Financial Stability Paper No. 2 – April 2007

A new approach to assessing risks to financial stability

Andrew Haldane, Simon Hall and Silvia Pezzini

BANK OF ENGLAND

BANK OF ENGLAND

Financial Stability Paper No. 2 – April 2007

A new approach to assessing risks to financial stability

Andrew Haldane, Simon Hall and Silvia Pezzini

This paper reflects substantive inputs from a number of contributors. In particular, the Annexes are authored by Nick Vause, Glenn Hoggarth, Alistair Barr, Robert Hamilton, Colin Miles, Tom Belsham, David England and Garreth Rule. We are also grateful for contributions, comments and suggestions from Andrew Bailey, Tom Belsham, Simon Brennan, Peter Brierley, Victoria Cleland, Geoffrey Coppins, Matthew Corder, Mathias Drehmann, Philip Evans, Prasanna Gai, Nigel Jenkinson, Sujit Kapadia and Rain Newton-Smith.

andy.haldane@bankofengland.co.uk
simon.hall@bankofengland.co.uk
silvia.pezzini@bankofengland.co.uk
Financial Stability, Bank of England, Threadneedle Street, London, EC2R 8AH

The views expressed in this paper are those of the authors, and are not necessarily those of the Bank of England. This paper was finalised on 10 April 2007.

ISSN 1754–4262

Contents

A new approach to assessing risks to financial stability

Andrew Haldane, Simon Hall and Silvia Pezzini

The Bank's July 2006 *Financial Stability Report* (*FSR*) included a new approach to assessing risks to the stability of the UK financial system. This paper explains the methodology and analysis behind this work and outlines what is being done to improve and extend it. Section 1 of the paper sets out the conceptual rationale for this approach. Section 2 describes its practical implementation in the July 2006 *FSR*, with further detail on methodology provided in a series of annexes. Section 3 concludes by discussing how this framework is being developed over time to improve the analysis of risks to the UK financial system and to strengthen the management of these risks by the financial sector.

1 A new approach to risk assessment

The Bank of England's July 2006 *Financial Stability Report* (*FSR*) included a significantly changed presentation of its assessment of risks to the UK financial system.(1) Some of the key changes were:

- a focus on a small number of key vulnerabilities in the UK financial system;
- a systematic and analytical approach to assessing these vulnerabilities, including a broad-based attempt to assess their materiality in terms of probability and impact; and
- an assessment of actions that might be undertaken to mitigate their potential impact.

This paper explains the rationale for these changes and the way in which they were implemented.

Unlike with monetary policy, non-supervisory central banks — such as the Bank of England — have few direct policy levers to achieve their financial stability objectives. That means that indirect tools, such as external communication about existing and potential future risks to financial stability, have a particularly important role. This communication can be an important public good, in particular by serving as a means of focusing efforts by the private sector and the public authorities to mitigate the key risks. The perceived benefits of such communication are evident in the increase in recent years in the number of publications on financial stability by central banks and other financial authorities.(2)

An important element in communication on financial stability is clarity about its objectives. While the allocation of official sector responsibilities in the United Kingdom for maintaining financial stability is clearly set out in the tripartite Memorandum of Understanding between the Bank, FSA and HMT, there is no specific statement about how the stability of the system as a whole is defined and assessed.(3) This issue of defining financial stability has been an active area of debate for some years.(4) This paper does not take a stand on this definitional question. Instead it focuses on setting out an approach for improving our understanding of how stress can affect the financial system and for assessing the overall impact of such stress events.

Both the private and public sectors are interested in this 'financial stability transmission mechanism' and in measuring the impact of shocks on the financial sector. Financial institutions (and their supervisors) wish to gauge the scale of potential stress events when assessing the adequacy of their loss absorption capacity. Those in the public sector with responsibility for maintaining financial stability will be particularly interested in impacts that may lead to significant impairment of the ability of the financial system to provide its normal level of services to the real economy. Public intervention — *ex ante* to help avert such events and/or *ex post* to facilitate their management — may be aimed at reducing the potentially large costs associated with such episodes. The public sector is likely to be particularly concerned when the private sector may have given insufficient

(1) See Bank of England (2006a).
(2) Cihak (2006) provides a useful overview of existing financial stability publications.
(3) See the Tripartite Memorandum of Understanding at www.bankofengland.co.uk/financialstability/mou.pdf.
(4) See for example Allen and Wood (2006), Schinasi (2006) and Haldane *et al* (2004).

attention to such risks. For example, that might be the case for risks that involve spillovers and feedbacks between financial market participants and between the financial sector and the real economy, which are hard for individual firms to identify, price and manage properly.

Whatever the precise part of the transmission mechanism that is of interest, there is a clear need to identify, assess and measure the source of risks, the channels through which they may propagate and the ways that they may affect ultimately the financial system. Section 2 of this paper discusses the progress made so far towards mapping out risk transmission mechanisms for specific vulnerabilities and to measure their impact. Section 3 describes an agenda of work that aims to improve the measurement and management of risks to the financial system.

