RAMSI: a top-down stress-testing model

Oliver Burrows, David Learmonth and Jack McKeown

BANK OF ENGLAND

BANK OF ENGLAND

RAMSI: a top-down stress-testing model

Oliver Burrows, David Learmonth and Jack McKeown

oliver.burrows@bankofengland.co.uk
Financial Stability, Bank of England, Threadneedle Street, London, EC2R 8AH

david.learmonth@bankofengland.co.uk
Financial Stability, Bank of England, Threadneedle Street, London, EC2R 8AH

jack.mckeown@bankofengland.co.uk
Financial Stability, Bank of England, Threadneedle Street, London, EC2R 8AH

Contents

RAMSI: a top-down stress-testing model

Oliver Burrows, David Learmonth and Jack McKeown

Top-down stress testing is one way of assessing the resilience of the financial system to the risks it might face now, or in the future. And by considering a range of different risks, top-down stress testing can also provide an indication of the key vulnerabilities of the system. The Bank of England's Risk Assessment Model of Systemic Institutions (RAMSI) is an example of a top-down stress-testing model and is one part of the Bank's risk assessment toolkit. This paper offers an overview of RAMSI and provides, by way of illustration, a detailed description of its implementation as part of the comprehensive set of stress tests carried out during the IMF's 2011 UK Financial Sector Assessment Program (FSAP).

Introduction

RAMSI is a large-scale model of the UK banking sector that is designed to assess the solvency and liquidity risks faced by the UK financial system. The model has been under development at the Bank of England for several years. Previous publications[1] have provided a description of the structure of the prototype model and an exploration of how the model might be used to generate liquidity feedbacks. RAMSI has developed further in recent years and is now part of the Bank of England's risk assessment toolkit. This paper provides a summary of the RAMSI model with an illustration of its recent application in the IMF's 2011 UK Financial Sector Assessment Program (FSAP).

In 2010, the Government outlined plans for reform of the UK regulatory framework, including the creation of a Financial Policy Committee (FPC) at the Bank of England. The FPC will be required to have a view on risks to the financial system and to understand the role of system-wide and cyclical imbalances in threatening its resilience. RAMSI's detailed description of each bank's balance sheet offers policymakers a quantitative and internally consistent framework to consider the outlook for the banking sector and the potential impact of different shocks to the macroeconomy and the financial system. Its use as a forecasting and stress-testing tool can identify weaknesses at individual institutions and across the system as a whole. That said, it is important to note that RAMSI represents only one part of a wider risk assessment toolkit currently in use, and being developed, at the Bank.

This paper will describe how RAMSI can be used as a tool to analyse the outlook for, and risks surrounding, the UK banking sector. RAMSI can be applied in several different ways, but is particularly suitable as a top-down stress-testing tool. Since the financial crisis, stress tests have become an increasingly important device for supervisors to assess the ability of the banking, insurance and other sectors of the financial system to deal with adverse projections for the macroeconomy.[2] Notable examples include the 2011 EU-wide stress test EBA exercise[3] and the US authorities' Supervisory Capital Assessment Program[4] for the banking sector.

As an illustration of RAMSI as a stress-testing tool, we focus on the IMF's 2011 UK Financial Sector Assessment Program, in which it was used to run stress tests to assess the solvency of the UK banking system under various adverse economic scenarios. The FSAP was carried out in early 2011. As a result, the FSAP stress test described in this paper is not reflective of current conditions and the results do not take into account the changes in balance sheets, macroeconomic conditions or policy measures that have occurred since the time of the test. The scenarios and results we present in this paper are therefore not an assessment of the current state of the UK banking

system but are an illustration of the types of outputs that RAMSI can produce.

Before describing the use of RAMSI as a stress-testing tool, we first provide a simple, intuitive description of the model architecture. In addition to explaining the details of the model, we will also explain the various strengths and weaknesses of using RAMSI in a stress-testing context. In particular, there is a huge amount of uncertainty involved in stress testing. This paper notes areas where RAMSI is less well equipped to model certain elements of stress tests, and highlights that a balance of model-based estimates and user judgement is required to appropriately inform policy.

1   An overview of the model

RAMSI is comprised of a set of equations that model each component of the largest UK banks' income, dependent on the composition of their balance sheets and projections for various macrofinancial variables. Alessandri *et al* (2009) describe the estimation and robustness of each of the equations. This paper does not go into such details, focusing instead on how each can be used in a stress-testing context. The appendix contains the key equations in the model.

An appealing aspect of RAMSI is its simplicity and interpretability. Forecasts of banks' income are largely based on reduced-form econometric equations. Further, banks' responses to exogenous shocks are dictated by simple behavioural rules rather than by the solution to an explicit forward-looking optimisation problem. This makes it easy to map outcomes in the model directly back to changes in the macrofinancial drivers in the model. This direct mapping permits economically intuitive explanations to be given for changes in the model's projections for banks' profits and capital. This approach does have some disadvantages, however. The simple behavioural rules and lack of optimising behaviour mean that banks in RAMSI largely act in a passive manner, as discussed below. In addition, the reduced-form relationships may break down in periods of extreme stress.

Modelling the behaviour of banking systems under stress is difficult. RAMSI is a model that provides one way of doing this, but it is in no sense perfect. The simplicity of much of RAMSI means it must be combined with judgement when running stress tests. And we have more confidence in some parts of the model than others. For example, the UK credit equations perform better than the international credit equations. But despite its shortcomings, we believe RAMSI is a useful tool for helping us to understand the vulnerabilities of the system to various risks.
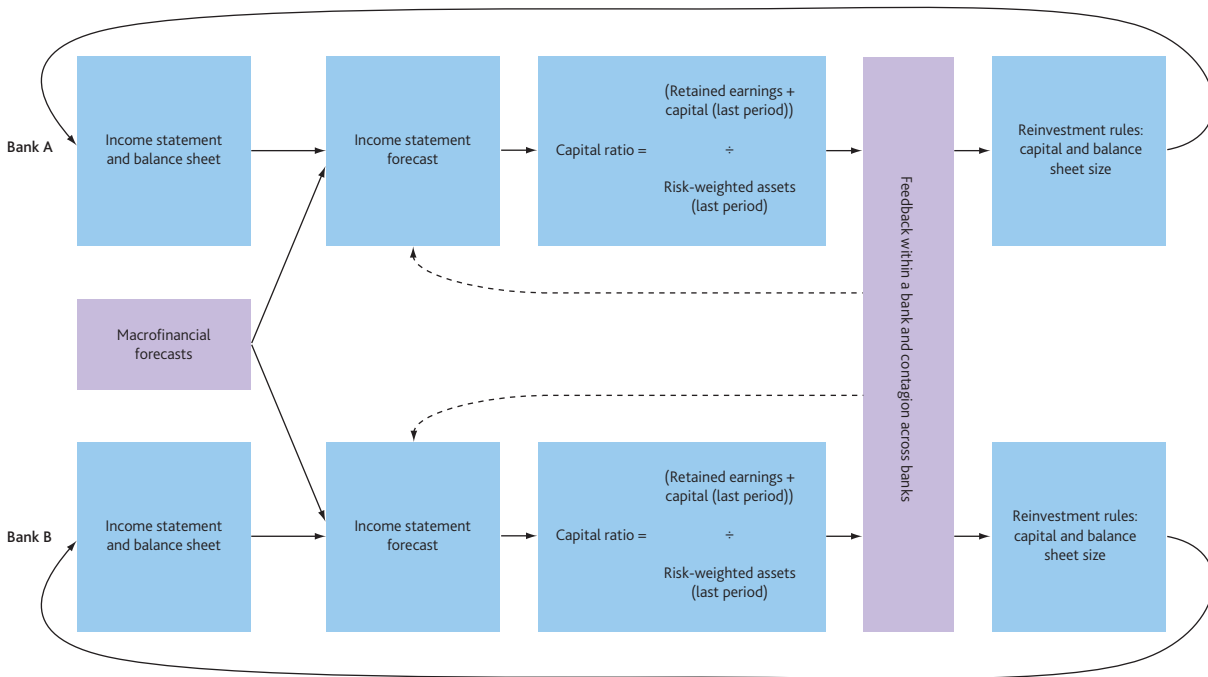
---

(1) Alessandri *et al* (2009), Aikman *et al* (2009) and Kapadia *et al* (2012).
(2) For a recent summary of macro stress testing, see Borio, Drehmann and Tsatsaronis (2012).
(3) See www.eba.europa.eu/EU-wide-stress-testing/2011.aspx for more details.
(4) www.federalreserve.gov/bankinforeg/scap.htm.

