The contagion mechanism is applied for each value

[21] BNPP, SG, GCM, GCA, BPCE, HSBC, LBP, CRH, CLog, Dexia, AFD, Oseo, Laser, PSA, RCI.

giving the corresponding equilibrium balance sheet and the distribution of associated risk indicators.

### V.1.4 Macro-prudential indicators

Three macro-prudential indicators are envisaged. Each of them compares the French banking system in two set-ups. The first set-up applies the shocks to the network as observed. The second set-up applies the same shocks in a network in which some interconnections – depending on the indicator – have been eliminated. This counterfactual can be interpreted as a public intervention to isolate one or several institutions from the network by repurchasing positions at current price. To ensure balanced balance sheet, these positions are assumed to be reinvested in external assets.

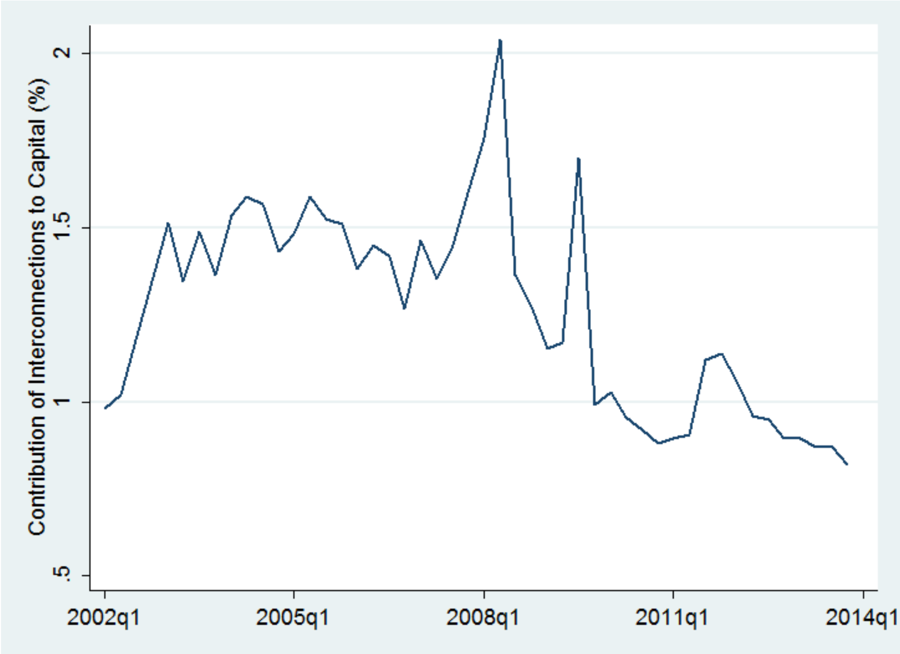
The interconnectedness contribution to capital (ICC) is the difference between capital in the banking sector in a normal set-up and capital which would be hold without interconnections (normalized by capital in a normal set-up). Formally, at each date t, for all banks indexed by I, it equates :

$$\mathrm{ICC}_t = \frac{\sum_i \left(\mathrm{ECapital}_t(\mathrm{i;with\ interco}) - \mathrm{ECapital}_t(\mathrm{i;without\ interco})\right)}{\sum_i \mathrm{ECapital}_t(\mathrm{i;with\ interco})}$$

where ECapital indicates expected capital.

Figure 4 pictures the evolution of this indicator between 2002 and 2014 for the French banking system. First, ICC is always positive. Consequently, interconnections have a positive impact on system capital. This phenomenon can be in all likelihood, accounted by a diversification effect. As Allen and Gale (2000) clearly pointed out, interconnections have a positive effect in case of mild shocks. They deter financial stability in case of extreme shocks. The sample of French banks between 2002 and 2014 does not includes such important shocks. A first regime from 2002 to the crisis, when the contribution is stable around 1.5% can be seen. During the financial and sovereign crises, the contribution increases and becomes volatile. It reaches up to 2% in 2008. Since 2010, ICC has stabilized around 1%, below the previous-crisis level.