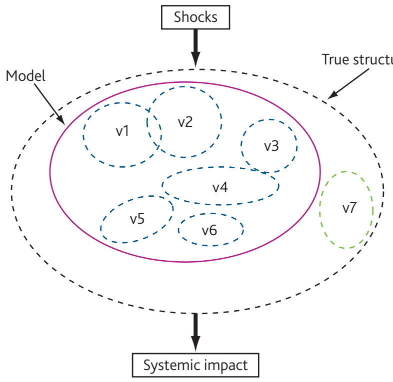
Identifying vulnerabilities

The Bank's financial stability surveillance work is directed to identifying the most material risks to the UK financial system. There are a number of ways of classifying such risks. At one end of the spectrum, they could be specified according to shocks that could trigger them — for example, an oil price rise, a terrorist attack or a corporate fraud. But the problem with this approach is that there are many such potential triggers. So this approach could end up producing a long list of risk events, many with very low probabilities. At the other end of the spectrum, risks could be grouped into broad risk buckets — for example, credit, market and operational risk. But because these risk buckets are broad, this approach does not necessarily identify the underlying sources of risk that need to be managed. Moreover, in system-wide crises, these buckets are unlikely to be independent.

An alternative approach is to focus on identifying and assessing key structural vulnerabilities that could, in unlikely but plausible adverse circumstances, expose the system to significant stress. By their nature, these fault lines are likely to be long-lived. The risk assessment process is, in essence, about improving understanding of these fault lines, to help predict the potential location and possible scale of any future 'financial earthquake' and to help focus attention on monitoring these areas for signs of imminent tremors. This in turn can help in forming judgements on the desirable scale and design of actions to reduce the likelihood and impact of such events. In Section 2 we provide some practical examples of possible systemic fault lines within the UK financial system.

By examining key structural vulnerabilities in greater detail, we can start to build up a picture of the overall risks facing the UK financial system. Examination of identified vulnerabilities (shown as v1–v6 in **Chart 1**) can help improve understanding of the structure of the financial system and its robustness to shocks. There will, of course, be other vulnerabilities (such as v7) that have not yet been identified or analysed. And the

Chart 1 Modelling vulnerabilities within the financial system



vulnerabilities themselves are likely to interact following certain kinds of shock to the system — in other words, some of the ellipses in **Chart 1** will tend to overlap (as indicated for v1 and v2). Section 2 discusses how an overall picture of aggregate risk within the system can be built up by considering how broad-based shocks might affect a number of individual vulnerabilities, simultaneously or sequentially.