Figure 1 Stylised overview of RAMSI

1.1 The sequence of events during a stress test in RAMSI

Figure 1 gives a stylised overview of the sequence of events that occur in each period in RAMSI. The diagram shows just two banks, fewer than are included in RAMSI. The macrofinancial data set used in RAMSI has a quarterly frequency, while balance sheet and income statement data for the banks are generally updated semi-annually, in line with UK banks' historical disclosure practice.

Starting from the left of **Figure 1**, there are two sets of inputs to RAMSI: banks' income statements and balance sheets; and projections of macrofinancial variables. These then combine with the estimated equations in RAMSI to generate a forecast for each individual item in each bank's income statement. This approach to modelling the basic items of income and risks for banks is standard in most stress-testing models. In addition, an asset pricing model is used to estimate any changes in the market value of banks' assets triggered by changes in equity prices, market interest rates or credit risk premia.

Once retained earnings forecasts have been generated, each bank's capital ratio is calculated. At this stage, feedbacks both within and across banks can occur, as represented by the dashed lines in **Figure 1**. As the forecasts of bank fundamentals, such as profitability and solvency, worsen, banks experience higher costs of funding in RAMSI. Further, as fundamentals pass certain thresholds, banks can be shut out of certain funding markets altogether.

This feedback effect extends to interactions across banks. For example, a bank that is perceived to be similar to a bank that

has already been shut out of funding markets will also experience an increase in likelihood of being shut out itself.

The most direct forms of contagion occur when a bank suffers losses so severe that its capital ratio falls below a set threshold and is deemed to fail. At this point, a feedback loop occurs that causes losses at other banks, generated by the type of externalities that can generate systemic risk, such as counterparty credit risk and asset fire sales.

In the absence of bank failures, or after the feedback loop has completed, any retained earnings are used to update the banks' balance sheets. At this point, all top-down models have to make an assumption about what banks do with these earnings. One option is that banks use a certain proportion of their earnings to increase the amount of risk-weighted assets they hold, and retain whatever is left over as capital. Another is to assume that banks have a specific capital target in mind. In that case, banks would only increase their risk-weighted assets once they have met those targets.

As a conditioning assumption, the illustrations presented in this paper make the latter assumption. This seems an appropriate description of bank behaviour, especially in the current environment where there is a market focus on resilience.

Figure 2 sets out the rules for the reinvestment of earnings in RAMSI under the assumption that banks have capital ratio targets. If a bank's earnings are negative, then its capital will be depleted and its assets 'run off' to allow the balance sheet to balance. If a bank makes positive earnings, but does not earn sufficient profit to hit its target, it will not increase its

Box 1
A comparison of stress-test approaches

Top-down and bottom-up stress-testing models
Stress testing using RAMSI is an example of a top-down process. In a top-down stress test, the authorities set the macroeconomic scenario and conditions under which the test should be run, and calculate the results without the involvement of the banks themselves. The focus with top-down tests is as much on the banking system as a whole as it is on individual institutions. By applying the same scenario on the same model with the same assumptions at the same time, top-down tests allow for direct and transparent comparisons across banks, as well as offering a framework for understanding and identifying particular areas of vulnerability in the banking system as a whole. And crucially, top-down models can also capture the impact that actions by one bank have on others in the system. But a weakness of these models is that they lack the balance sheet granularity, especially in areas such as trading assets and liabilities, and detailed firm-specific modelling that bottom-up tests provide.

Bottom-up tests are generally run by banks themselves using their internally developed models. An important difference to top-down tests is that the banks' models are institution-specific. By implication, if two banks were given identical balance sheet and income statement starting points, the impact of the same stress scenario would differ. Unlike top-down tests, therefore, comparing stress-test results across banks is more difficult. But the advantage of the bottom-up tests is their use of extremely granular information on individual banks' trading portfolios and overall exposures. This permits a more detailed insight into how an individual bank might be affected by worsening macroeconomic and market conditions.

In the FSAP, the banks ran the same macroeconomic scenarios as in the top-down tests through their models, under oversight of the FSA. The use of both top-down and bottom-up tests in the FSAP provided a superior overall picture of the banking system, and allowed each to be used as a cross-check on the results of the other.

Differences from traditional macro models
RAMSI also differs in important ways from modern macroeconomic models. To be useful for risk assessment, it needs to forecast banks' balance sheets and income statements in some detail, to be able to address the impact of scenarios on banks' capital and liquidity. This richness of coverage cannot be incorporated into a general equilibrium model, in which banks' behaviour is micro-founded and they solve optimisation problems to determine their behaviour. Instead, the model has a simple recursive structure, with data

at the start of the projection being mapped deterministically into data in the next period, and the model iterating forwards through time.

What is the best model for macroprudential policy?
The models described above are based on different philosophies. Both top-down and bottom-up models start with an empirically credible description of banks' balance sheets, and then add components that capture the parts of the real economy that are most relevant to the balance sheets (eg interest rates and credit risk drivers). Top-down models are weighted towards consistent and coherent modelling of risks across banks, while bottom-up models have more detailed balance sheets.

Macroeconomic models such as dynamic stochastic general equilibrium (DSGE) models start with a high-level view of the interactions between firms, households and financial markets, and attempt to formalise the role of banks in that context.

Combining the 'granularity' of bottom-up stress-testing models with the 'general equilibrium' nature of some macroeconomic models is extremely difficult. The figure below shows how models might be distributed along this trade-off.

Figure A Trade-off between theoretical coherence and empirical detail of stress-testing models
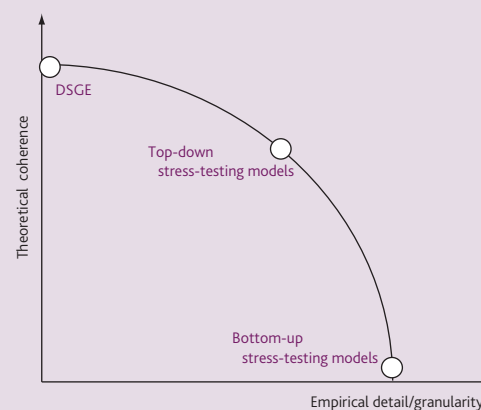
In practice, the FPC will want to consider a broad range of indicators in forming and evaluating its policy decisions. In so doing, the FPC will look to a wide range of models, as well as to other sources of information such as data and market intelligence.