**Figure 4: The interconnectedness contribution to capital, 2002-2014**




Source: Large Exposures, authors' computations

Note: The interconnectedness contribution to capital (ICC) is the difference between capital in the banking sector in a normal set-up and capital which would be hold without interconnections (normalized by capital in a normal set-up).

Note, however, that the previous findings are sensitive to the assumption made regarding the relative size of the aggregate shock *vs* the exposure to the network. In order to assess systemic risk, it is therefore better to consider alternative indicators based on the effects on individual P&L. Systemic Importance (SI) measures the risk generated by an institution. SI of bank i is the sum over all other banks j of the difference between counterparty bank j P&L in a normal situation and its P&L if bank i does not borrow from any counterparty. Formally, this indicator is defined as:

$$\widetilde{SI}_{i,t} = \sum_j \left(\mathrm{EP\&L}_t(\mathrm{j, i\ borrows}) - \mathrm{EP\&L}_t(\mathrm{j, i\ does\ not\ borrow})\right)$$

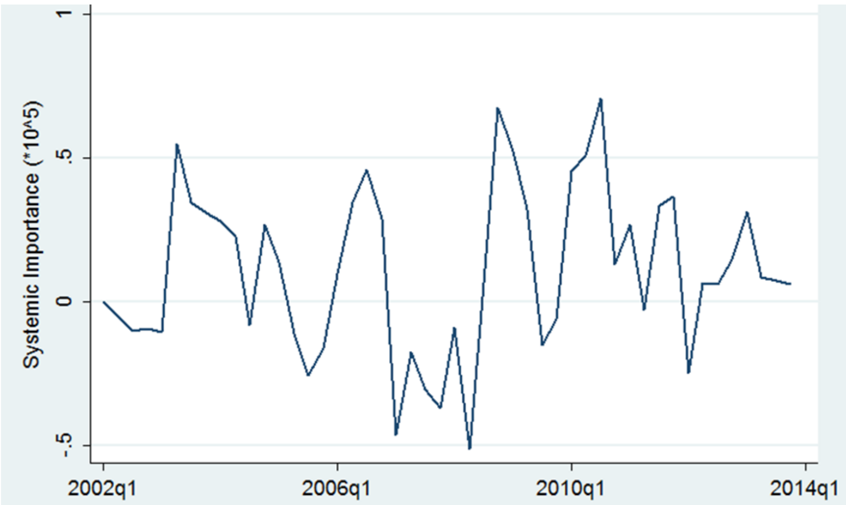
This indicator for an anonymous bank between 2002 and 2014 is exhibited in graph SI. When the indicator is positive, the system is more resilient without the bank. When it is negative, it is more resilient with the bank. Note the indicator's volatility, the bank being alternatively beneficial and detrimental to financial stability (relatively to the banks' average). The 2007-2008 period is specific: the indicator is less volatile and below zero. The bank contributed to the financial system's resilience during the financial crisis.

Systemic Fragility (SF) measures the dependence of a bank on the rest of the banking system. Bank i SF is the difference of P&L between a normal situation and a situation in which bank i does not lend to any bank and is thus not exposed to interbank risk. The indicator compares the interbank assets risk to the risk of the rest of the balance sheet. Formally, we define:

$$\mathrm{SF}_{i,t} = \mathrm{EP\&L}_t(\mathrm{i;observed}) - \mathrm{EP\&L}_t(\mathrm{i;i\ does\ not\ lend})$$

Figure 6 presents this indicator for an anonymous bank between 2002 and 2014. Throughout the period, the bank is less fragile if isolated (the indicator is negative). SF deepens until the crisis. It has reduced afterwards, without getting back to pre-crisis levels.

