Macro stress tests of UK banks

Glenn Hoggarth, Andrew Logan and Lea Zicchino
Bank of England

1. Introduction

Stress testing the vulnerability of financial institutions to adverse macroeconomic events is an important tool in assessing financial stability. Central banks and financial regulators increasingly use this approach in calibrating the risks facing the financial system. A number of recent policy initiatives also aim to formalise a role for stress tests. One of these has been the inclusion of stress tests in the IMF Financial Sector Assessment Programmes (FSAPs). Stress testing is also important as part of Pillar 2 of the New Basel Accord. For example, with regard to the procyclicality debate, macro stress testing might give some indication of how the impact on bank capital during a recession would vary depending on the *type* of recession (eg whether it is consumer- or export-led).

This paper describes a number of approaches used in the financial stability area of the Bank of England to stress test banks and draws on our experience from last year, when stress tests were carried out as part of the IMF's FSAP on the United Kingdom. We also outline some of our future proposed work.

2. Possible approaches to stress tests

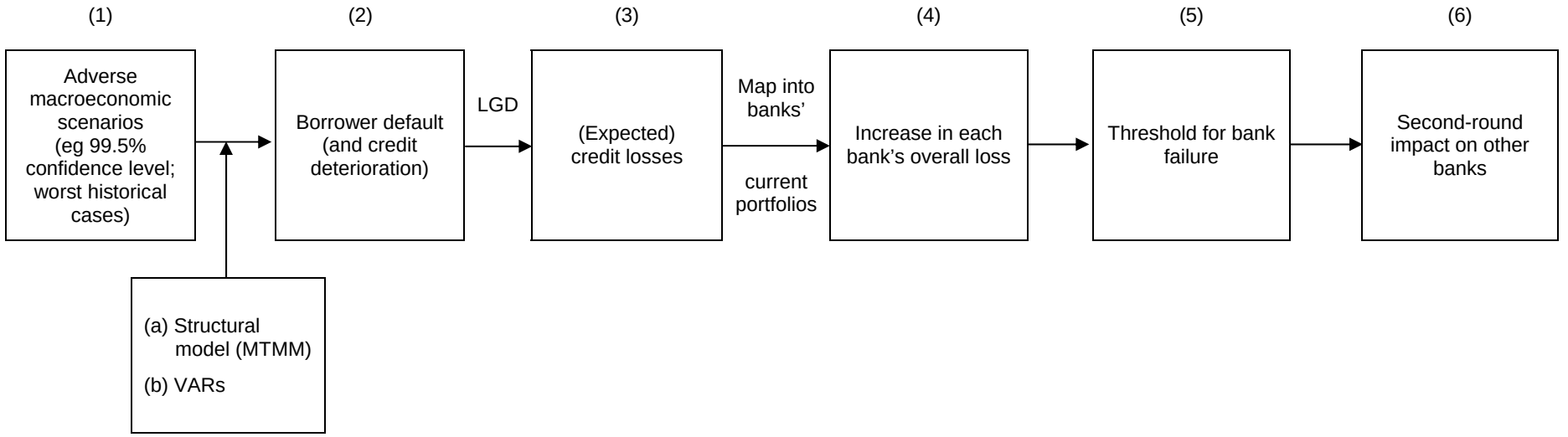
Stress tests involve a number of elements. These are illustrated in Figure 1. First, plausible and internally consistent but "challenging" macroeconomic scenarios or single factor sensitivity tests need to be devised to illustrate possible extreme downside risks - so-called "tail events" (Box (1)). Whereas the former assess the impact on credit risk of a combination of changes in macroeconomic variables, the latter focus on the change in one variable and assume that other variables remain unaffected. Second, these scenarios (or sensitivity tests) need to be mapped into measures of increases in credit default by loan type or borrower (Box (2)). Third, changes in borrower default need to be translated into bank credit losses, ie allowing for recoveries, by loan type (Box (3)).

In a "bottom-up" approach, each bank would estimate the increase in credit losses on its entire portfolio (allowing for the possibility that losses are interdependent). This was one of the approaches adopted in the FSAP exercise (see below and also Hoggarth and Whitley (2003)). Such an approach has the advantage of evaluating banks' portfolios at a detailed level of disaggregation. It also provides information on how banks themselves assess the likely impact of adverse events on the quality of their loan book. However, such estimates are not based on applying a consistent framework across banks and, in any case, would not be practical for the authorities to carry out on a frequent basis. An alternative approach is to adopt a "top-down" methodology. Here macroeconomic scenarios are linked to banks' aggregate sectoral losses.

The various approaches described below aim to estimate the impact of a variety of common macro shocks on the credit losses of the UK banking system (steps (1) to (3) in Figure 1). There are a number of approaches that can be used to carry out macroeconomic stress tests, and we have adopted an eclectic approach building upon the stress testing exercise conducted last year for the UK FSAP.

Figure 1

Framework for macro stress testing UK banks



UK FSAP:	bottom-up:			banks estimated their own losses - the major UK banks were given simulations from an extended version of the BoE's macroeconometric model (MTMM) 1(a). They gave us back (4), having done (2) and (3) themselves.
	top-down:	equations on banks' aggregate provisions	-	direct from MTMM simulations (1)(a) to (4) without intermediate steps.
	top-down sectoral:	equations on banks' sectoral write-offs	-	linking equations to an extended version of the MTMM (1(a)==>3)
		VAR model including sectoral write-offs	-	1(b)==>3

3. UK FSAP[1]

In the UK FSAP of 2002 we constructed specific macroeconomic scenarios derived using an extension of the Bank of England's then current Medium-Term Macroeconometric Model (MTMM). The outputs from these scenarios were supplied to 10 large UK banks as inputs to their own assessments (the "bottom-up" approach). The UK-owned institutions were asked to consider the effects on a consolidated basis. However, the results do not, in all cases, capture the impact on all their non-bank and foreign operations. The tests were conducted in spring 2002, and firms assessed the impact on their profit and loss account and regulatory capital during the first year (until March 2003) - compared with their own internal forecast or base line.[2]

The "bottom-up" results were returned to us and compared with our own analysis of the impact of the scenarios on UK banks (the "top-down" approach). The latter used aggregate reduced-form relationships linking changes in macroeconomic variables to banks' aggregate loan loss provisions.