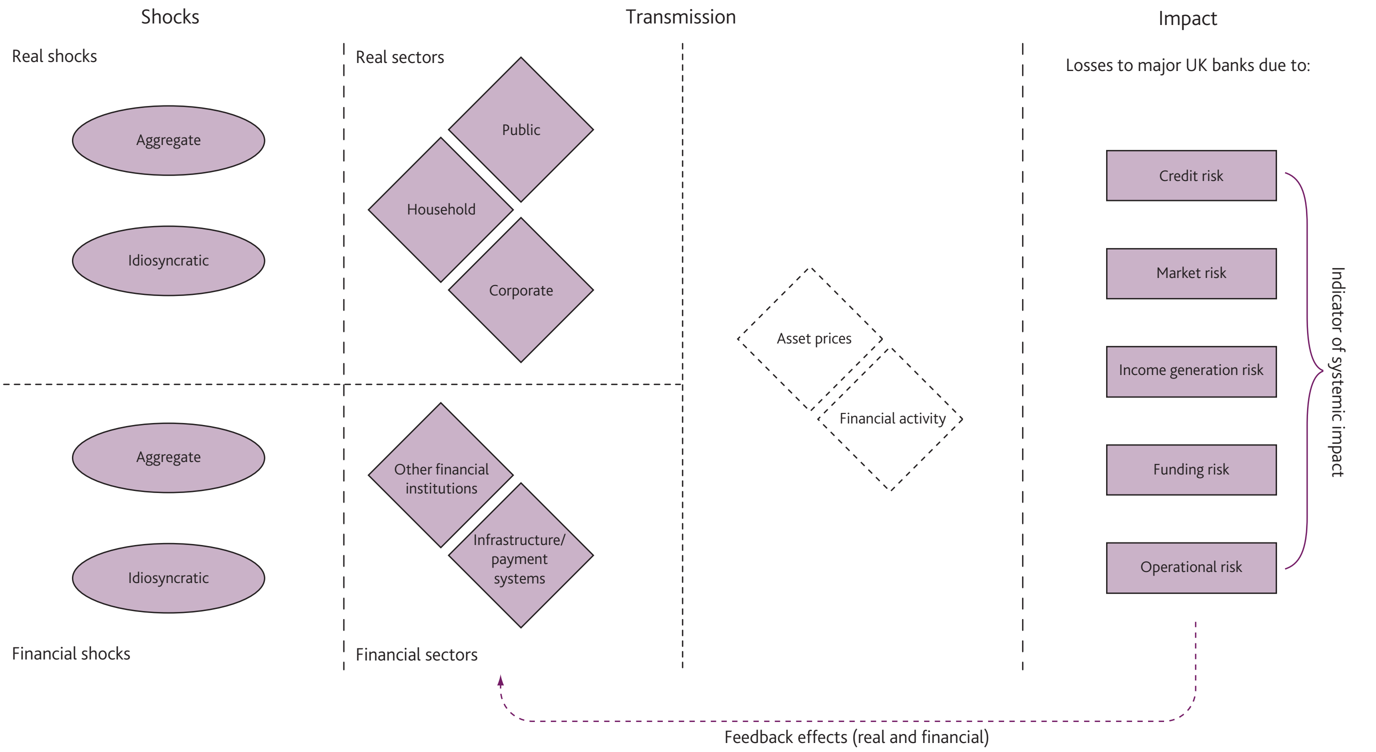
A financial risk transmission mechanism

A first step towards assessing the significance of vulnerabilities is to develop a better understanding of the ways in which they affect the functioning of the financial system. What are the potential shocks that could trigger the vulnerability? Which parts of the financial and non-financial sectors would be affected initially? What second-round feedback and interaction effects between the real economy and the financial system, or between financial sector participants, might be set in play? And how, ultimately, would the combined effects of the various transmission channels affect UK financial system stability? Answers to these questions are fundamental to a clear and consistent understanding of the nature of each vulnerability and the risk it poses to the system.

Chart 2 presents a stylised example of a financial risk transmission map. This offers a succinct schematic way of thinking consistently about how financial stability risks might flow through to the UK financial system. It also helps provide a narrative account of how and why each vulnerability is a potential source of threat to UK financial stability. In the annexes, risk transmission maps are presented for each of the key vulnerabilities identified in the Bank's July 2006 *FSR*.

To the far left of the transmission map are the triggers — or 'shocks' — that might cause a vulnerability to crystallise. They can be broken down in two ways: shocks to the macroeconomy or financial system as a whole (aggregate shocks) or shocks to individual firms or sectors (idiosyncratic shocks); and shocks affecting initially the real or financial sectors. **Chart 3** provides some examples of shocks over the past decade and how they might be classified.

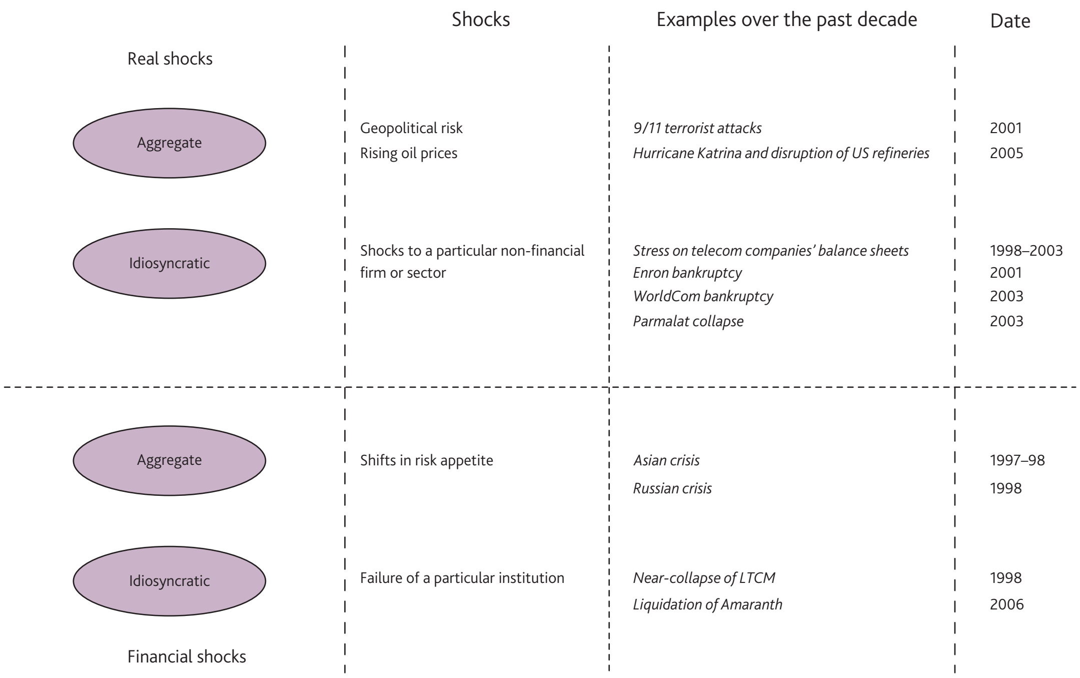
Chart 2 Generic financial stability transmission map



The central part of the map — 'transmission' — shows where the effect of shocks is initially felt. It captures the sectoral and behavioural interactions that might take place if a vulnerability crystallises. The first part of that block shows the sectors affected, broken down between the financial and non-financial (or real) sectors. The real sectors are standard — public, corporate and household. The financial sector is split between infrastructure (covering payment, clearing, settlement and related services) and other financial institutions (covering all other parts of the financial system — commercial and investment banks, pension funds and insurance companies, hedge funds etc).

The second part of the transmission block captures propagation mechanisms, including behavioural effects that may amplify the impact of an initial shock. These can take a variety of forms and, somewhat artificially, are broken down here between transmission effects working through asset

Chart 3 Shocks with the potential to trigger vulnerabilities



prices and through financial activity. Asset price channels involve price changes that have knock-on effects on balance sheets and behaviour.(1) Financial activity channels arise, for example, because shocks may lower volumes traded in financial markets, thereby reducing financial sector profitability. But they can also include more serious dislocations in markets. For example, a drying up of market liquidity could severely curtail activity and could lead to a spiral of falling asset prices as market participants sell assets to meet funding needs. This may in turn affect firms' ability to hedge positions. These effects could have significant consequences for risks to firms' balance sheets.