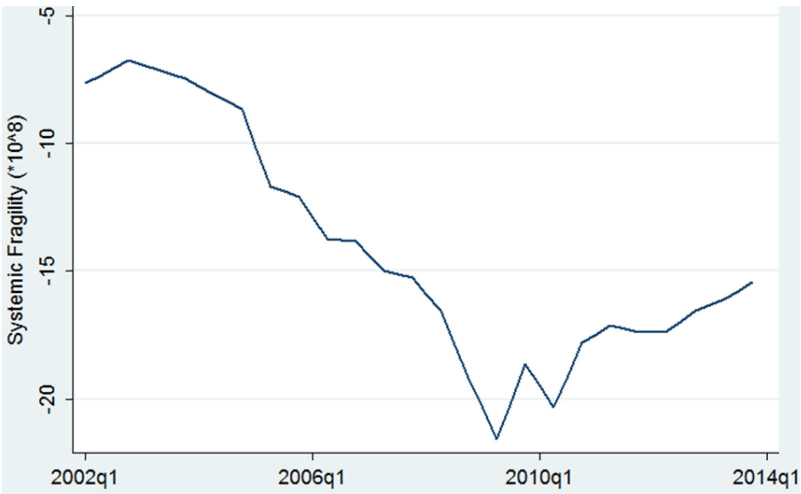
**Figure 5: Systemic Importance for an anonymous bank, 2002-2014**




Source: Large Exposures, authors' computations

Note: Systemic Importance (SI) measures the risk generated by an institution. SI of bank i is the sum over all other banks j of the difference between counterparty bank j P&L in a normal situation and its P&L if bank i does not borrow from any counterparty

**Figure 6: Systemic Fragility for an anonymous bank, 2002-2014**




Source: Large Exposures, authors' computations

Note : Systemic Fragility (SF) measures the dependence of a bank on the rest of the banking system. Bank i SF is the difference of P&L between a normal situation and a situation in which bank i does not lend to any bank and is thus not exposed to interbank risk.

Results show interconnections are more important in crisis times. At each date banks that contribute the most to the increase of the risk in the financial system are singled out from the others. Each bank plays various roles across time. Systemic fragility helps capturing to what extent each bank depend on the network's other institutions. Systemic fragility deepened until the crisis and stabilized since then.

### V.2 Solvency and Liquidity contagion: illustration for the French banking sector

Considering the network of 11 French banking groups, interbank exposures represents in average about 2% of the total asset but 34% of the equity. The distribution of exposures (in % total assets or in % equity) has a (right) fat tail with a variation coefficient about one. The network is represented in Figure 7.

After estimation step of joint returns on four classes of mark-to-market assets, the network is shocked by the severe drop in value of these classes (for more details, see Fourel et al. 2013). In addition to this common shock, one institution is arbitrary pushed in default. This shock triggers solvency and liquidity contagion. The left tail of the PnL (extreme losses) is grasped through quantiles (VaR) and average on extreme values (ES). These extreme losses are decomposed into three terms: the impact of the initial shock, the losses due to solvency contagion and the losses due to liquidity contagion. An example of results is provided in Table 4.