Figure 2 Reinvestment of earnings in RAMSI
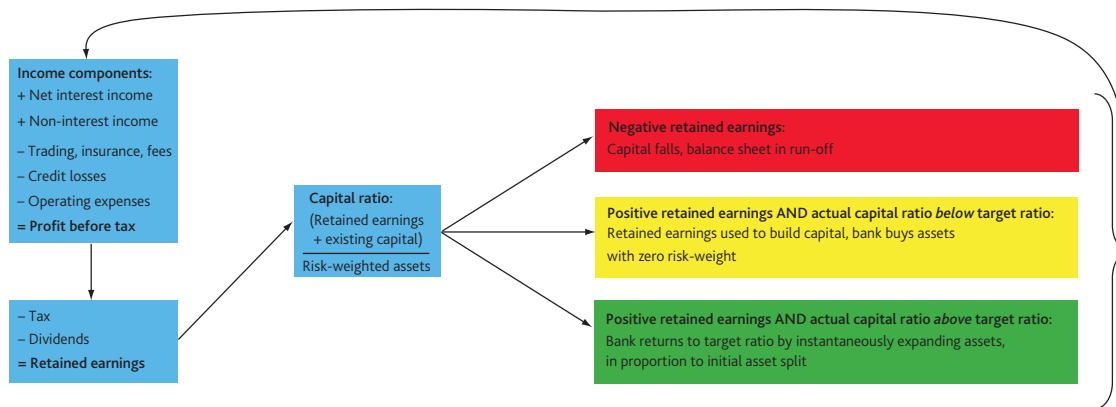
risk-weighted assets. If, however, it is at, or above, its target, it will (holding constant the distribution of assets at the start of the projection) increase its risk-weighted assets, and maintain a ratio equal to the target.

Once reinvestment of earnings has taken place, the next period begins. The updated assets and liabilities on the balance sheet combine with the macrofinancial conditions, and the sequence of events shown in **Figure 1** is repeated. RAMSI is therefore a complex feedback loop: if banks make sufficient income, they increase their risk-weighted assets, which allows them to make yet more income (since income is a positive function of assets), and so on.

2   Mapping macroeconomic forecasts into income statement projections

This section describes in more detail how specific elements of income that tend to be of most relevance for stress tests are modelled in RAMSI.

2.1 Inputs to the model
RAMSI requires a detailed breakdown of each bank's income statement and balance sheet. These are largely constructed from published accounts, so do not have the granular detail contained in bottom-up models. They also include regulatory data on large exposures between banks, some finer details on historical write-off rates, provisions and the geographical and sectoral split of banking book assets.

The second input is a set of 26 domestic and foreign macroeconomic and financial variables, projections of which drive the future evolution of each bank's income statement and balance sheet.

RAMSI can generate its own macrofinancial projections using a medium-scale Bayesian vector autoregression model (BVAR) that relies on a set of priors and the two most recent quarterly observations. The BVAR ensures a consistent forecast for the macroeconomy, and allows the user to set the paths for

certain variables, such as GDP, and generate paths for other variables conditional on that profile.

Alternatively, RAMSI includes the option to bypass the BVAR and 'fix' the variable projections. This is relevant when running stress tests that involve predetermined economic downturns. A stress scenario involves analysis of an extreme event — for example a severe recession. Such events will not have happened very often in the past and would not be expected to occur very often in the future. It is important that stress scenarios are plausible as well as being severe. In constructing stress scenarios, therefore, it is typical to use: a macroeconomic model; a historical episode; or a combination of the two, to ensure plausibility and coherence. The IMF FSAP scenarios were constructed using a macroeconomic model, cross-checked against severe historical downturns.

2.2 Credit risk
Credit losses are modelled separately in RAMSI for residential mortgage, unsecured and corporate lending in the United Kingdom, United States, euro area and rest of the world. A more disaggregate breakdown, for example one that separated commercial property exposures, would be desirable, but is challenging due to data limitations.

The ultimate output of the credit risk model is bank-specific write-off rates that can be applied to banks' exposures to derive credit losses in each period. This is achieved in two stages.

First, aggregate — economy-wide — probabilities of default and write-off rates are estimated. These use projections for the macroeconomic and financial variables as inputs: for example, the corporate probability of default in the United Kingdom is estimated using forecasts for commercial property values, GDP growth, the ratio of M4 lending to nominal GDP, and the corporate effective interest rate as determinants. As the outlooks for these variables worsen in a stress, the aggregate write-off rate will be projected to increase as a result. It is worth noting that the aggregate write-off rate is implicitly the product of the probability of

default and the loss given default, but the loss given default is not explicitly estimated at any stage.

The aggregate write-off rates are then translated into bank-specific write-off rates for each type of exposure by adjusting for each bank's historical performance. So banks that made lower losses in the past will be projected to incur lower credit losses than the typical bank over the forecast horizon: the profiles of write-off rates will be similar across banks, but the levels will differ. This attempts to capture persistent differences in the riskiness of lending that banks undertake.

Our internal validation process found that, while the credit module performs reasonably well for UK exposures, data limitations impede the reliability of the bank-specific write-off rates on foreign exposures. In our applications, we have tended to apply the UK part of the credit module but have overwritten the non-UK forecasts with off-model forecasts and judgement. This has been particularly important in the euro area, where write-off rates across banks have differed dramatically, driven by differences in country and sector exposures.

2.3 Net interest income

Net interest income is one of the principal sources of income for most banks. In principle, one could calculate net interest income by estimating line-by-line the cash flows generated from interest-bearing assets, alongside expenses incurred on interest-bearing liabilities for each bank's balance sheet. But such an approach is heavily dependent on comprehensive data on individual banks' repricing maturities and hedging practices. In practice we do not have the necessary data to estimate net interest income in such a bottom-up way.

Therefore, in RAMSI we have implemented a three-part approach to estimating net interest income. The first step estimates an amount of net interest income earned through changes in the risk-free (government) yield curve. This is done using an econometric panel data investigation of the determinants of bank income recently completed at the Bank.[1] That work finds an economically significant positive relationship between net interest income and: (i) increases in short rates; and (ii) a steepening in yield curve slope.

The second step estimates the additional spread banks charge in response to changes in the perceived riskiness of their debtors: an increase in actual or expected credit risk translates into a wider desired lending spread. However, banks' ability to reprice is constrained by the maturity structure of their balance sheets. Since assets and liabilities typically do not have matched maturities, these constraints generate significant income risk. Meaningful cross-bank differences in income risk and dynamics arise from underlying balance sheet structures.

Third, in order to capture more realistic wholesale funding costs we have added the capability to include both exogenous and endogenous increases in interest expense for each bank. Endogenous increases in spreads are the product of RAMSI's ratings module. This module maps banks' fundamentals into a model-implied rating, which in turn is mapped onto funding costs. Therefore, as fundamentals, and hence ratings, deteriorate, banks in RAMSI face an increase in funding costs. We can also apply an exogenous increase in interest expense for each bank to allow us to introduce shocks to funding costs.

2.4 Trading and other income and expenses

Trading income is an important component of income for some of the largest UK banks. But its volatile nature and dependence on the quality of the trading book, which is difficult to observe without detailed information, make forecasting difficult.

In RAMSI, the trading income module projects the share of trading income in (net) trading assets as a linear function of its lagged value, marked-to-market changes in trading asset values, and stock market volatility. The module does not model repo activity or derivatives. The volatility term is consistent with banks taking profits from 'volume trading' (for example, the provision of market-making services) rather than 'position trading'.

Perhaps unsurprisingly, validation work found that the model does poorly at predicting trading income over the recent financial crisis. In particular, losses on structured products are not well captured, driving large forecasting errors. For this reason, we have generally attempted to capture trading book losses in stress tests using simple off-model estimates (as described in the next section on the FSAP stress test).

Other sources of income not already covered include such items as fees and commissions, income from insurance, and service charges. Although this comprises a large share of banks' income, it also includes large one-off items, making it erratic and difficult to forecast. RAMSI models the ratio of other income to total assets as a positive function of its lagged value and of GDP. That makes the ratio procyclical, reflecting the view that, for example, fees and commissions from market-making tend to rise when the aggregate level of economic activity grows.