The scenarios

Four scenarios were chosen in the UK FSAP exercise to include both domestic and global events, and shifts in both the demand for and supply of goods and services in the economy:

1. Decline of 35% in world and UK equity prices. The macroeconomic transmission is largely through household balance sheets, whereby lower household sector wealth reduces household consumption and hence aggregate GDP. But the impact on demand and output is partly offset by an easing in monetary policy in the United Kingdom and elsewhere. The main adverse consequences for the financial system are predicted to occur in the corporate sector, as a result of lower GDP and profits.

2. Decline of 12% in UK house and commercial property prices. Since housing accounts for one half of UK households' net worth, the personal sector's balance sheet deteriorates and UK household consumption is reduced. Output is lower than otherwise, but the adverse effect is a little smaller than under the first scenario. Similarly, the monetary authorities are assumed to respond by cutting UK interest rates. Nonetheless, the net effect is that mortgage arrears increase relative to base, even though they remain low by historical standards. Corporate sector income is expected to fall relative to base as a consequence of weaker aggregate demand, and capital gearing rises because of the decline in commercial property prices. This shock is expected mainly to hit banks with a high concentration of property loans.

3. A one and a half percentage points unanticipated increase in UK average earnings growth (reflecting a step increase in real reservation wages). This supply shock boosts personal incomes and consumption. But the transmission to higher inflation induces a rise in official interest rates. Overall there is a marginal decline in GDP compared with the base case. Both corporate and household sectors are adversely affected. Despite higher household incomes, there is a rise in income gearing, which implies an increase in household mortgage and credit card arrears. Corporate profits fall relative to base and corporate liquidations increase.

4. A 15% (initial) unanticipated depreciation in the trade-weighted sterling exchange rate. This results in higher inflation and, in response, nominal interest rates increase. Nonetheless, since wages and prices adjust only gradually, there is a temporary depreciation in the real exchange rate, which, in turn, boosts net export volumes. On balance, GDP growth is higher than otherwise. The corporate sector benefits from higher net exports, and profits rise relative to base, although aggregate corporate liquidations increase because of the increase in interest rates and therefore gearing. However, this scenario also hurts the household sector through the shift in the terms of trade and the rise in interest rates. Consequently, mortgage arrears increase substantially.

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[1] This section draws on Hoggarth and Whitley (2003).

[2] Some banks could not provide quantitative estimates beyond a one-year horizon.

The error variances from the equations in the Bank of England's MTMM were used in order to calibrate the initial shocks. The equations were estimated from 1987, so the conditional variances include the early 1990s recession. But this approach could not be applied for the shocks to the exchange rate and equity prices.[3] In these two cases, historical variances and peak-to-trough estimates were used.

In choosing the threshold probability for the shock to be regarded as a scenario worthy of analysis, a balance needs to be struck. On the one hand, if the probability were set too high - and thus the size of shocks too low - there would be little impact. Nothing would be learnt about how the banking system would fare in a period of stress. On the other hand, if the size of shocks were extremely large, there would be almost no possibility of the event occurring. The size of the events chosen broadly corresponds to an event three standard deviations away from the mean.[4]

All the scenarios were estimated relative to a base case that was broadly consistent with the central outlook underlying the Bank's Inflation Report for November 2001. The impact of the shocks was estimated over a 12-month period (2002 Q2 to 2003 Q1) to provide an internally consistent set of outcomes for key macroeconomic variables, as well as for components of corporate and household sector balance sheets. The alternative scenarios also assumed that UK monetary policy (interest rates) reacted to the shocks according to a Taylor rule, which sets interest rates as a function of inflation and the output gap.[5] The assumed policy responses were intended to be broadly consistent with an inflation targeting monetary policy regime (but they should not be interpreted as indicating how the Bank of England's Monetary Policy Committee would respond in practice). This assumption played an important role in the scenarios in stabilising some of the macroeconomic responses to the events.

Results

Bottom-up approach

Panel (i) in Table 1 shows the overall impact of the four scenarios on the UK-owned banks' P&L account, while Graph 1 shows details of the effects on individual banks.[6] Panels (ii) to (iv) in Table 1 show the impact of the scenarios as a percentage of the banks' annual operating profits (averaged over the previous three years), risk-weighted assets and Tier 1 capital, respectively.

Overall, the effects on UK banks were estimated to be quite small in all the scenarios. Aggregating across the major UK-owned banks, the adverse impact on profits varies from an average in scenario 1 (fall in world equity prices) of £432 million (23% of annual profits) to £146 million (6% of profits) in scenario 3 (rise in wage pressure). Looking at individual banks, only one was estimated to have suffered a loss of more than 50% of average annual profits (over the past three years) or 10% of Tier 1 capital. This happened in the first scenario (panels (b) and (c) in Graph 1): the marked fall in equity prices reduces profits in a range of activities - loans and trading income, and, in some cases, income on asset fund management and insurance business. Overall, the results suggest that under all scenarios the major UK banks would have a sufficient cushion in profits to absorb the shocks without depleting their capital. The size of the impacts (after allowing for tax) is also small in relation to UK-owned banks' risk-weighted assets - the biggest adverse impact, under scenario 1, is in the range of 0.12 to 0.56% of risk-weighted assets (1.5 to 10% of Tier 1 capital).