On the right of the transmission map is the 'impact' column. Private and public institutions will be interested in different measures of impact. Firms and prudential supervisors tend to focus primarily on the impact of stress events on individual firms' balance sheets. Authorities with financial stability responsibilities are interested primarily in the impact of shocks on the functioning of the financial system as a whole and in feedback effects to the real economy (indicated by the dotted line in **Chart 2**) should financial intermediation be materially impaired. In the quantitative work reported in the July 2006 *FSR*, the focus was on a summary indicator of system-wide impact — specifically, on the impact on the profits and capital of the major UK banks, which are at the core of the UK financial system. This measure was derived by aggregating estimates of potential losses on credit and market exposures, from reductions in income generation, from additional funding costs and from operational risk. The major UK banks account for around 80% of borrowing and lending to UK individuals and corporates, so the focus on these firms provides a plausible initial gauge of the potential impact of stress events on the financial system and the UK economy.

Two points should be emphasised about this impact measure. First, it does not imply that developments in financial markets and the behaviour of other financial sector institutions — such as investment banks, hedge funds, insurance companies and pension funds — are ignored. Their resilience, particularly in times of stress, is important in ensuring the efficient intermediation of risk within the financial system, in supporting the stability of UK banks and, more broadly, for economic welfare. Second, risks that are large as measured by this summary indicator will not necessarily be those that are most important from a public policy perspective. The impact of shocks on the major UK banks is important as one indicator of the overall resilience of the system. But public authorities are likely to be particularly interested in those impacts that affect the real economy adversely or arise from market failures — such as a collective underinvestment in resilient market infrastructure — because in these circumstances there may be scope for welfare-enhancing public intervention. In future work, Bank staff intend to consider alternative metrics of financial sector impact, which might capture more directly the effect of financial sector stress on the real economy and those impacts arising from market failures.

Quantification of vulnerability channels

There are considerable benefits from rigorous, quantitative assessment of the materiality of financial stability vulnerabilities and the ways in which they might crystallise, in particular for informing risk management and mitigation work and in strengthening crisis management planning. But there are formidable challenges in evaluating such threats. By their nature, system-wide disturbances tend to be low probability events. And structural developments, including innovation in financial products and risk management practices, changes in regulation and in the legal regime, mean that the topology of financial systems is changing almost continuously. So past experience is rarely a reliable guide to the future and such risks are unlikely to be predictable with any degree of precision. These uncertainties call for a degree of eclecticism when assessing vulnerabilities, with information drawn from a variety of sources including published data, models and intelligence from financial market participants. It also means that such assessments will inevitably contain a significant degree of judgement.

At the Bank, a Financial Stability Board, which comprises the Bank's governors and most of its executive directors, is responsible for making those judgements. The judgements can be guided by analytical work to assess the materiality of alternative threats, including the results of quantitative models applied at a system-wide level. Encouraged by regulators and supervisors, in recent years financial firms have used stress-testing approaches to improve their own quantitative understanding of tail risks to their balance sheets. Such stress testing typically involves assessing the adequacy of firms' financial resources in a selection of stress scenarios. These techniques are also being used increasingly within the official sector, perhaps most notably as part of the IMF's Financial Stability Assessment Programmes (FSAP), which subject national financial systems to a selection of hypothetical stress scenarios in order to assess overall resilience.(2)

Stress-testing approaches can help improve understanding of the nature and scale of risks to the UK financial system as a whole. The next section describes the mechanics of this process in greater detail, using as an example the vulnerabilities highlighted in the Bank's July 2006 *FSR* and the qualification work carried out at the time. In essence, this approach amounts to identifying a low probability stress scenario that might cause a given vulnerability to crystallise and then quantifying the associated risk channels identified in a risk transmission map. In some cases, well-articulated

(1) See Brunnermeier and Pedersen (2006) for a model describing feedback effects between asset liquidity and banks' balance sheets.
(2) See Hoggarth and Whitley (2003), Sorge (2004) and Bunn *et al* (2005).

macroeconomic and financial models can be used to gauge the scale of these channels. In other cases, more informal approaches or historical experience can be used. In other cases still, it is not yet possible to quantify the channels with any accuracy, typically as a result of insufficient data or modelling difficulties.

Clearly, 'what if' experiments of this type require some strong simplifying assumptions — for example, regarding the responses of financial firms and policymakers to shocks. The quantitative estimates themselves are also subject to significant biases and uncertainties. As such, these estimates are best viewed at present as preliminary and illustrative. But these uncertainties should not detract from the broader benefits of the approach, which provides consistent and quantitative measures of the potential scale of vulnerabilities that can be tracked and improved over time. Perhaps most crucially, it also offers an analytical framework within which judgements can be applied and varied and the importance of issues can be explored.

Identifying policy actions

One of the key benefits of this approach to assessing vulnerabilities is a sharpening in the focus of risk mitigation work. For the Bank, the focus here is on actions to mitigate risks that may have not yet been adequately addressed by the private sector. The division of responsibilities for these actions between the public and private sectors will depend on the nature of the risk and the capacity of firms individually to improve their risk preparedness.(1)

One important action that might arise from the risk assessment approach is further exploration of gaps in understanding of the significance of different risks. The risk transmission map provides a consistent framework for identifying what we do and do not know about the impact of different vulnerabilities. Actions to address gaps might involve exploration or gathering of new data, targeted discussions with market participants and research to improve modelling techniques.