Operating expenses are, in turn, modelled as a ratio to non-interest, non-trading income. This ratio depends positively on its lagged value and relates negatively to GDP growth. This indicates 'cost stickiness': when GDP falls, income falls by more than expenses, so the ratio of the latter to the former rises.

---

(1) Alessandri and Nelson (2012).

2.5 Interactions and feedbacks across and within banks

As mentioned previously, RAMSI incorporates two types of feedback: from a firm's own fundamentals to its cost of and access to funding; and second-round 'contagion' effects where the actions of one bank can affect others, providing a systemic risk aspect to stress testing using RAMSI. The most important of these mechanisms are:

Interbank exposures: counterparty credit risks are estimated using a network model. When a bank defaults, losses incurred by other banks are estimated using a matrix of reported large exposures.

Fire sales: as seen in the crisis, when a bank is in trouble it may sell assets, which may push down the prices of these assets and cause mark-to-market losses at other banks. This is captured in RAMSI using a fire-sale model, where the impact on asset prices increases in a non-linear manner as the size of the fire sale increases. Currently, fire sales only occur in RAMSI when a bank defaults, and not as a defensive tactic.

Closure of funding markets: a particularly important feature of the recent crisis was stress in the wholesale funding market. In RAMSI banks can fail as a consequence of the withdrawal of market funding, as well as as the result of a shortage of capital.

Modelling the outright closure of funding markets is very difficult, in large part because of the binary, non-linear nature of liquidity risk. As described in detail in Kapadia *et al* (2012), the closure of funding markets is modelled in RAMSI using a simple and transparent scoring approach in which outputs from the rest of the model are mapped into specific indicators of funding stress. The scores were calibrated using a range of case studies.

Outputs from the rest of the model are mapped into specific indicators of funding stress relating to the three key areas of solvency, liquidity and confidence that theoretical models have identified as important. The most important determinant of whether or not a bank is shut out of funding markets is, perhaps unsurprisingly, its expected solvency.

Feedback effects on other banks are generated through a pure confidence channel. This is estimated using the correlation of stock prices across banks over the past. If two (or more) banks have tended to move together historically, it is assumed that investors will pull funding from all banks identified as being 'similar' when one gets into trouble.

A realistic modelling of feedbacks is particularly important from the perspective of a systemic risk model. And work is ongoing to improve RAMSI's feedback mechanisms. For example, at present in RAMSI, contagion only comes into play when set thresholds, such as capital ratios or liquidity scores,

are breached. So unless the macroeconomic projection is sufficiently severe and a bank starts with a weak balance sheet, these feedback effects will often not occur. In future research we intend to consider triggering these interactions in stages. Among other things, this will allow us to use RAMSI to identify more comprehensively potential scenarios belonging to the tail of the distribution.

3   A practical application of RAMSI as a stress-testing tool

RAMSI can be used to run stress tests of the UK banking system. Stress tests are forward-looking evaluations of the resilience of banks to a range of plausible but severe outcomes for the macroeconomy and financial markets. They provide supervisors and the banks themselves with a better understanding of weaknesses and vulnerabilities in the system, and can be an important input into banks' planning decisions and supervisory actions.

This section provides an example of how RAMSI can be used as a top-down stress-testing tool. It takes the example of the recent IMF UK FSAP, in which RAMSI was used to assess the solvency of the UK banking system under various adverse economic scenarios. The FSAP contained both top-down tests — run using RAMSI and the IMF's Contingent Claims model — and bottom-up stress tests, run by the banks themselves under the oversight of the FSA.

It is important to note that the FSAP was based on banks' balance sheets as they were at the end of 2010, and that the stress test was constructed in early 2011 — so it reflects the conditions at that time. The results and stress-testing methodologies were published by the IMF in July 2011.[1] The scenarios and results from the stress test we present below are therefore not an assessment of the current state of the UK banking system but are an illustration of the types of outputs that RAMSI can produce.

3.1 The FSAP macroeconomic scenarios

The first step in stress testing in RAMSI involves the construction of the macroeconomic and financial variables. The FSAP outlined a baseline and three distinct stress scenarios, all over a five-year horizon (2011–15).

Two of these stress scenarios simulated 'double-dip' recessions of differing severity, and share similarities to the scenario applied by the EBA in the 2011 EU-wide exercise, and to the FSA's 2011 anchor stress-test scenarios. Underlying these scenarios are simultaneous demand and supply shocks emanating from a sharp fall in demand from the rest of the world for UK exports and an increase in commodity prices respectively. The third scenario was unique to the FSAP, and

---

(1) www.imf.org/external/pubs/ft/scr/2011/cr11222.pdf.

outlined a negative shock to factor productivity that significantly reduces the trend growth rate of the economy.

In this paper we focus on the 'severe double-dip' stress scenario (the results of the other two stresses can be seen in the Technical Note accompanying the FSAP).[1] The scenario involved average annual real GDP growth in 2011 of -0.2% (+2.2% in the baseline), -2.6% (+2.0%) in 2012 and +0.2% (1.9%) in 2013 (**Chart 1**).

**Chart 1** UK real GDP growth in the FSAP[a]
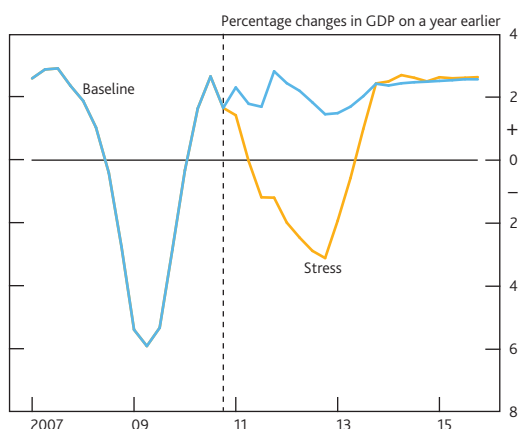
Source: IMF.

(a) Data to the right of the dashed vertical line are projections.

The severe scenario included sharp falls in both residential and commercial property prices (**Chart 2**), as well as falls in equity prices and a large persistent increase in the unemployment rate. Because the scenario included a supply-side impact, inflationary pressures remained fairly elevated and only abated gradually. So despite depressed demand, short-term interest rates in these scenarios were assumed to increase gradually over the horizon, broadly in line with the baseline projection. Long-term rates were assumed lower than in the baseline, however, implying a flattening of the yield curve.

Chart 2 Non-financial asset prices in the FSAP[a]
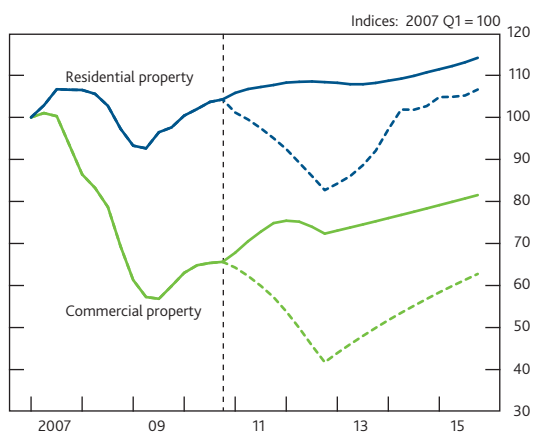
Sources: Bank of England, Department for Communities and Local Government, IMF, Investment Property Databank and Bank calculations.

(a) Solid (dashed) lines show baseline (stress) scenario. Data to the right of the dashed vertical line are projections.

The FSAP defined profiles for several variables that are used in RAMSI's macrofinancial module. These were GDP, CPI inflation, unemployment, house, commercial property and equity prices, and short and long-term interest rates. The other macrofinancial variables, such as household income gearing and unsecured debt levels, were generated using internal Bank of England macroeconomic models, assuming a similar scenario as that used in the FSAP.