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[3] Although the macroeconomic model has rules of thumb for the determination of equity prices and the exchange rate, the equations do not have standard error distributions.

[4] Assuming a normal distribution, multiplying the standard deviation of the variable by 2.8 would imply a 5 in 1,000 occurrence (ie 99.5% confidence level) - suggesting an extreme but still plausible event. However, applying a normal distribution will understate the likelihood of extreme events if the tails of the distribution are fat.

[5] See Taylor (1993).

[6] The impact of the scenarios on the foreign-owned institutions are not reported since they only cover a part of their business and are therefore not estimated on a comparable basis.

Table 1

Impact of stress scenarios performed by major UK-owned banks on profits[1, 2]

(i) In millions of pounds sterling

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Mean	–432	–252	–146	–214
Median	–408	–195	–57	–81
Standard deviation	305	219	270	359

(ii) As a percentage of banks' annual pre-tax profits[3]

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Mean	–22.7	–15.0	–6.3	–1.8
Median	–18.4	–8.1	–6.1	–3.4
Standard deviation	21.2	18.1	8.3	18.4

(iii) As a percentage of (end-2001) risk-weighted assets

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Mean	–0.2	–0.2	–0.1	–0.1
Median	–0.2	–0.1	–0.1	–0.1
Standard deviation	0.2	0.1	0.1	0.2

(iv) As a percentage of (end-2001) Tier 1 capital

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Mean	–4.9	–2.9	–1.5	–1.5
Median	–4.4	–2.8	–1.2	–0.9
Standard deviation	3.3	2.2	2.1	3.6

[1] Negative implies stress test reduces profits, positive implies an increase in profits (relative to base). [2] On a group basis other than HSBC which relates to HSBC Bank. [3] Measured, on average, over previous three years.

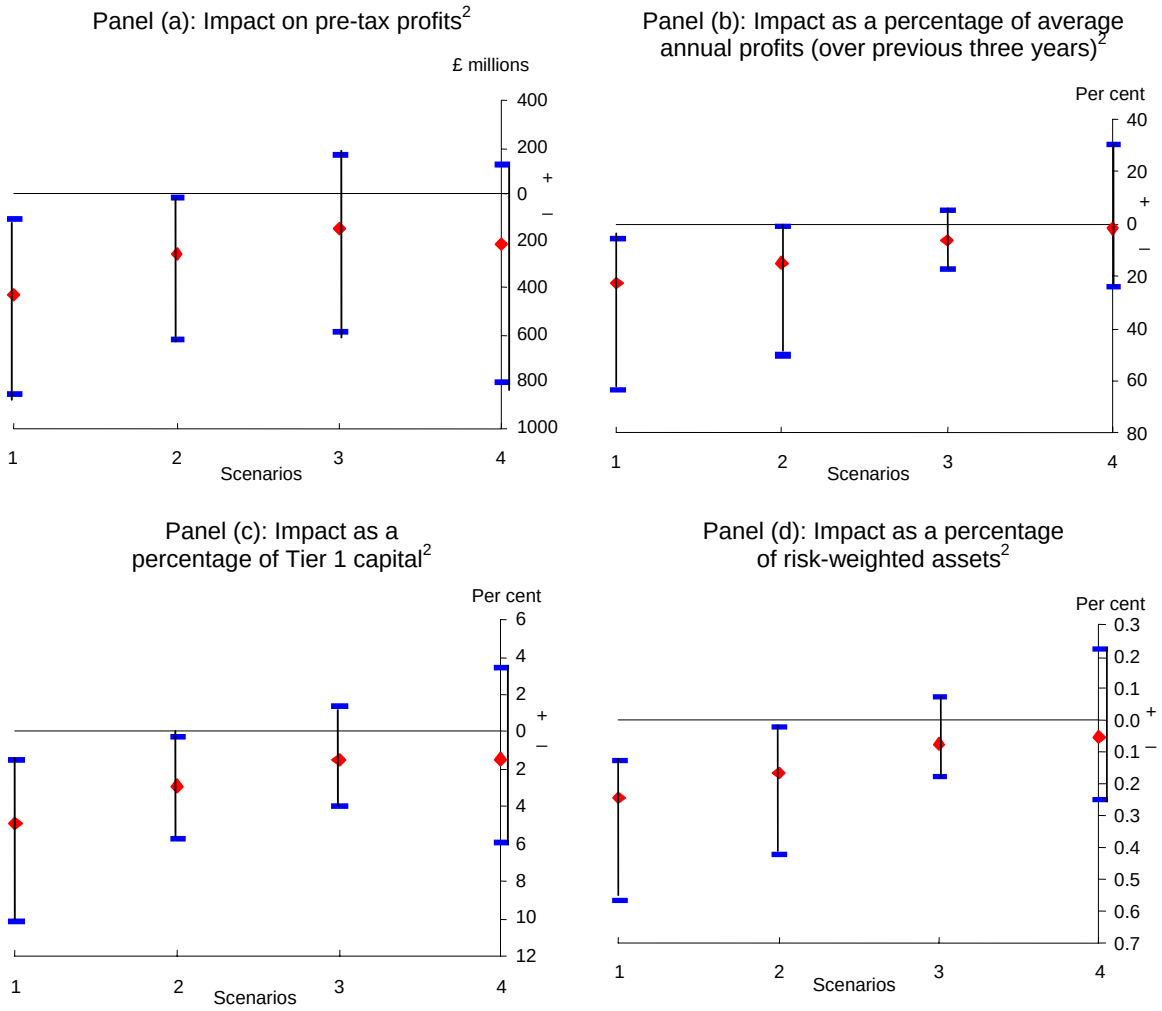
Source: Major UK-owned banks.