**Figure 7: The French Banking Networks (Excerpt from Fourel *et al.* (2013))**

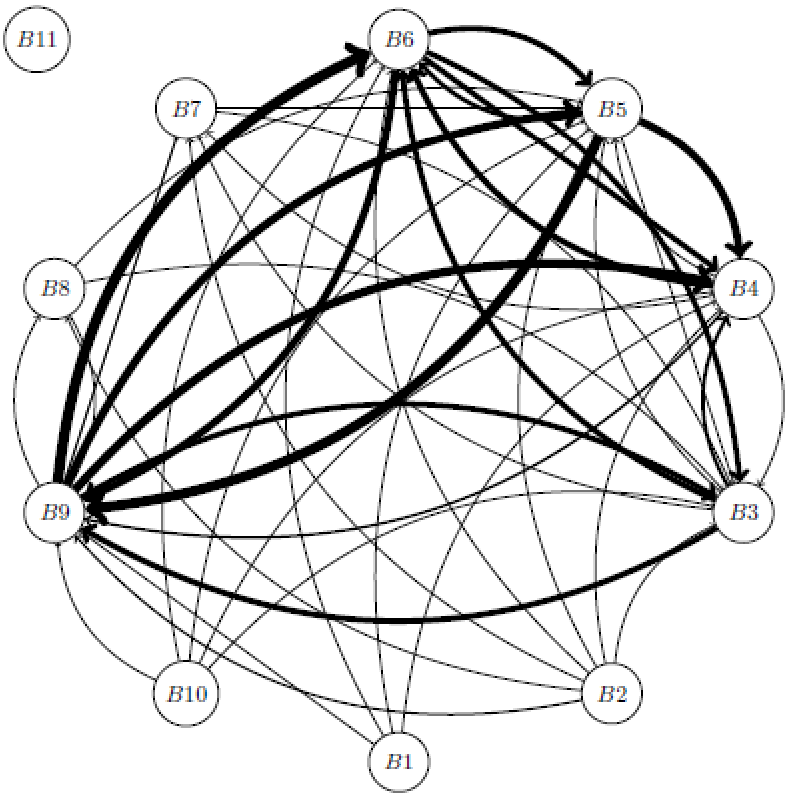



Figure 7: The French Banking Network in December 2011. The nodes correspond to the 11 largest French credit institutions while the edges represent the exposures (loans and securities) between the credit institutions. The widths of edges are proportional to the exposures.

**Table 4: Capital loss in a French banking system (as a % of the total capital of the system) after being impacted by different market shocks (Excerpt from Fourel et al. (2013))**

| Bubble Shock on Large Corporate Bonds + Idiosyncratic shock (Capital Loss, % of the Total Capital) | | | | | | |
|---|---|---|---|---|---|---|
| | VaR(5%) | VaR(1%) | VaR(0.1%) | VaR(0.01%) | ES(5%) | ES(1%) |
| Shock (A) | 28,49 | 38,87 | 48,15 | 51,19 | 34,61 | 43,01 |
| Solvency Contagion (B) | 1,18 | 1,18 | 1,18 | 1,18 | 1,18 | 1,18 |
| Liquidity Contagion (C) | 0,26 | 0,63 | 0,64 | 0,65 | 0,63 | 0,64 |
| Total (=A+B+C) | 29,93 | 40,68 | 49,98 | 53,02 | 36,42 | 44,83 |

Notes: The results correspond to an adverse shock on large corporate bonds combined with specific default of banks. Average Value-at-Risk (VaR) and Expected-Shorfall (ES) over the banking system are reported in columns for different risk levels. The line "Shock (A)" reports the risk measures when there is no contagion phenomenon. The line "Solvency Contagion (B)" reports the additional risk generated by the solvency contagion. The line "Liquidity Contagion (C)" reports the additional risk generated by the funding) liquidity contagion. The line "Total (=A+B+C)" provides the risk measures when shocks and contagion phenomena are taken into account.

This methodology has also been applied on a network of European banks thanks to ad hoc collect of data launched by the European Systemic Risk Board (ESRB) and on the December 2011 vintage.