Another potential mitigating action, which mirrors directly the quantitative approach, is enhanced firm-level stress testing. By setting out potential stress scenarios for the financial system as a whole, firms may be encouraged to examine their resilience to such scenarios in the course of their own risk management work (alongside other scenarios that they might choose to analyse from the perspective of their own balance sheets). More ambitiously, the results from these 'bottom up' stress tests of system-wide scenarios by firms could be compared with the results from the 'top down' stress tests conducted by Bank staff. That may shed light on potential system-wide feedback and interaction effects that can have a material impact but which individual firms may find hard to assess. For example, it is difficult for individual firms to judge how financial market liquidity might behave in times of stress, since that requires an understanding of the behavioural response of other firms.

A third potential action lies in the field of prudential policy — for example, in the design of standards for capital and liquidity requirements. Typically these standards are not targeted at specific vulnerabilities, but rather at ensuring that individual firms hold adequate buffers to cushion the effects of a range of potential disturbances. These regulatory rules are the responsibility of the FSA in the United Kingdom, but the Bank has a role in advising on regulatory design when this has systemic risk implications. Increasingly, these regulatory standards are being calibrated on the basis of quantitative evaluations of balance sheet risks, which is the same principle underlying the approach set out here.

Finally, the mapping of vulnerability channels can help in devising effective crisis management plans. Understanding the potential shape of future crises can help in the identification of data required to assess the systemic impact of such crises and in the formulation and testing of procedures for their management. An example of the latter would be the use of risk assessment techniques to identify and design crisis contingency exercises.

Taken together, these four elements — detection of key vulnerabilities, mapping of risk transmission channels, quantification of impact and probability, and identification of priority risk mitigation policies — comprise the new approach to financial stability risk assessment. The hallmarks of this approach are intended to be greater clarity, analytical coherence, and consistency in risk assessment, together with a more explicit link to mitigating policy actions. These ingredients should increase the chances of the risk assessments having practical and operational effect on the risk decisions of other parties, particularly in the private sector.

2 The new approach in practice

The quantitative approach to risk assessment outlined in Section 1 was used explicitly as a tool for informing the Bank's judgement for the first time in the July 2006 *FSR*. This section describes the practical steps that were taken in arriving at that assessment.(2)

Identifying vulnerabilities

A first step in making the new approach operational is the identification of the most material threats to financial stability. In practical terms, this amounts to filtering the Bank's extensive surveillance of financial sector activity to identify a

(1) Resolving backlogs in confirmations of credit derivative transactions is a good example of an issue that individual firms were able to identify but found hard to resolve without public intervention.
(2) These steps build on the approach set out in Bunn *et al* (2005).

small number of underlying vulnerabilities. The Bank is interested in risks that could have a material impact on the system as a whole, in particular where this impact may not be fully anticipated and managed by individual financial institutions. So while the list of key vulnerabilities identified by the Bank is likely to overlap to some extent with that monitored by individual firms, it may not correspond completely because the objectives of private sector firms and the public sector are not always fully in line.

Six broad areas of vulnerability were identified and analysed in the July 2006 *FSR*. These are set out in Box A. None of them is new and most are long-standing. The characteristics of these vulnerabilities do differ somewhat. Some arise from potential mismatches or possible mispricing in international financial markets. Others are rooted in extended balance sheet positions in parts of the non-financial sector or reflect structural dependencies within the financial system. Despite these differences, each can be assessed consistently using the same analytical apparatus: identification of the shocks that might trigger the vulnerability; articulation of the risk channels that might then operate; and quantification of these channels.

Selecting stress scenarios

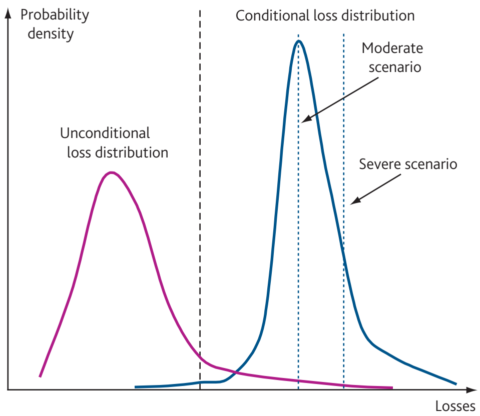
The next step is to identify stress scenarios that could expose these vulnerabilities with potential consequences for the financial system as a whole. The behaviour of the system in the stress scenarios can then be examined and the financial sector impact of the scenarios can be compared with some baseline projection to gauge the scale of each vulnerability. In most cases, the baseline scenario is an assessment of the impact on banks' profits and capital assuming the most likely evolution of the macroeconomy. For the July 2006 *FSR*, the May 2006 *Inflation Report* was used as the basis for the macroeconomic projections.