3.2 Underlying assumptions made in the stress test

Following the specification of the stress scenario, the next step is to define the conditions under which the test will be run. These assumptions are important determinants of the results, and small changes in definition can lead to large changes in the results. For this reason, it is important that those running stress tests are aware of the main factors driving the results and how sensitive these results are to the initial assumptions made. This section will describe some of the main assumptions underlying the top-down stress tests.

Capital ratio targets

An important assumption in RAMSI is the choice of capital ratio targets that banks aim for. As discussed earlier, this determines how banks use their retained earnings. A high capital ratio target may lead to retained earnings being used to invest in safe assets, while a lower target might allow more room to increase risk-weighted assets. This choice will have impacts on profits in future periods. On the one hand, riskier assets tend to have a higher yield. On the other hand, if capital ratios are too low, then elevated funding costs might eat into profits. Higher profitability will support balance sheet expansion in future periods. The IMF FSAP stress test included relatively challenging capital targets.

Dividends

In the baseline and stress scenarios, we assume that banks' dividend policies are linked to their capital levels. If banks are on pace to meet the capital ratio targets, then dividends are paid as a proportion of profits at the levels in place at end-2010. However, if banks are not on pace to meet their capital targets, they do not pay out dividends, retaining all income instead. There are several equally plausible assumptions that could be made about dividend policy. It is possible, for example, that pressure from shareholders could, in practice, force banks to increase dividends prematurely.

Provisions

The appropriate treatment of provisions is a challenging issue faced in all stress tests. UK banks built up a stock of provisions from 2008 — the question is how these should be treated over the stress horizon.

(1) See www.imf.org/external/pubs/ft/scr/2011/cr11227.pdf.

In the FSAP baseline and stress scenarios we use the credit equations described previously to forecast bank-by-bank write-offs. We separately allow banks to deplete their stock of provisions to cover part of these write-offs, using the assumption that starting stocks fall halfway back to their pre-crisis averages by 2015. This is equivalent to forecasting a lower impairment charge than would be suggested by write-offs alone.

Asset disposals

In line with both the guidelines provided by the IMF for the bottom-up tests and the recent EBA stress tests, our analysis does not incorporate planned asset disposals at the UK banks. In practice, asset disposals might boost capital ratios by reducing risk-weighted assets. To this extent, both the top-down and bottom-up results may overstate the need for banks to have retained earnings.

3.3 The baseline scenario

The baseline forecast represents a projection of the profits, losses and capital growth of banks under: (i) the macroeconomic projections applied in the FSAP (which come from the IMF's *World Economic Outlook*); and (ii) the specific assumptions described above. Given these specific inputs, its usefulness is largely as a benchmark against which the results of the stress scenarios can be compared.

The baseline (and stress) scenarios were run for the largest five providers of banking services to the UK economy: Barclays, HSBC, Lloyds Banking Group, Royal Bank of Scotland and Santander Group.

Chart 3 shows the breakdown of UK banks' profits before tax in our *baseline* scenario. Profits rise steadily over the five-year projection, largely driven by smaller credit losses. There are two factors behind this. First, as the macroeconomic outlook improves and unemployment falls, write-off rates decline from 2009 peaks. And second, the assumed partial release of excess provisions built up over the crisis to cover write-offs further reduces impairments.

UK banks also collectively generate a small increase in net interest margin in the baseline scenario, as the negative impact of a flatter yield curve in the baseline scenario is outweighed by the positive impact of the rise in short rates.

Aggregate trading profits in each year going forward are substantially lower than the level seen in 2009. We also include a bank-specific 'bank levy' from 2011 onwards of between £260 million–£400 million per annum, with the estimates of the size of the levy taken from bank disclosures.[1] The combination of the bank levy, along with other income and operating expenses is shown in **Chart 3** as 'Other'.

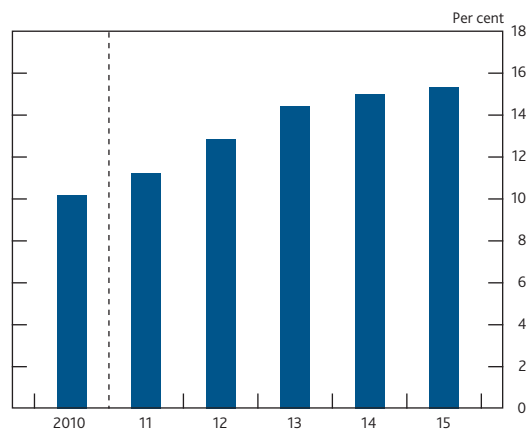**Chart 3** Aggregate profits in the baseline scenario[a]
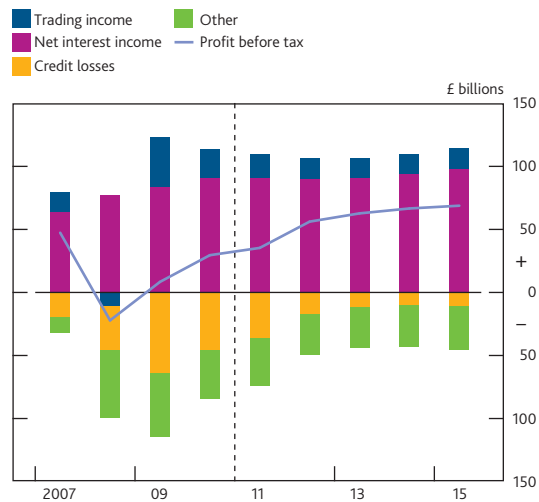
Sources: Published accounts and Bank calculations.

(a) Data to the right of the dashed vertical line are projections. The combination of other income and operating expenses is shown as 'Other'.

The overall increase in profitability translated into higher capital ratios across the banks. **Chart 4** shows that, on a Basel II basis, UK banks' aggregate core Tier 1 capital ratios were projected to increase by 5 percentage points over the five years in the baseline scenario.

Chart 4 Aggregate core Tier 1 capital ratio in the baseline scenario[a]
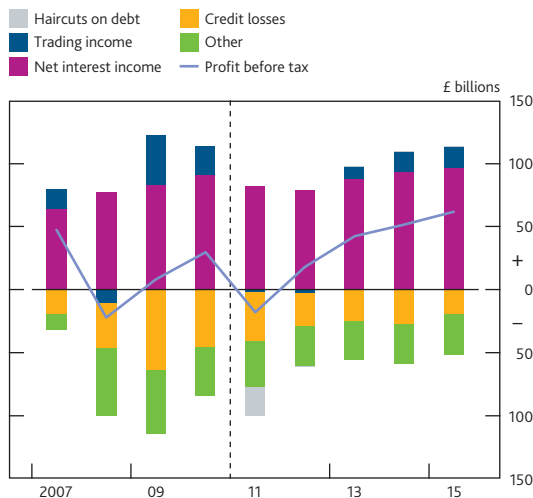

Sources: Published accounts and Bank calculations.

(a) Aggregate capital ratio defined as total core Tier 1 capital as a percentage of total risk-weighted assets. Expressed in Basel II terms. Data to the right of the dashed vertical line are projections.

3.4 The stress scenario

In the stress scenario profits were projected to be materially weaker than in the baseline. **Chart 5** shows a summary of the aggregate profits of the UK banks. Banks were projected to make a small loss in the first year and profits in future years were significantly lower than in the baseline. The impact on aggregate profits relative to the baseline over the projection as a whole came largely through falls in trading income, lower net

(1) The Chancellor announced that the UK Government would introduce a bank levy from 1 January 2011.

Chart 5 Aggregate profits in the stress scenario(a)

Sources: Published accounts and Bank calculations.

(a) Data to the right of the dashed vertical line are projections. The combination of other income and operating expenses is shown as 'Other'.