## V.3 Illustration for extended networks including non-banking institutions

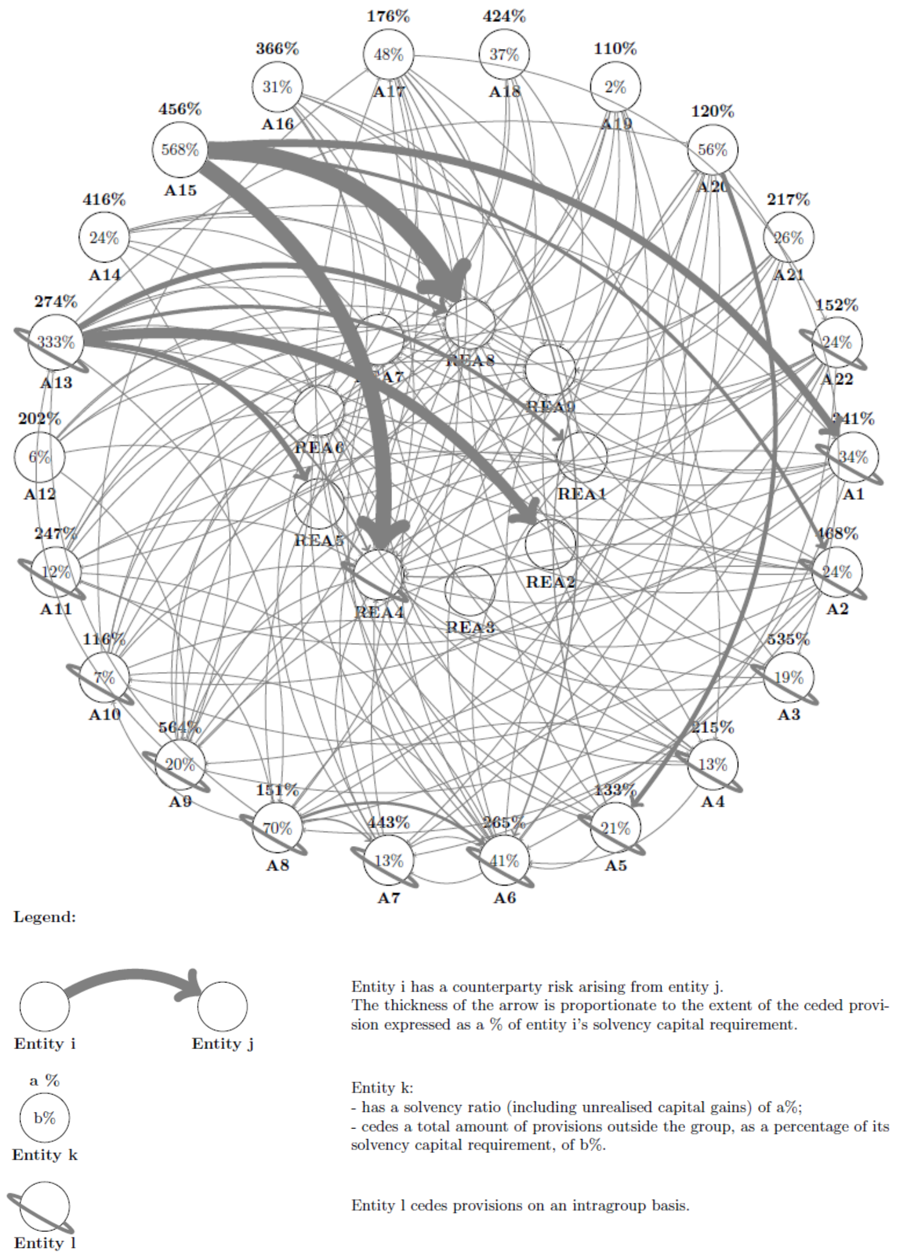
### V.3.1 The case of insurers and reinsurers

Interconnections between insurers and reinsurers are of great interest for financial stability analysis. The counterparty risk for insurers stemming from their reinsurance activity have been assessed through a stress test exercise (see Frey et al. (2013)). Using regulatory data (Annual Disclosures), a network of provisions ceded was built, including insurance groups formed with French insurance entities and groups of international reinsurers. Two hypothetical stress scenarios are considered.

In the first scenario, each reinsurer is supposed to default sequentially on their commitments towards insurers, considering in the same time that some guarantees were pledged by reinsurers (see figure 8 for a description of the network and table 5 for the results of idiosyncratic shocks).

In the second type of stress scenario the realization of an extreme event is envisaged (storm for non-life insurers and pandemic for life insurers) together with the default of all reinsurers. This exercise is based on single entities and does not take into account possible involvement of groups towards companies experiencing difficulties. As a follow-up, it would be instructive to model explicitly the shock leading to the reinsurers' default since this event would be of an even more significant amplitude than those studied in this analysis -hence would be less probable- but should also include, to improve realism, major direct effects on insurers, beyond the mere counterparty risk stemming from reinsurance.

**Figure 8: Gross cessions of provisions by insurers at end-2011 as a percentage of their margin requirement**




Source: Annual disclosures to the ACPR
Note : the outer circle represents the 22 groups of insurers; the inner circle the 9 pure-insurers

**Table 5: - Idiosyncratic stress test results. Impact on insurers' solvency ratio (LGD=100%) from net exposure to reinsurers (via ceded provisions). Excerpt from Frey et al. (2013).**