The stress scenarios are deliberately simple representations of the world, in which a shock (or combination of shocks) leads to the exposure of a vulnerability. It is crucial, however, that the scenarios are plausible — that is, they should involve economically coherent movements in key variables or risk factors. This involves thinking about the shock that might trigger an event and tracing through its impact in a consistent fashion, perhaps using a macroeconomic model with theoretical underpinnings. Related to this, the stress scenario is likely to involve adjustments in multiple rather than single risk factors. Capturing the correlation between variables contemporaneously and through time is a key benefit of a model-based scenario approach to stress testing, relative to approaches that vary stand-alone risk factors.

While choosing appropriate stress scenarios requires a significant degree of judgement, historical and empirical analysis can be used as a guide in their design and calibration. For example, past episodes of sharp macroeconomic downturns, unwinds of large current account imbalances, large adjustments in asset prices and stresses within the financial sector were used to motivate and quantify the stress scenarios for the six vulnerabilities in Box A, alongside macroeconomic models of various types (see the annexes).

Plainly, a scenario is only one draw from the full distribution of possible outcomes. As such, any individual scenario has a probability of almost zero of occurring. To provide a picture of the potential range of possible impacts, two illustrative stress scenarios were considered for each vulnerability. These scenarios were similar in nature but differed in their intensity and hence likelihood, with one judged to be 'moderate' and the other 'severe'. So while both were drawings from the lower tail of the distribution of possible outcomes, one was a draw from further out in the tail (**Chart 4**).

Chart 4 Loss distributions conditional and unconditional on a vulnerability crystallising



As a specific example, the UK downturn in the early 1990s was taken as an historical precedent for the scenario that might trigger the corporate debt vulnerability. In this case, the severe scenario was calibrated broadly to resemble the macroeconomic developments experienced at that time, while the moderate scenario was designed to capture a more likely and less extreme event, with the economy slowing in a similar way but not falling into recession.

The initial scenarios used are summarised in **Table A**. Full details are provided in the annexes. It should be noted that the scenarios vary in their nature, severity and likelihood, making it hard to make comparisons of materiality across vulnerabilities. Future work will explore the sensitivity of the results to alternative stress scenarios and will seek to improve consistency in scenario selection across vulnerabilities.

Measuring the impact of vulnerabilities

The next stage is to draw risk transmission maps for each vulnerability that identify some key propagation channels

Box A
Key vulnerabilities affecting the UK financial system as indentified in the July 2006 *FSR*

Unusually low premia for risk in asset markets
Risk premia on a number of financial assets are well below levels in the past. While this may partly reflect durable factors, such as financial innovation, other influences, such as low global risk-free yields and benign macroeconomic conditions, may not last indefinitely. A sharp and sustained unwinding of the price rises seen in recent years across a range of asset markets would affect directly financial institutions with substantial exposures to these assets, including large complex financial institutions (LCFIs), hedge funds and some internationally active UK banks. Other UK banks could also be affected indirectly through counterparty credit links to other banks and through dependencies on wholesale market funding. All UK banks may face losses if asset price falls are accompanied by a substantial weakening in the financial position of borrowers.

Large financial imbalances among the major economies
International financial imbalances have grown significantly in recent years. The US current account deficit has reached unprecedented levels; surpluses among Asian economies and, more recently, among oil exporters have increased markedly. Imbalances on this scale, and their associated financing, cannot continue indefinitely. The question is whether the adjustment path towards more balanced global capital flows will be smooth or abrupt. There is a risk of a disorderly correction involving sharp movements in asset prices and exchange rates. This could in turn affect the UK financial system through its impact on asset markets, global growth and credit risks.

Rapid re-leveraging in parts of the corporate sector globally
Corporate profitability remains strong and insolvencies continue to be very low. But there are signs of a re-leveraging in parts of the corporate sector globally. UK banks' exposures to the sector are increasing, with continued rapid growth in lending to the commercial property sector and a pickup in syndicated lending activity, including lending to finance leveraged buyouts (LBOs) and private equity deals. In addition to domestic exposures, UK banks also have significant overseas corporate exposures. A substantial proportion of lending to non-financial companies is secured on commercial property.

High UK household sector indebtedness
UK banks have increased their unsecured exposures to UK households in recent years. Combined with already large secured household exposures, this means that the household sector now accounts for 32% of UK banks' total lending. Higher household debt in relation to income may mean households are more sensitive to adverse shocks. There are signs of stress among a minority of households, with personal insolvencies rising sharply in the recent past.

The rising systemic importance of LCFIs
LCFIs play a pivotal role in the international financial system. Their balance sheets have expanded rapidly in recent years, with growth in activity in markets for complex financial instruments. Although risk management has improved markedly in recent years, innovation may have outpaced the capacity of the LCFIs or their counterparties to manage the associated risks. The increasing scale and complexity of their activities and links to the UK banking sector suggests that significant distress at a major LCFI could have a large impact on the UK financial system. This would be true whether the LCFI itself was a source of disturbance or a propagator of shocks from elsewhere in the system.

Dependence of UK financial institutions on market infrastructures and utilities
Financial systems depend on the smooth functioning of financial market infrastructures. In the United Kingdom, financial institutions rely particularly on CHAPS, CLS, CREST and LCH.Clearnet Ltd for clearing and settling financial transactions. Although severe disruption to any of these systems is very unlikely, it could have large and widespread implications. A common dependency among UK financial firms and wholesale market infrastructures is on the messaging services provided by SWIFT. Given these dependencies, a potential (albeit highly unlikely) SWIFT outage is used as a case study.