Aggregate top-down approach

As a complement to the stress test results provided by the large banks, as part of the FSAP we also estimated the effects on the provisions made against aggregate credit losses by the major UK-owned commercial banks measured on a consolidated basis using a single equation econometric model. These top-down simulations compared the model-based predictions for banks' new provisions charged against profits under each scenario relative to a base case.

Graph 1

Impact of stress scenarios[1] on UK-owned banks - bottom-up approach



[1] For any given scenario the rank ordering of banks varies across the four measures shown above. [2] The blue line represents the range across individual banks, the pink diamond shows the mean.

Source: Major UK-owned banks.

The econometric model for banks' provisions is a reduced form showing the relationship between key macroeconomic (and bank-specific) variables and banks' new provisions on their total loan book (see Pain (2003) for a further explanation). An advantage of this top-down approach is that the impact of the scenarios can be estimated beyond the one-year horizon.[7]

One of the preferred equations estimated using a small panel dataset on the UK bank is

$$\ln\frac{prF_{it}}{1-prF_{it}} = -6.3 - 0.07\Delta gdp_t - 0.08\Delta wgdp_t + 0.09\Delta RR_{t-1} + 0.04\Delta M4L_{it-3}$$
$$+ 0.04 propsh_{it-1} + 3.3 herf_{it-1} \qquad (1)$$

$$\bar{R}^2 = 0.75$$

[7] However, a potential disadvantage of this approach is that it is based on the average historical relationships rather than on the impact on banks' current loan portfolios.

where:

- *prF* is the new provisions charge against profits relative to loans and advances
- Δgdp is annual growth in real GDP
- $\Delta wgdp$ is annual growth in world real GDP
- ΔRR is a measure of ex post real interest rates based on base rates and the GDP deflator
- $\Delta M4L$ is the annual growth in M4 lending
- *propsh* is the share of total (sterling) lending to domestic commercial property companies
- *herf* is the Herfindahl measure of concentration of the domestic (sterling) loan portfolio
- Δgdp is significant at the 5% level, all other variables significant at the 1% level

Using the equation, the impact of a shock was calculated as the difference between the "shocked" value and a base case.

Table 2 summarises the average impact on provisions for the top-down simulations for those UK-owned commercial banks that also provided individual bottom-up estimates for the effects on provisions.

As in the case of the bottom-up approach, the largest effect on UK banks' provisions occurs in scenario 1: the 35% fall in world equity prices. Under this scenario, reductions in two of the key macroeconomic variables in equation (1) - UK and world GDP growth - increase the new provisions charge, more than offsetting the impact of lower real interest rates.

Overall, the top-down simulations also suggest that the likely increases in credit losses arising under all scenarios are quite small - all scenarios would result in an increase in banks' new provisions charges, both in the first year and cumulatively after three years, of less than £200 million on average (less than 10% of annual profits or 2% of Tier 1 capital).

4. Sectoral top-down approach

One drawback with the top-down approach used in the FSAP is that provisions are only available on UK banks' ***total*** loan book. Actual write-offs (losses) on loans to UK residents, on the other hand, are available at a (broad) sectoral level on a quarterly basis back to the early 1990s (Graph 2).[8] These more disaggregated data can be used to assess the impact of adverse shocks on different components of banks' loan portfolios. Bank write-offs relate to the losses (net of recoveries) made by UK-owned banks on loans initiated from their UK-resident banking operations.[9]

Two approaches have been adopted to stress testing banks' sectoral write-offs: (1) we have integrated sectoral write-offs with a version of the Bank's extended Medium-Term Macroeconometric Model (see Benito et al (2001) for details of the latter); and (2) we have included sectoral write-offs in a small VAR model.

[8] Quarterly data at a sectoral level (households, corporates, etc) are not reported for all banks. For banks that only report annual sectoral data, the quarterly data have been derived by applying the annual sectoral shares to the aggregate quarterly data.

[9] Therefore, the data exclude losses made by overseas branches and subsidiaries of UK-owned banks and losses made by domestically located non-bank businesses.

Table 2

Potential impact of stress test scenarios on UK commercial banks' provisions charge against profit[1]