| Impact on insurers. Decrease in solvency ratio (in points) | | Pre- stress test solvency ratio | Reinsurer in defaut (recovery rate = 0%) | | | | | | | | | | Post- stress test solvency ratio of 9 defaulting reinsurers |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | A1 | REA8 | REA2 | REA3 | REA4 | REA5 | REA6 | REA7 | REA1 | Total impact (9 reinsurers) | |
| | A1 | 0% | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0% |
| | A2 | 341% | 0 | 0 | 2 | 0 | 0 | 0 | 3 | 1 | 0 | 7 | 334% |
| | A3 | 468% | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 467% |
| | A4 | 535% | 0 | 0 | 8 | 0 | 0 | 5 | 0 | 0 | 0 | 12 | 523% |
| | A5 | 215% | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 213% |
| | A6 | 133% | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 132% |
| | A7 | 265% | 0 | 0 | 0 | 2 | 0 | 2 | 6 | 3 | 4 | 19 | 246% |
| | A8 | 443% | 0 | 0 | 1 | 2 | 0 | 0 | 1 | 0 | 1 | 4 | 439% |
| | A9 | 151% | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 151% |
| | A10 | 564% | 0 | 0 | 3 | 1 | 0 | 0 | 1 | 0 | 3 | 8 | 556% |
| | A11 | 116% | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 115% |
| | A12 | 247% | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 246% |
| | A13 | 202% | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 202% |
| | A14 | 274% | 0 | 0 | 1 | 2 | 0 | 3 | 0 | 4 | 1 | 12 | 262% |
| | A15 | 416% | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 415% |
| | A16 | 456% | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 2 | 0 | 5 | 451% |
| | A17 | 366% | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 15 | 16 | 350% |
| | A18 | 176% | 0 | 0 | 0 | 7 | 0 | 0 | 0 | 2 | 0 | 9 | 167% |
| | A19 | 424% | 0 | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 1 | 4 | 420% |
| | A20 | 110% | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 110% |
| | A21 | 120% | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 119% |
| | A22 | 217% | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 2 | 215% |

.
Source: Annual Disclosures to the ACPR
Note: for example, A16 would incur a 15points loss on its solvency ratio if REA9 defaulted with an LGD of 100%. Data at end 2011

### V.3.2 The case of banks and insurers

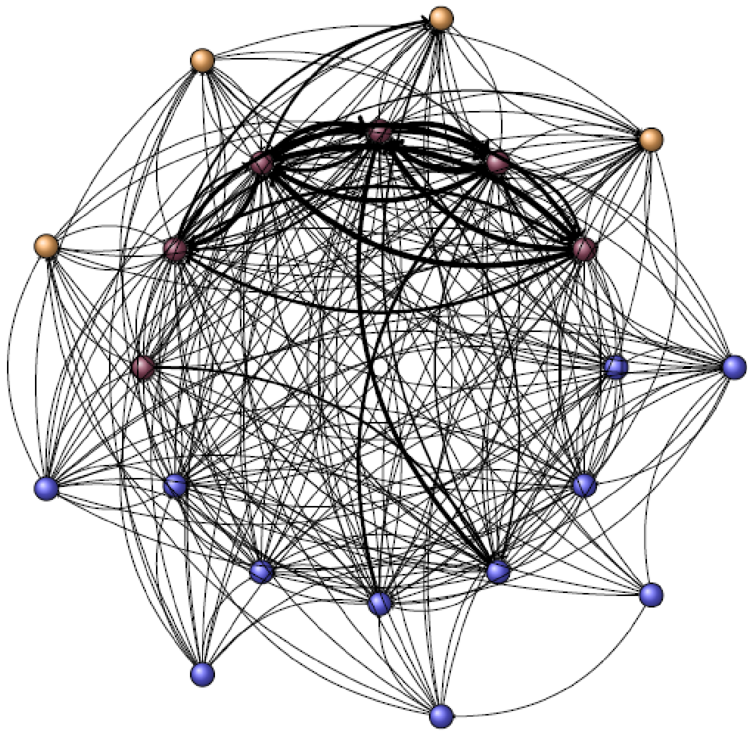
In a macro-prudential and trans-sectorial perspective, the network of 21 financial institutions counting 6 conglomerates22, 4 pure banks and 11 pure insurers, at 12/31/2011 is scrutinized (for more details, see Hauton and Héam, 2014). The topological analysis show that conglomerates are dealing with large volumes of exposures but do not present very typical risk profile in terms of allocations of inter-financial institutions assets and liabilities. Figure 9 maps the exposures between the 21 institutions. The contagion model developed in Gourieroux et al. (2012) to analyse the impact of two classes of deterministic shocks is once again implemented.