Table A Summary of stress scenarios as identified in the July 2006 *FSR*

Vulnerability	Moderate stress scenario	Severe stress scenario
Low risk premia correction	Risk premia return to their historic average…	
	…in an orderly way (eg high-yield corporate spreads increase by about 100 basis points to around 400 basis points).	…and rise further (eg high-yield corporate spreads increase by about 400 basis points to 700 basis points).
Global imbalances unwind	A combined shock to the US dollar, global long interest rates and US GDP, such that the US current account deficit shrinks to…	
	…4.5% of GDP over three years. Annual US GDP growth falls to 1.5%; US dollar falls 15%; US long rates rise to about 7%.	…2% of GDP over three years. Annual US GDP growth falls to 0.5%; US dollar falls 30%; US long rates rise to about 8%.
Global corporate stress	A combined supply shock to both the UK and overseas markets, leading to a macroeconomic slowdown and rising inflation…	
	…UK GDP growth slows to 1%, house prices fall by around 10% and commercial property prices by 20% over three years. Overseas countries experience a shock of similar magnitude.	…UK GDP growth falls to -1.5%, house prices fall by around 25% and commercial property prices by 35% over three years. Overseas countries experience a shock of similar magnitude.
UK household stress	Same supply shock as in global corporate vulnerability (featuring macroeconomic slowdown and rising inflation), but affecting the United Kingdom only.	
LCFI stress	Potential losses on a portfolio of large counterparty exposures to LCFIs with probabilities of default and correlations derived from CDS premia…	
	…losses above 95th percentile, based on recent CDS spreads.	…losses above 95th percentile, based on CDS spreads in October 2002 and an adjustment to correlation to simulate heightened systemic risk between LCFIs.
Infrastructure disruption	Outage of SWIFT messaging services…	
	…for one day.	…for two weeks.

through which risks may affect the UK financial system as a whole. These transmission maps are contained in the annexes.

In quantifying the channels, various simplifying assumptions were made. Two key ones concern the behaviour of financial institutions on the one hand and policymakers on the other. There is no strictly 'correct' set of behavioural assumptions here. Rather, the aim was to choose as simple a set of counterfactual assumptions as possible to allow the financial stability risk to be assessed.

For UK banks' behaviour, the assumption used was that they do not adjust their balance sheets in response to the stress scenarios, for example, by changing their lending and borrowing policies. In essence, banks are assumed to be passive in response to stresses to their balance sheet. Although unlikely to hold in practice, it is impossible to foresee *ex ante* how each bank would adjust its portfolio. Relaxing this assumption is important when considering feedback effects, as these reactions are an important component of systemic impact.

For policymakers, the convention used was that there is no discretionary adjustment in fiscal or prudential policies, but that monetary policy responds in line with a standard interest rate rule.(1) These assumptions are unlikely to be satisfied in reality and it is important to consider the sensitivity of results to them. But they are useful for helping clarify, for financial institutions and for policymakers, the actions that they might need to take to address stresses to balance sheets.

Table B shows the risk channels that were quantified for each of the vulnerabilities examined in the July 2006 *FSR*. The

Table B Channels quantified for identified vulnerabilities in July 2006 *FSR*

Quantified channels	Low risk premia	Global imbalances	Global corporate debt	UK household debt	LCFI stress	Infrastructure disruption
Credit risk, exposures to:						
UK households	•	•		•		
UK corporates	•	•	•			
overseas households	•	•				
overseas corporates	•	•	•			
Counterparty credit risk, exposures to:						
LCFIs					•	•
Other financial institutions						•
Market risk in trading book	•	•				•
Income generation risk	•	•	•	•		•
Funding risk	•	•	•	•		•
Operational risk						•
Feedback effects						
Market liquidity disruption						

(1) Specifically, monetary policy is assumed to evolve according to a Taylor rule, with interest rates responding to the deviation of inflation from target and output from trend.

methodologies used to quantify each channel are discussed in detail below. The table illustrates that some channels (such as credit and market risk) could be quantified better than others (such as macroeconomic feedback effects and market liquidity disruption). This means the reported estimates of the impact of shocks are partial, which is another reason why they cannot be compared easily across the vulnerabilities.

Credit risk

Scenarios in which credit losses are quantified use an econometric model to generate a consistent macroeconomic outlook. This in turn is then used to estimate the likely impact on borrowers' repayment ability over a three-year horizon. This horizon is important because write-offs typically lag the initial shock. Separate equations are used to assess losses on banks' corporate, unsecured household and mortgage lending (Box B). These equations have been estimated using publicly available aggregated data. This contrasts with stress testing of portfolios by commercial banks, which often uses disaggregated information on individual loans.

Banks' corporate write-offs are estimated from projections of the corporate liquidation rate and commercial property prices. The most important estimated influence on the liquidations rate is the ratio of corporate interest payments to profits (income gearing), which measures the servicing burden of the debt. GDP growth, long-run interest rates and the level of corporate debt are also found to be important explanatory factors. Commercial property prices are used as a proxy for the value of available collateral, which influences loss in the event of default. These are modelled in the stress tests by assuming that prices return to their average historical relationship with rental income and interest rates.