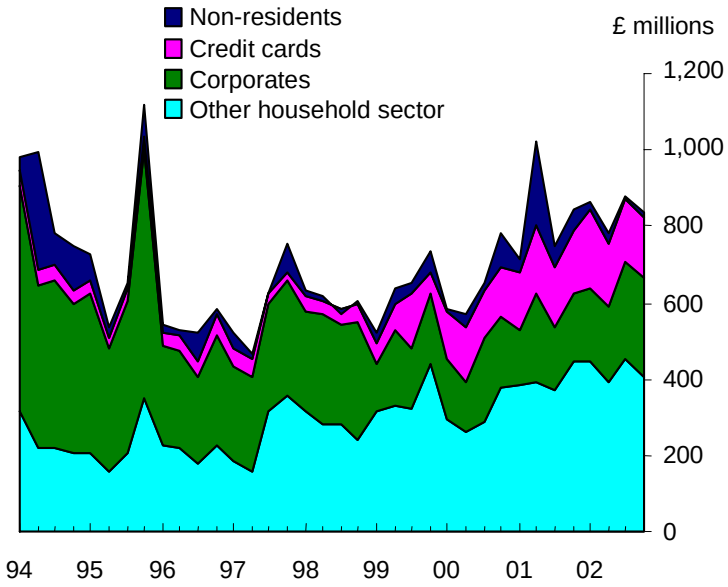
	Scenario 1			Scenario 2			Scenario 3			Scenario 4		
	£m	% of profits[2]	% of Tier 1 capital[3]	£m	% of profits[2]	% of Tier 1 capital[3]	£m	% of profits[2]	% of Tier 1 capital[3]	£m	% of profits[2]	% of Tier 1 capital[3]
First year												
Mean	–172	–5.7	–1.6	–47	–1.6	–0.4	–4	–0.1	0.0	–31	1.0	0.3
Median	–182	–6.1	–1.6	–50	–1.7	–0.4	–4	–0.1	0.0	–32	1.1	0.3
Standard deviation	39	0.8	0.3	11	0.2	–0.1	1	0.0	0.0	7	0.1	0.0
After three years[4]												
Mean	–130	–4.3	–1.2	–3	–0.1	0.0	–53	–1.8	–0.5	–110	–3.7	–1.0
Median	–138	–4.6	–1.2	–4	–0.1	0.0	–56	–1.9	–0.5	–116	–3.9	–1.0
Standard deviation	29	0.6	0.2	6	0.0	0.0	12	0.2	–0.1	25	0.5	0.2

[1] A negative sign means a decrease in profits, a positive sign an increase in profits. Banks were Barclays, Lloyds TSB, HSBC and Royal Bank of Scotland. [2] Percentage of previous three years' annual profits. [3] End-2001 Tier 1 capital. [4] Cumulative impact. Assumes that the key macroeconomic variables return to base by 2004 Q4.

Source: Bank of England calculations.

Graph 2

UK-owned banks' write-offs[1]

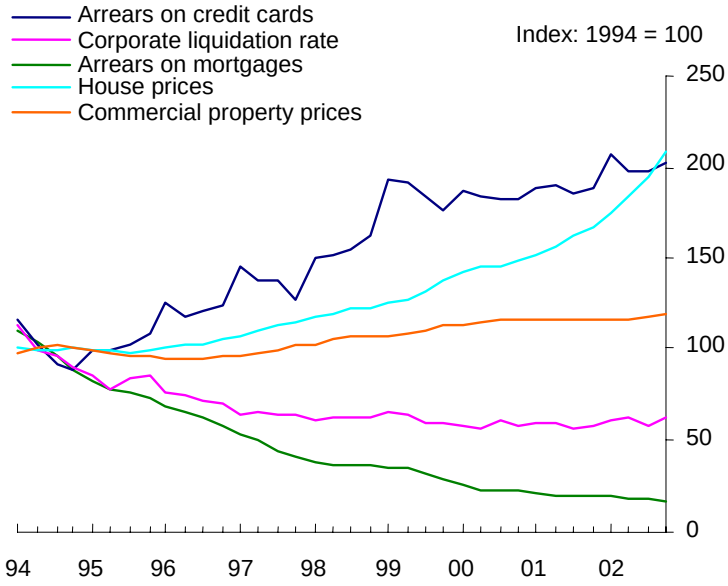


[1] Corporates include both financial and non-financial companies. Other household sector includes unincorporated businesses and non-profit organisations.

Source: Bank of England.

Graph 3

Sectoral delinquency rates and asset prices



Source: Bank of England.

A Extending the Medium-Term Macroeconometric Model (MTMM) for sectoral write-offs

The aim here is to extend the Bank's MTMM to include equations for sectoral write-offs. Only variables that are currently available in the MTMM are used to ensure that the impact of any initial shock can be traced through using an internally consistent scenario.

Bank losses$_i$ = p_i*lgd$_i$*loans$_i$

where *i* refers to the sector, *p* is the probability of default and lgd is the percentage written off given default (ie 1 minus the recovery rate). Rearranging then

bank losses$_i$/loans$_i$ ≡ write-off rate$_i$ = p_i*lgd$_i$

Actual sectoral defaults or credit deteriorations are used to proxy p_i. There are no UK data on lgd/recovery rates, so we use variables that are likely to ***affect*** the recovery rate, in particular sectoral asset values. So the modelling strategy is:

write-off rate$_i$ = *f*(default proxy$_i$, recovery rate proxy$_i$)

In the ***corporate*** sector, default is proxied by the corporate liquidation rate (the number of insolvencies in the period/number of registered firms). In turn, in the MTMM the corporate liquidation rate depends positively on corporate income gearing, changes in real interest rates and changes in net corporate debt/GDP and negatively on the growth in UK output and commercial property prices. The recovery rate is proxied by commercial property prices.

For the ***household*** sector, the proportion of credit card debt in arrears is used as the default proxy in the equation for credit card write-offs. The recovery rate is assumed to be zero. Credit card arrears, in turn, depend on household income gearing and the number of active credit card balances. As discussed in Cox et al (2004), the latter is used as a proxy for supply side influences such as UK banks' recent move down the credit quality spectrum, the adoption of more aggressive marketing techniques and generally the increase of competition in the UK credit card market during the past decade.