Chart 6 Aggregate UK banks' profits, stress scenario relative to the baseline(a)

Sources: Published accounts and Bank calculations.

(a) The combination of other income and operating expenses is shown as 'Other'.

interest income and higher loan impairments. In addition, in 2011 we applied haircuts to the values of sovereign and bank debt held in banks' trading and banking books, consistent with the methodology used in the FSAP.

Chart 5 also shows how the stress scenario compares to bank profitability during the financial crisis. In 2008 aggregate profits for the largest five UK banks were negative, as two banks made large losses and profitability dipped at the others. In the stress scenario, aggregate profits in 2011 were projected to be comparable to those made in 2008, suggesting a similar-sized shock to profits in the stress scenario as that experienced during the height of the crisis.
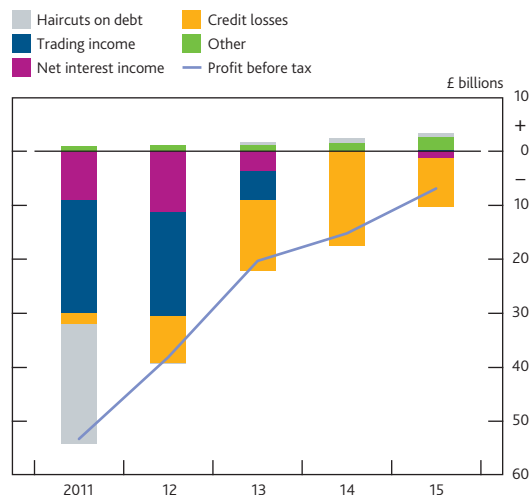
The total reduction in aggregate profits over the five years of the stress scenario, relative to the baseline, was around £115 billion (60% of profit in the baseline). The change in aggregate profits relative to the baseline, broken down by income component, is shown in **Chart 6**.

We will now describe in more detail how each of these elements of profit was derived in the stress scenario.

3.5 Net interest income

Across the first two years of the stress scenario net interest income was projected to be weaker by over £20 billion in aggregate relative to the baseline.

The main driver of this reduction in net interest income came from an assumed increase in banks' funding costs. This shock was calibrated using the relationship between the change in bank spreads on senior and subordinated debt and the change in GDP growth between 2008 and 2010. During this period banks' funding costs increased sharply as GDP growth fell. We take this episode as a reasonable proxy for the behaviour of

funding costs under stress and assumed that funding costs follow a similar pattern in the FSAP stress scenario. In the stress scenario, we used an increase of spreads of between 40 basis points and 90 basis points, with the increase in funding costs calculated on a bank-by-bank basis, with the weaker banks suffering the most. This change in funding costs led to an increase in interest expense across the banks. Because we also assumed that banks would be unable to pass on to customers the rise in their funding costs immediately, this rise in interest expense meant that banks' profitability was squeezed as a result of increased funding costs.

This is an example of the type of situation where it was necessary to apply judgement when running a stress scenario. Here, model testing had revealed that RAMSI was unable to generate increases in funding costs endogenously that were large enough to have a similar impact as the financial crisis. Therefore, we applied judgement, assuming costs would increase in line with the crisis.

The advantage of taking this approach to modelling the effect on bank funding costs was its simplicity. Estimating the change in funding costs that banks might experience during a stress of this type is a challenging task and our approach is clearly a rudimentary method and subject to a large degree of uncertainty.

3.6 Credit losses

Credit losses were the largest driver of the reduction in profits in the stress scenario relative to the baseline. Credit losses reduced profits by around £140 billion over the five years of the stress scenario — £50 billion more than in the baseline. However, as shown by **Chart 6**, much of this effect was slow to come through, with the peak impact of credit losses not coming until 2014. The lags in the transmission from

macroeconomic deterioration to banks' balance sheets reflect the fact that it takes time for borrowers to fall into distress following a shock to their income and that it takes banks some time to realise losses once borrowers have fallen into distress.

The increase in unemployment and household income gearing in the stress scenario, and the fall in property prices and GDP, led to higher default rates and, ultimately, credit losses on all exposures. But the impact was not uniform across exposure types. For example, **Chart 7** shows that the model-implied write-off rate on household residential lending increased significantly in the stress relative to the baseline, rising well above the 2009 peak in write-off rates. There is clearly uncertainty around the extent to which mortgage write-offs would increase in a stress scenario, but **Chart 7** suggests a cumulative write-off rate over the five years of the stress scenario of around 3% — more than double that seen over the period 2006–10.

Chart 7 UK household secured aggregate write-off rate in the FSAP[a]
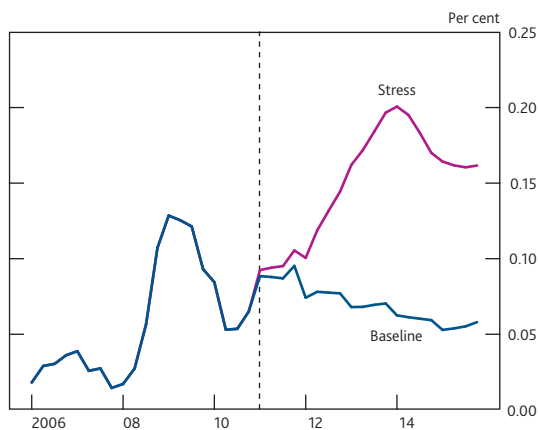
Source: Bank of England.

(a) Annualised quarterly write-offs divided by the corresponding loans outstanding at the end of the previous quarter. Data to the right of the dashed vertical line are projections.

The aggregate write-off rate on the non-financial corporate sector (**Chart 8**) also picked up in the stress and remained elevated throughout. And although the corporate write-off rate remained below rates seen in 2009 and 2010 (which were largely driven by lumpy write-offs by a subset of banks), the cumulative write-off rate for the five years of the stress was only slightly lower than that in the years 2006–10 (17% versus 18%).

3.7 Trading income

The largest impact on profits in the stress scenario over the first few years of the scenario came through trading income. The trading income element of the stress reduced profits by £45 billion over the first three years, with a £40 billion reduction in the first two years.

As with funding costs, it is difficult to project forward banks' trading income with any degree of precision, especially in

Chart 8 UK private non-financial corporate aggregate write-off rate in the FSAP[a]
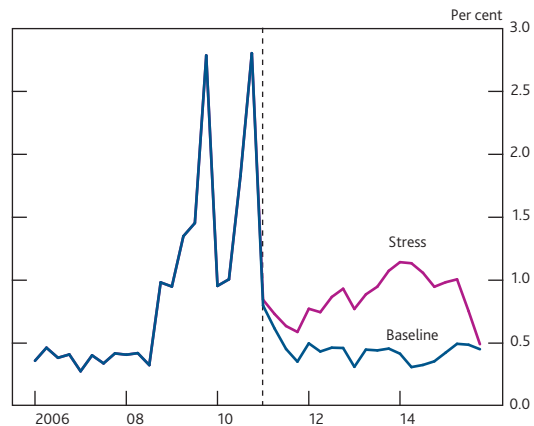
Source: Bank of England.

(a) Annualised quarterly write-offs divided by the corresponding loans outstanding at the end of the previous quarter. Data to the right of the dashed vertical line are projections.

top-down stress tests where detailed information on the composition of trading portfolios is unavailable. We followed the guidelines for the stress tests provided to banks by the IMF, which suggested that trading income 'should be aligned with GDP growth, based on historical data'. Trading income fell sharply during the recent recession and is calibrated in the adverse scenario based on this historical experience and the relative falls in GDP in the two episodes. Banks with large trading operations therefore suffered a material drain on trading income in the adverse scenario.