First, 21 scenarios corresponding to the initial default of one institution are implemented. For each institution, a score of systemic importance and a score of systemic fragility are computed. The systemic importance of institution A is the number of institutions suffering losses higher than 10% of their equities when institution A is assumed in default. The

[22] For clarity, we adopt the continental European understanding of « conglomerates »: a financial conglomerates is a financial group with a significant activity both in the banking sector and in the insurance sector.

systemic fragility of institution A is the number of scenario where institution A suffers losses higher than 10% of its equity. Figure 10 sets each institution according to its systemic importance score on the x-axis and to its systemic fragility score on the y-axis. Three groups of institutions are identified: the institutions that are systemically important, the institutions that are systemically fragile and the institutions that are neither systemically important nor systemically fragile.

**Figure 9: Networks of the French Banks and Insurers. Excerpt from Hauton and Héam (2014)**

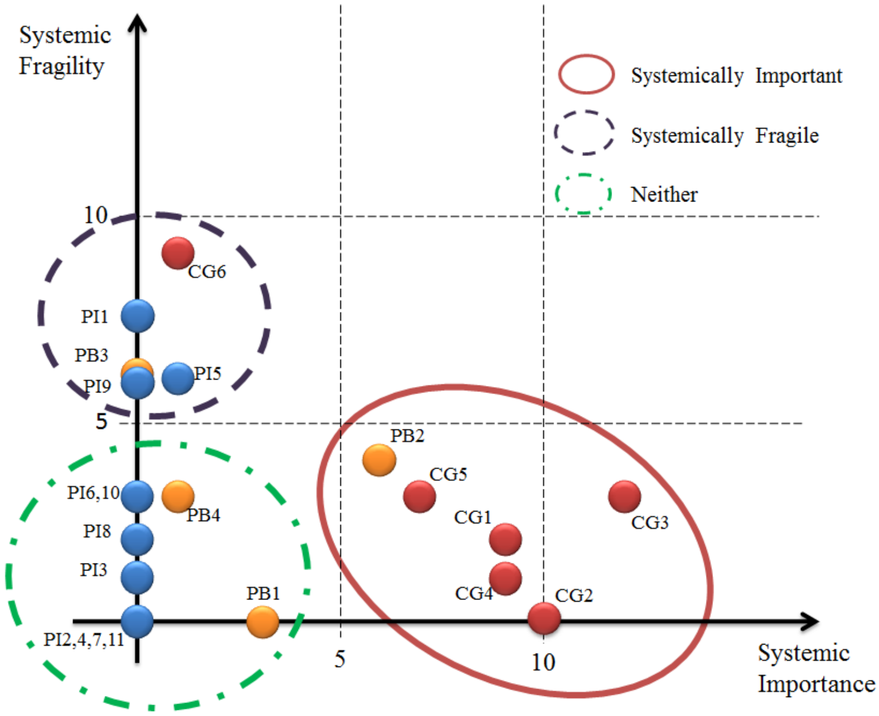


Legend: Node color indicates legal status (red for conglomerates, blue for pure insurers and yellow for pure banks), edge width is proportional to exposure.

Figure 5: Network on a fully-consolidated basis for total exposures. 12/31/2011

Source : Large exposure and TCEP reporting

**Figure 10: Indicators of Systemic Importance and Systemic Fragility.**




Source: Excerpt from Hauton and Héam (2014)
Note: The default of CG1 leads 9 others institutions to lose more than 10% of their equity. Only two institutions through their defaults generate loses for CG1 higher than 10% of its equity.