There is no further breakdown of household write-offs by loan type available on a consistent basis back to the first half of the 1990s, implying that non-credit card household write-offs ("other household sector") include write-offs on both secured debt (ie housing loans) and unsecured consumer debt (other than credit cards). Therefore, both mortgage and consumer credit arrears are included in the equation for other household sector write-offs to capture the likelihood of default. In the MTMM, in turn, mortgage arrears depend positively on mortgage income gearing and unemployment and negatively on undrawn housing equity and the loan-to-value (LTV) ratio of first-time buyers (as a proxy for the credit risk of new borrowers).[10]

House prices were included in the initial specification for other household sector write-offs to capture the impact of changes in loss-given-default on mortgage debt but were not found to be statistically significant. This may be attributable to house prices and mortgage arrears being dependent on the same factors. So that in periods when mortgage defaults decline, house prices increase. As seen from Graph 3, mortgage arrears have been on a steep downward trend since the early 1990s while over the same period house prices have been on a steep upward trend.[11] Therefore, the impact of mortgage arrears on other household write-offs may not only be capturing the impact of changes in default but also changes in loss-given-default.

Results

The equations linking variables of sectoral fragility to bank write-offs are shown in Table 3. All variables enter contemporaneously, other than credit card arrears, which have a four-quarter lag. This suggests that as households become fragile, they first delay paying their consumer debt and only later

[10] Cox et al (2004) argue that banks undertake high LTV mortgage lending with customers they judge to be of high credit quality.

[11] The simple correlation coefficient between house prices and mortgage arrears over the period is –0.81.

their mortgage debt.[12] These simple equations seem to explain past movements in bank write-offs quite well, especially on corporate and other household loans (panels (a) to (c) in Graph 4). The equations capture the steady decline in corporate write-off rates throughout the past decade, the gentler decline in other household write-offs and, to some extent, the initial decline and then rise over the past five years in credit card write-offs.[13]

Table 3

Sectoral write-off rate linking equations, 1994 Q1 to 2002 Q4

Explanatory variables	Corporate sector	Household sector	
		Credit cards	Other
Corporate liquidation rate$_t$	1.275 (0.00)		
Commercial property prices$_t$	–0.002 (0.00)		
Mortgage arrears$_t$			0.038 (0.00)
Credit card arrears$_{t-4}$		1.133 (0.00)	0.107 (0.00)
1995 Q4 dummy	0.207 (0.00)		0.075 (0.00)
R-bar squared	0.94	0.59	0.80
DW	1.5	1.4	2.0
Number of observations	36	36	36

Note: Corporates include both non-financial and financial companies. Other household sector consists of secured household, unsecured household (other than credit cards), unincorporated businesses and non-profit organisations. Corporate liquidation rate is the number of corporate insolvencies as a percentage of the number of registered companies. Mortgage arrears are the number of mortgage arrears more than six months as a percentage of the number of mortgages outstanding. Credit card arrears are the value of credit card balances in arrears by more than three months as a percentage of the value of all credit card balances.

p-values in parenthesis. All variables are significant at the 1% level.

The sectoral linking equations can only be estimated from 1993, since when sectoral write-off data have been available. However, the equations explaining the default proxies are estimated back to the late 1980s. This implies that the scenarios for sectoral defaults, at least, are based on relationships that include the last boom and bust in the United Kingdom in the late 1980s/early 1990s.

We then repeated the four scenarios used in the FSAP and traced through the impact on banks' sectoral write-offs. The results are shown in Table 4 below.

As seen in Table 4, again the impact on banks' balance sheets is estimated to be quite small. None of the scenarios results in write-offs increasing (relative to base) in the first year or cumulatively after three years by more than 2% of the banking system's Tier 1 capital. However, there are differences across the scenarios. Since income gearing is an important determinant of sectoral default, particularly for the household sector, the assumed interest rate response has an important impact on write-offs in the simulations.

[12] It may also partly reflect differences in the definition of when a late payment is categorised as an arrear. For mortgages the variable is measured as arrears of more than six months, and for credit cards it is arrears of three months or more.

[13] However, credit card arrears seem to overstate credit card write-offs somewhat in 1997-98 and understate them in 2001.

Graph 4

Sectoral write-off rate linking equations - actual vs fitted

[1] Financial and non-financial companies. [2] Non-credit card household plus unincorporated businesses and non-profit making organisations.

Source: Bank of England.

Monetary policy is assumed to ease in response to the sharp fall in equity and property prices (scenarios 1 and 2 respectively). The consequent fall in household income gearing implies that the net effect is to ***reduce*** household sector write-offs albeit slightly. In scenario 2, although mortgage arrears (and thus implicitly mortgage write-offs) rise relative to base, this is more than offset by an implied reduction in (non-credit card) unsecured write-offs due to the fall in household income gearing. However, corporate sector write-offs increase in both these scenarios despite a decline in corporate income gearing. This is partly attributable to the initial fall in output growth (relative to base). Also in scenario 2, the large fall in commercial property prices increases both corporate liquidations and loss-given-default.

In contrast, scenarios 3 and 4 - an increase in earnings growth and a depreciation of sterling respectively - lead to higher inflation, which is met by a tightening of monetary policy. Under both scenarios, there is a rise in households' income gearing - interest payments increase and disposable incomes fall. The impact of sterling depreciation (scenario 4) on the fragility of the corporate sector is

partially offset by an increase in export volumes and output (relative to base) over the simulation period. Consequently, in this scenario the write-off rate for companies rises by less than for households.