3.8 Other income and operating expenses

Other income and operating expenses both fell sharply in the stress test. Taken together, they do not greatly influence the results relative to the baseline. Other income fell in the stress scenario, in line with its historical procyclical relationship with GDP growth. But the impact on headline profits was muted by a related fall in operating expenses, which, as explained earlier, are themselves related to income. As a result, the ratio of other income to operating expenses remained at a similar level to the baseline.

3.9 Write-downs of debt holdings

The IMF required that the UK banks' holdings of: (i) sovereign; and (ii) bank debt, be written down through the application of 'haircuts' of a prescribed size. The impacts of the haircuts were estimated using the most recent data available at the time of the exercise, which were 2010 CEBS stress-test disclosure for sovereigns and BIS exposures data for bank debt holdings. These haircuts had a sizable impact on capital levels, with a reduction in aggregate profits of more than £20 billion relative to the baseline.

3.10 Capital ratios

The combined impact on these elements of income in the stress scenario pushed core Tier 1 capital ratios materially

lower relative to the baseline case (**Chart 9**). While capital did not fall sufficiently far at any bank to trigger the various crisis effects modelled in RAMSI — in which banks can be shut out of funding markets and/or forced to sell liquid assets, with knock-on effects for other banks — risk-weighted assets expanded at a slower pace than in the baseline scenario.

Chart 9 Aggregate core Tier 1 capital ratios: stress and baseline scenarios[a]
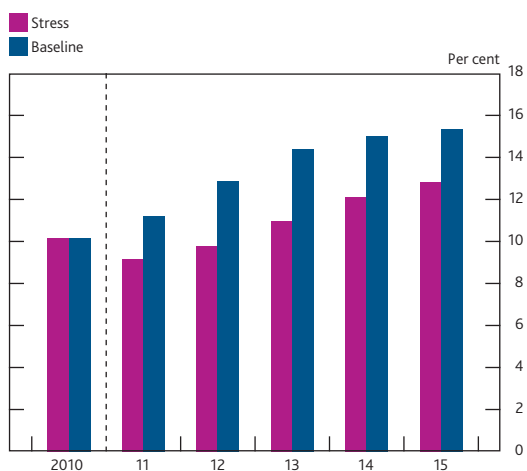
Sources: Published accounts and Bank calculations.

(a) Aggregate capital ratio defined as total core Tier 1 capital as a percentage of total risk-weighted assets. Expressed in Basel II terms. Data to the right of the dashed vertical line are projections.

Taken at face value the results suggested that the UK banking system would have been resilient to a severe macroeconomic downturn, such as that considered in the adverse scenario outlined by the IMF. However, the results are highly uncertain and were sensitive both to our top-down approach using RAMSI and to the particular assumptions used. In the next section we compare our results with the bottom-up component of the FSAP exercise as a cross-check on our results.

3.11 Comparison with the bottom-up results

As discussed earlier, despite the use of the same macroeconomic scenario, there are many reasons why stress-test results from top-down and bottom-up models will diverge. But comparing the two can be a useful exercise and shed light on whether one approach misses or overemphasises a particular source of risk.

The aggregate bottom-up and top-down results are compared in **Chart 10**. A notable difference is that the baseline core Tier 1 ratio projection was higher in RAMSI. It is difficult to identify exactly what drove this difference without reviewing the banks' models or having access to more detailed results. One possible cause is the assumption about risk-weighted growth.

Risk-weighted assets (RWAs) were assumed to grow in line with nominal GDP in the bottom-up tests, but were held flat

Chart 10 Aggregate core Tier 1 capital ratios: bottom-up and top-down baseline scenarios[a]
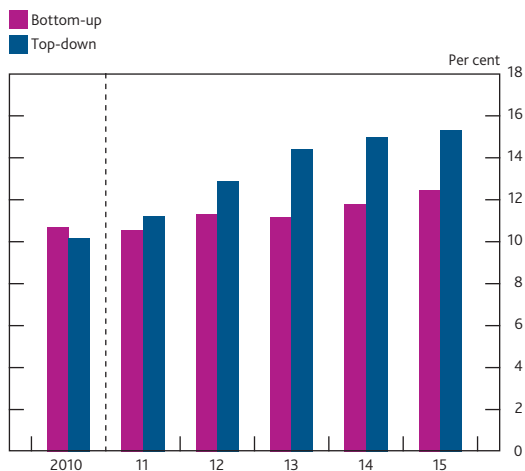
Sources: FSA, published accounts and Bank calculations.

(a) Aggregate capital ratio defined as total core Tier 1 capital as a percentage of total risk-weighted assets. Data to the right of the dashed vertical line are projections.

until capital targets were met in RAMSI. Higher RWA growth pushed down on the bottom-up capital ratios, and appears to explain a large part of the difference over the first three years of the stress.

In order to abstract from these differences, it is useful to consider the impact of the stress in terms of the change in capital ratio relative to the relevant baseline (**Chart 11**). In this case, the changes in capital ratio in the stresses look broadly similar — although the top-down RAMSI results are slightly larger, particularly in 2013. The difficulty is, of course, in knowing whether this similarity is due to the tests identifying the same risks and vulnerabilities facing UK banks, or is simply due to chance. This requires a detailed decomposition of the results across income categories. But overall, the similarity of

Chart 11 Impact of the stress scenario on aggregate core Tier 1 capital ratios: bottom-up and top-down results[a]
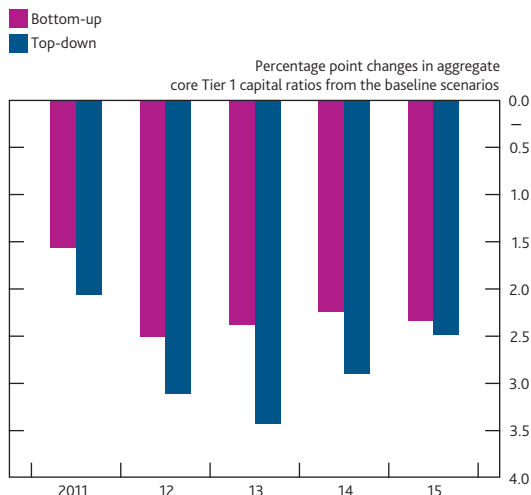

Sources: FSA, published accounts and Bank calculations.

(a) Aggregate capital ratio defined as total core Tier 1 capital as a percentage of total risk-weighted assets.

the stress-test impacts provides some reassurance regarding the results from each approach.

3.12 Identification of system-wide risks

The results in the top-down and bottom-up exercises were similar. As discussed previously, a benefit of top-down stress tests is that they offer a framework for understanding and identifying particular areas of vulnerability in the banking system as a whole.

The FSAP stress test highlighted several areas in which the UK banking sector might be vulnerable to specific shocks. One such risk to profitability is the potential for overreliance on wholesale funding. A prolonged period of higher funding costs could have a damaging impact on banks' aggregate profits.

In the second half of 2011, following the publication of the FSAP, banks' exposures to certain European sovereign debt came under strong scrutiny by financial markets. The FSAP exercise also identified that risk, with **Chart 6** highlighting just how significant the impact of haircuts on sovereign and bank debt would be.

In addition, our results suggest that (perhaps unsurprisingly) UK banks would see a marked increase in impairments following the global double-dip recession considered in the FSAP. But the exercise says less about how UK banks might fare in specific regional downturns. In future work, we intend to explore the consequences of severe downturns in Asia and South America.

4   Conclusion

Top-down stress testing is a way of assessing the resilience of the financial system and can help shed light on the vulnerabilities facing the system and the institutions within it. RAMSI is a top-down stress-testing model which has been developed at the Bank of England. The model allows us to consider the impacts of different macroeconomic stress scenarios on the UK financial system.