Second, nine sovereign debt crisis scenarios based on a fall of 50% in value of sovereign exposures to Germany, Spain, France, the United-Kingdom, Greece, Ireland, Italy, Portugal and the United-States of America are put in place. The shocks are applied considering conglomerates either on a fully-consolidated basis or on a partially-consolidated basis where the banking parts are distinguished from the insurance parts. Comparing the outcomes in both situations provide an insight on the role of financial conglomerate on the financial resilience. Table 6 reports the number of institutions in defaults as well as the average recovery rate on defaulted institutions. The losses do not lead any institutions to default except for France and Italy. For Italy, only one insurance component is in default. However, the corresponding conglomerate is not in default when the results are analysed on a fully-consolidated basis. There is a clear home bias in the sovereign exposures: a sovereign crisis on France has significant impacts. On a fully-consolidated basis, one conglomerate is in default with a recovery rate of 98%. On a partially-consolidated basis, the six insurance parts and one banking part are in default (with an average recovery rate of 98%). In that perspective, financial conglomerates appear to increase the resilience of the French financial sector.

**Table 6: Contagion Risk Based on Sovereign Scenario**

| | DE | ES | FR | GR | GB | GR | IE | IT | PT | US |
|---|---|---|---|---|---|---|---|---|---|---|
| **Fully-consolidated** | | | | | | | | | | |
| Number of conglomerates in default | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Recovery rate on defaulted institutions | . | . | 98% | . | . | . | . | . | . | . |
| **Partially-consolidated** | | | | | | | | | | |
| Number of banking parts in default | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Number of insurance parts in default | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Recovery rate on defaulted institutions | . | . | 91% | . | . | . | . | 98% | . | . |

Notes : Each column refers to a sovereign shock leading to a fall of 50% in value of sovereign exposures. The table reports the number of institutions in defaults as well as the average recovery rate on defaulted institutions for each shock. The analysis is ran both at the consolidated level (a bank and its insurance subsidiary are considered separately) and at the partially consolidated level (a bank and its insurance subsidiary are
Legend: "." indicates that the value cannot be computed.

## Conclusion

This paper provides an overview of the top down model MERCURE developed by the ACPR over the years. Particular attention is given to the description of data used as inputs to the quantitative models. Their comprehensiveness and their time coverage are keys to the robustness of the models. Change in the regulatory frameworks and in the regulatory reporting over the years have made very challenging the building of such a data base consistent over the years.

Over the recent years and taking stocks of the financial crisis, the ACPR developed granular credit risk models both in the corporate and the retail sector. Contagion models able to disentangle the risk stemming from interconnections from the elevation of risks due to a common shock were set up. They are now operationalised through the construction of indicators capturing systemic importance and systemic resilience of financial individual institutions, including banks, insurers and reinsurers.

On the banking side, several improvements of the top down models are currently considered. First, one of the purpose of the top down model is to challenge bottom up exercises for which an assumption of static balance sheet applied. Thus, no particular effort was exerted in order to integrate the reverse impact of capital shortfalls on credit distribution in the stress testing modelling. The ACPR has recently contributed to the analysis of the relationship between capital requirement and credit distribution. These analyses were made using original data set and sharp identification strategies on reduced form equations (See Fraisse et al., 2015 and Labonne and Lamé, 2014 and Labonne and Welter-Nicol, 2015 for recent illustrations). Building on these works, the integration of a module on the bank capital channel in the top down tool is under development. This would allow for relaxing the assumption of static balance sheet. The dynamic balance sheet could become a requirement of the bottom up exercises to come. In addition, this would allow using the top down models for the calibration of the macroprudential tools made available by CRD 4 (article 124, 130, 164 and 458) to the competent authorities.

Some risks should be explicitly covered by top down models. Fourel et al. (2014) aims at incorporating liquidity risk into a contagion model of defaults. However, the lack of data on the maturities of the asset and liability sides of the banks clearly limits the analysis and the possibility to run funding stress tests. Ad hoc data collection such as the ones undertaken during the 2014 EBA stress tests could be a solution. Another interesting source of data are the new prudential reporting collected since the start of the SSM. These reporting provide more detailed structure of the maturity and served interest rates of the asset and liability side of the banks.

On the insurance side, the top down models under the Solvency II framework are at the infancy stage and requires tremendous works before being operationalised. This contrasts with the well advanced stage of the top down models measuring the systemic importance of the French insurance sector. Progresses on the modelling side will be paired with the collection of data under this new regulatory framework. While first regulatory reporting under Solvency II will only be collected in 2016, ACPR has already been collecting on an annual basis the most important tables since 2013 in order to prepare undertakings to new reporting standards.

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