Table 4

Impact of stress test scenarios on UK banks' sectoral write-offs[1]

(a) First year

Sector	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	£m	% of Tier 1 capital	£m	% of Tier 1 capital	£m	% of Tier 1 capital	£m	% of Tier 1 capital
Corporates	115	0.1	545	0.5	40	0.0	125	0.1
Credit cards	0	0.0	0	0.0	0	0.0	0	0
Other household sector	–15	0.0	20	0.0	0	0.0	90	0.1
Total	100	0.1	565	0.5	40	0.0	215	0.2

(b) After three years[2]

Sector	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	£m	% of Tier 1 capital	£m	% of Tier 1 capital	£m	% of Tier 1 capital	£m	% of Tier 1 capital
Corporates	270	0.3	1,845	1.8	930	0.9	470	0.5
Credit cards	–105	–0.1	–70	–0.1	115	0.1	250	0.2
Other household sector	–350	–0.4	–50	–0.1	465	0.5	1,050	1.0
Total	–185	–0.2	1,725	1.6	1,510	1.5	1,770	1.7

[1] A positive sign implies an increase in write-offs, a negative sign a reduction in write-offs compared with the base case.
[2] Cumulative impact. Assumes that the key macroeconomic variables return to base by 2004 Q4.

B VAR approach

We also adopted another approach to derive the scenarios and to apply the shocks directly to UK banks' actual losses (write-offs). We produced a vector autoregressive (VAR) model consisting of a limited number of macroeconomic variables and bank write-offs.

The choice of macroeconomic variables included in the VAR was motivated by the existing literature on reduced-form macro models, for example Blake and Westaway (1996), Ball (1998) and Batini and Haldane (1999). So the VAR consisted of UK output (relative to a simple trend), nominal short-term interest rate, the real exchange rate, the annual RPIX inflation rate and banks' write-off rate (net write-offs divided by the value of loans outstanding).

Since quarterly data on bank write-offs are available only from 1993 Q1, the data period covers only the recovery phase of the early 1990s economic cycle. It also implies that some of our variables show little variation over the period - in particular retail price inflation and the banks' base rate, which have

remained in a relatively narrow range of between 1.75 and 3.5% per annum and between 4 and 7.5% respectively over the past decade. We experimented with including house price inflation in the VAR since it shows more movement over the past decade and might be expected to affect bank write-offs. As a check on our results, we also used annual data on the main UK banks' consolidated published accounts to derive aggregate banking system data back to 1988 (ie to capture the economic downturn). Our data are spliced in 1993 Q1, and the annual data before 1993 are interpolated onto a quarterly basis.

We tested for stationarity using the augmented Dickey-Fuller (ADF) test. Though the tests were not always able to reject a unit root at the 10% level, the *p*-values were never far from 10%. Given that it is well known that the ADF test suffers from low power and we expect that the series should be mean-reverting, we treat them as such.

In order to ensure that the shocks are uncorrelated, we applied a Cholesky decomposition (with a degrees-of-freedom correction). The variables in the model were ordered in ascendance according to the likely speed of reaction to any particular shock. Variables at the front end of the VAR are assumed to affect the following variables contemporaneously but only to be affected themselves by shocks to the other variables after a lag. Variables at the bottom of the VAR, on the other hand, only affect the preceding variables after a lag but are affected themselves immediately. The financial variables - interest rates and the exchange rate[14] - were ordered at the bottom of the VAR, implying that they react instantaneously to shocks in the real-side variables, whereas the other variables react only after a lag following shocks to the financial variables. Output was ordered after write-offs, reflecting priors that the economic cycle affects bank losses in the United Kingdom only after a lag (Hoggarth and Pain (2002)).

In principle, inference in VAR models is sensitive to the choice of lag length based on the different information criteria and appropriate lag length can be critical. If a large number of lags is included, degrees of freedom are eroded. If the lag length is too small, important lag dependencies may be omitted. We used both the Akaike and the Schwarz information criteria to set the lag length equal to 2 for all the various specifications reported below.

Results

Using post-1993 data, none of the shocks had a statistically significant impact at the 95% confidence level on write-offs either in the basic aggregate VAR or where house prices are included. As mentioned above, this might reflect a lack of variation in a number of the variables. However, once the estimation period is taken back to 1988, then some shocks have a statistically significant impact. In particular, shocks to output always had a negative and statistically significant impact on write-offs.[15]

In the sectoral VAR for private non-financial companies (PNFCs) we also included PNFCs' income and capital gearing,[16] in addition to the macroeconomic variables discussed above, since, as discussed earlier, there is evidence that these types of financial variables also affect corporate liquidations in the United Kingdom. The maximum impact seems to occur more quickly than suggested by the VAR including aggregate write-offs - after nine months for changes in output (relative to trend) and six months for changes in interest rates.

But in both the aggregate and the corporate VARs, the economic impact was quite modest - the impact of a 1% adverse shock to output on write-offs never exceeded 2% of Tier 1 capital.

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[14] Although the real exchange rate is included in the VAR, short-term movements are driven by the nominal exchange rate.

[15] We also experimented with including world output in the VAR, since it was found important by Pain (2003) in affecting UK bank provisions. But this variable did not have a significant impact on write-offs. One reason that may explain the different result is that provisions data relate to the consolidated entity, including overseas branches and subsidiaries, whereas the (post-1993) write-off data relate only to the UK-based operations. The latter are likely to be less affected by adverse shocks abroad.

[16] Income gearing is defined as interest payments as a percentage of PNFC pre-tax profit and capital gearing is PNFCs' net debt as a percentage of net debt plus net equity.

5. Why do the stress tests not have a bigger impact on UK banks' balance sheets?

One factor helping to explain the small size of the effects is the higher quality of UK banks' loan books than in the late 1980s. Over the past decade, there has been a widespread decline in the ratio of "risk-weighted" assets (used by regulators to calculate capital requirements) to total assets and an increase in geographical asset diversification. Also, aggregate sectoral data on domestic loans suggest that the composition of the large UK-owned banks' retail loan book has shifted away from riskier unsecured lending to relatively safer mortgage lending over the past decade.[17] And within the mortgage market, loan-to-value ratios (LTVs) are now much lower than in the late 1980s. For example, the proportion of UK banks' new mortgages with LTVs over 90% has fallen since the mid-1990s, from almost 50% to below 30%.[18] Consequently, it would probably take a marked decline in house prices to cause a significant increase in losses on housing loans. UK banks' corporate loan portfolios also appear to be of a relatively high quality. Estimates indicate that almost half of major UK banks' corporate exposures have internal ratings equivalent to A or above.