The RAMSI model was used as part of the 2011 IMF FSAP exercise, alongside bottom-up stress tests run by banks and other top-down stress tests run by the IMF. It is important to note that the FSAP was based on banks' balance sheets as they were at the end of 2010, and that the stress test was constructed in early 2011. As a result, the stress test described in this paper is not reflective of current conditions and the results do not take into account the changes in balance sheets, macroeconomic conditions or policy measures that have occurred since the time of the test. For example, the stress tests were carried out before the heightening of concerns, from the summer of 2011, about the sustainability of imbalances within the euro area. The scenarios and results are therefore not an assessment of the current state of the UK banking system but are used as an illustration of the types of outputs that RAMSI can produce.

The FSAP exercise tested the resilience of the UK banking system to a severe global downturn, which included large falls in output and in property prices. The results from the RAMSI model suggested that such a scenario would have had material impacts on UK banks' profits and capital ratios. In particular, the results highlighted the potential vulnerability of UK banks to wholesale funding market stresses and to substantial sovereign debt haircuts. But, despite these material impacts, the results suggested that the UK banking system was resilient enough to withstand the severe scenarios considered in the exercise. The results from RAMSI were consistent with the results from the other stress-test elements of the FSAP.

Going forward, we intend to develop RAMSI further to help us understand better the second-round effects that are the hallmarks of systemic crises. RAMSI already includes some prototype feedback mechanisms — for example, for funding liquidity feedbacks and asset fire sales — but we hope to improve these mechanisms as well as introducing macroeconomic feedback loops.

Appendix

This appendix contains the key equations in the RAMSI model. More technical details on the RAMSI model can be found in Aikman *et al* (2009).

(a) Credit losses

Bank-specific credit loss rate (UK)

$$CL_t^{b,i} = \alpha_t^{b,i} + \left(ACL_t^i - \overline{ACL_t^i} \right)$$

$$\alpha_t^{b,i} = \left(1 - \rho^b\right)\mu^{b,i} + \rho^b \alpha_{t-1}^{b,i}$$

where

i : asset class index (household secured, household unsecured, corporate, others)

$CL_t^{b,i}$: asset class i's credit loss rate of bank b

ACL_t^i : the aggregate credit loss rate of asset class i (derived below)

$\overline{ACL_t^i}$: the long-run average of ACL_t^i

$\alpha_0^{b,i}$: the actual write-off rate of bank b's asset class i

$\mu^{b,i}$: the historical average of $CL_t^{b,i}$

ρ^b : the bank b's speed of convergence to the historical average $\mu^{b,i}$

Aggregate credit loss rate (UK, household secured)

$$ACL_t^{h.sec} = -0.003 + 0.06 PD_{t-2}^{h.sec} - 0.02\left(\frac{P_t^{res.pr}}{P_{t-8}^{res.pr}} - 1 \right)$$

where

$PD_t^{h.sec}$: the probability of default of households' secured loans

$P_t^{res.pr}$: residential property price

Aggregate credit loss rate (UK, corporate)

$$ACL_t^{corp} = -0.49 + 1.21 PD_{t-2}^{corp} - 0.80\left(\frac{P_t^{comm.pr}}{P_{t-8}^{comm.pr}} - 1 \right)$$

where

PD_t^{corp} : the probability of default of corporates

$P_t^{comm.pr}$: commercial property price

Probability of default (UK, household secured)

$$PD_t^{h.sec} = 7.97 + 0.26 IG_{t-4} - 14.6 UEQ_{t-2} + 0.19 UNEMP_{t-2}$$

where

IG_t : income gearing

UEQ_t : undrawn equity

$UNEMP_t$: unemployment rate

Probability of default (UK, corporate)

$$PD_t^{corp} = 0.07 - 14.7\Delta\ln RGDP_{t-4} - 18.6\Delta\ln RGDP_{t-8}$$
$$- 5.34\Delta\ln P_{t-8}^{comm.pr} - 6.77\Delta\ln\left(\frac{M4L}{NGDP} \right)_{t-4} - 0.194 r_t^{corp}$$

where

$RGDP_t$: real GDP

$M4L$: M4 lending

$NGDP$: nominal GDP

r_t^{corp} : nominal effective corporate interest rate (estimated as a function of ten-year gilt yield)

(b) Net interest income (NII)

$$NII_t^b = \sum_i rl_t^{b,i} A_t^{b,i} - \sum_j rb_t^{b,j} L_t^{b,j}$$

where

NII_t^b : bank b's net interest income

$rl_t^{b,i}$: bank b's lending rate for asset class i

$rb_t^{b,j}$: bank b's borrowing rate for liability class j

$A_t^{b,i}$: bank b's amount of asset class i (loans and advances to customers)

$L_t^{b,j}$: bank b's amount of liability class j

$$rl_t^{b,i} = f\left(\left\{ r_\tau^f \right\}_t^{t+M}, \left\{ CL_\tau^{b,i} \right\}_t^{t+M} \right)$$

where

r_t^f : risk-free rate at time τ

M : the maturity of asset i

$$rb_t^{b,j} = Libor_t + sp\left(rating_t^b\right)$$

where

sp : ratings spread function, mapping bank b's credit rating to a funding spread

$rating$: ratings function, mapping variables such as the bank's profit and funding gap to ratings

(c) Non-interest income less trading (NIILT)

$$\frac{NIILT_t^b}{A_{t-1}^b} = \beta^b + 0.729 \frac{NIILT_{t-1}^b}{A_{t-2}^b} + 0.011\Delta\ln RGDP_t$$

$$\beta^b = \left(1 - 0.729\right)\overline{\frac{NIILT^b}{A_{t-2}^b}} - 0.011\overline{\Delta\ln RGDP}$$

where

$NIILT_t^b$: bank b's non-interest income (less trading income)

$\overline{NIILT^b}, \overline{\Delta\ln RGDP}$: long-run average of the variables

(d) Trading income (TI)

$$\frac{TI_t^b}{TA_{t-1}^b} = 0.007 + 0.5034\frac{TI_{t-1}^b}{TA_{t-2}^b} + 0.0202\frac{\Delta TA_t^b}{TA_{t-1}^b} + 0.2105\left(\Delta\ln EP_t\right)^2$$

where

TI_t^b :   bank b's trading income

TA_t^b :   bank b's net trading asset

EP_t :   world equity index

(e) Operating expenses (OPEX)

$$\frac{OPEX_t^b}{NIILT_t^b} = \gamma^b + 0.598\frac{OPEX_{t-1}^b}{NIILT_{t-1}^b} - 2.365\Delta\ln RGDP_t$$

$$\gamma^b = \left(1-0.598\right)\overline{\frac{OPEX^b}{NIILT^b}} + 2.365\overline{\Delta\ln RGDP}$$

where

$OPEX_t^b$:   bank b's operating expenses

$\overline{OPEX^b}$:   the long-run average of operating expenses

References

Aikman, D, Alessandri, P, Eklund, B, Gai, P, Kapadia, S, Martin, E, Mora, N, Sterne, G and Willison, M (2009), 'Funding liquidity risk in a quantitative model of systemic stability', *Bank of England Working Paper No. 372*.

Alessandri, P, Gai, P, Kapadia, S, Mora, N and Puhr, C (2009), 'Towards a framework for quantifying systemic stability', *International Journal of Central Banking*, Vol. 5(3), pages 47–81.

Alessandri, P and Nelson, B (2012), 'Simple banking: profitability and the yield curve', *Bank of England Working Paper No. 452*.

Borio, C, Drehmann, M and Tsatsaronis, K (2012), 'Stress-testing macro stress testing: does it live up to expectations?', *BIS Working Paper No. 369*.

Kapadia, S, Drehmann, M, Elliott, J and Sterne, G (2012), 'Liquidity risk, cash-flow constraints and systemic feedbacks', *Bank of England Working Paper No. 456*.