Second, the impact of the scenarios used in the "bottom-up" approach in the FSAP was estimated only over a one-year horizon. In practice, it takes longer than one year for the full impact of the shock to work through. Some of the defaults caused by an overall credit deterioration will not occur until later years. One bank extended the simulations beyond the one-year horizon. This analysis suggested that its provisions for retail credit losses could be on average six times higher in the second year than in the first. And, as a rough ready reckoner, another bank suggested that the peak effect on retail provisions was around three times the first-year effect and was likely to occur three years after the initial shock.

Also, in the MTMM scenarios at least, the policy reaction tempers the impact of two of the shocks (scenarios 1 and 2). Monetary policy is assumed to adjust partly to *offset* declines in output as well as rises in inflation (given the Taylor reaction function). So, for example, the decline in house prices is followed by a reduction in interest rates that moderates the impact on output, and thus on corporate liquidations and housing arrears. The large losses that UK banks incurred following asset price deflation in the early 1990s were accompanied by a sharp *increase* in nominal interest rates, and hence income gearing. In consequence, output fell substantially and liquidations and arrears rose sharply.

The analysis also ignores how banks and their creditors, including other banks, would react faced with a weakened bank. Although individual bank actions might be designed to reduce potential losses, the collective results might intensify economic stress - through a credit crunch, for example - and weaken banks' positions further. In extremis, if the shock were big enough to cause the failure of a large bank, this might have a direct impact on the capital, or even solvency, of other (counterparty) banks.[19] Wells (2002) provides the back end of this analysis through estimating the impact via the interbank market of a single bank failure on other banks. But this analysis assumes implicitly that the initial shock is specific to a particular bank.

It might also be the case that in order to maintain a high credit rating and to have access to interbank funding, the large UK banks hold capital in case of more extreme events than are considered here (Jackson et al (2002)).

6. Extensions and future work

The above top-down analysis focuses on the impact of adverse macroeconomic scenarios on the UK banking system as a whole. One planned extension is to compare the impact across the major UK banks at a bank by bank level. The size of the impact on any individual bank will depend on both

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[17] These changes reflect the impact of demutualisation as well as shifts in banks' portfolios.

[18] See Bank of England (2002), Part III.

[19] See Elsinger et al (2002) and Wells (2002).

the composition and quality of its portfolio (Box (4) in Figure 1) and the amount of capital it has to withstand the shock (Box (5)). An important aspect of the latter will be to assess the threshold beyond which a decline in capital would be likely to result in a bank "failure". This top-down analysis could also be bolted onto the interlinkages work to estimate the second-round effects of a bank failure on other banks (step (6) in Figure 1). The impact on sectoral losses discussed above focused on loans to UK residents. This analysis could be extended to include loans to non-residents.

The above approach has concentrated on accounting measures of bank losses. We also plan to complement this work through estimating the impact of adverse macroeconomic shocks on financial market measures of credit losses. This analysis will involve first generating macroeconomic scenarios either from the Bank of England's macroeconomic model or from a more parsimonious VAR model. The macroeconomic variables from this first stage will be included together with industry-specific (and firm-specific) variables in a model to explain firm equity returns.[20] The forecast equity returns will then be plugged into a Merton model to provide estimates of the conditional probability of default for each firm. The final stage will be to use information on loss-given-default and the pattern of banks' corporate exposures to generate projected bank-specific losses for different adverse macroeconomic scenarios.

7. Conclusions

We have carried out a range of stress tests on the UK banking system using a number of approaches building upon the analysis carried out as part of the UK FSAP. The estimated potential losses in no case exceeded annual profits or represented a large fraction of banks' capital. However, some caution needs to be exercised with these results.

The results are likely to be sensitive to the nature and specification of the macroeconomic stress tests. The size of the shocks is based largely on historical experience averaged over normal times and periods of stress, rather than taken from stress periods alone. The latter, by definition, occur infrequently and may be conditioned by the precise circumstances at the time. There may be sharp discontinuities in economic behaviour and relationships in crisis periods. The analysis also ignores how banks and their creditors, including other banks, would react faced with a weakened bank. Although individual bank actions might be designed to reduce potential losses, the collective results might intensify economic stress - through a credit crunch, for example - and weaken banks' positions further. It might also be the case that banks set capital as an insurance against more extreme events than have been considered here.

An important factor explaining the relatively modest impact of some of the scenarios derived from the MTMM on UK banks' profits is the assumed monetary policy reaction in response to a change in the outlook for inflation. Although the particular numerical results may depend on the precise specification of the interest rate reaction rule, to the extent that inflation targeting serves to stabilise some of the macroeconomic responses to unanticipated shocks, it will have beneficial implications for the stability of the UK financial system.

Overall, these estimates suggest that the stability of UK banks is unlikely to be threatened by a range of plausible adverse shocks, especially given that most UK banks are currently very profitable by international standards and have capital ratios well in excess of the regulatory minimum. Nonetheless, this exercise emphasises the importance for the authorities, and for banks themselves, of continuing to develop quantitative techniques which can be used to assess the resilience of the financial system to potential shocks.

[20] Pesaran et al (2003) adopt a similar approach. They use a global VAR in combination with an equity returns equation to produce estimates of defaults for 119 firms worldwide.

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