Mortgage write-offs are estimated by combining projections for mortgage arrears (in this case, estimated using projections of unemployment, interest rates, mortgage debt and house price growth) and repossession rates with estimates of loss given default. The latter is estimated using a model of the distribution of loan to value (LTV) ratios across banks' mortgage portfolios in different scenarios. LTV ratios are calculated from information on house values at loan inception, together with data on the evolution of aggregate house prices since purchase. In the absence of detailed microeconomic information on the households most at risk of default, it is assumed that those with higher LTVs are more likely to default than those with lower LTVs. It is also assumed that loss at default is higher than might be expected from the calculated LTV, reflecting cumulated mortgage arrears and the possibility that properties may be sold at a discount to the market value. The overall output from the model is calibrated to match the historical data on mortgage write-offs.

Losses on unsecured household lending are determined solely by write-offs on credit card lending in the absence of collateral. These are quantified using estimates of credit card arrears, which in turn are calibrated using projections for interest rates, economic growth, household disposable income and credit card balances.

While the estimated models provide a good explanation of the peak in write-offs in the early 1990s, the generated projections of credit losses are subject to significant uncertainty. An important source of uncertainty is that these models are reduced-form. Being based on historical relationships, they will not capture potential future structural changes in lenders' or borrowers' behaviour. For example, household unsecured loan write-offs have increased sharply in recent years, despite benign economic conditions, perhaps reflecting the increased availability of credit to higher-risk customers.

Counterparty credit risk

A Basel II advanced 'internal rating based' (IRB) approach is used to estimate counterparty losses for UK banks that might arise in the event that one or more LCFIs encounter serious problems. A hypothetical portfolio of the aggregate large exposures of UK banks to LCFIs is constructed. Default probabilities and correlations extracted from observed credit default swap prices are then used to generate an estimate of the average 'tail' losses that UK banks could incur in the event of extreme LCFI stress, as described in Annex 5. These loss estimates are highly sensitive to different assumptions about exposure levels, average default probabilities, default correlation and loss given default.

Market risk in trading book

Falling asset prices will lead to losses for banks holding long positions in assets that are marked to market, with the loss being given by the product of the change in price and the exposure to the asset. The Bank does not have data on individual institutions' trading book exposures. Given these data limitations, banks' exposures to different asset classes are backed out from Value-at-Risk (VaR) disclosures using a methodology outlined in Box C. An important assumption in this approach is that banks' losses arise because they hold long positions in an asset and potential falls in market prices determine the VaR.(1) But it could be equally true that banks are holding short positions in specific asset classes and that market price falls increase the value of these positions. Across the banking system, it seems more likely that the net position is long, reflecting the positive net supply of securities. But given that some banks may hold short positions, estimates derived from this technique might be most appropriately interpreted as upper bounds.(2)

(1) Banks' losses may also arise from changes in volatility and correlation. Although these effects may be relevant for banks' trading income, they have not been quantified at this stage.
(2) See Box 3 in the July 2006 *FSR*, which describes some limitations of VaR as a means to infer trading book exposures to market risk.

Box B
Estimating credit losses

This box lists the main equations used to assess banks' losses on corporate, unsecured household and mortgage lending. An earlier vintage of these models was described in Benito *et al* (2001), with further developments discussed in Whitley and Windram (2003), Bunn and Young (2004), Whitley *et al* (2004) and Bunn *et al* (2005). Note that all equations are estimated on quarterly data and that most right-hand side variables are taken from the Bank of England Quarterly Model, as described in Harrison *et al* (2005).

Default rates

D1 Corporate liquidations rate (*LQRQ*)

$$LQRQ = -0.024 + 0.89*LQRQ_{-1} - 0.357*(LQRQ_{-1} - LQRQ_{-2}) - 1.57*(\mathrm{LOG}(GDP) - \mathrm{LOG}(GDP_{-1}) - 0.006) + 0.004*IGEAR_{-2} - 0.002*(1.27*CAPITAL_{-1} - 1.27*CAPITAL_{-2}) + 0.012*(RRL_{-1} - RRL_{-2}) + 0.017*((NDEBT_{-1}/GDPL_{-1}) - (NDEBT_{-2}/GDPL_{-2}))$$

GDP = real GDP at factor cost
IGEAR = income gearing of private non-financial companies (PNFCs)
CAPITAL = commercial property capital values
RRL = a measure of the short-term real interest rate
NDEBT = net debt of PNFCs
GDPL = nominal GDP at factor cost

D2 Credit card arrears (*CREDARR*)

$$\mathrm{DLOG}(CREDARR) = -4.59 - 0.036*\mathrm{DIFF}(GDPGR_{-2}) + 0.519*\mathrm{DLOG}(RS_{-2}) + 0.066*Q1 - 0.032*Q2 - 0.354*(\mathrm{LOG}(CREDARR_{-1}) + 0.073*GDPGR_{-3} - 0.638*\mathrm{LOG}(RS_{-3}) + 1.152*\mathrm{LOG}(RPDI\%_{-3}) - 0.061*Q1_{-1} - 0.969*\mathrm{LOG}(CREDBAL_{-3}))$$

GDPGR = annual real GDP growth
RS = short-term nominal interest rate, annual rate (%)
Q2, *Q3*, *Q4* = seasonal dummies
RPDI = household disposable income as a proportion of GDP
CREDBAL = number of active credit card balances
$\mathrm{DLOG}(x) = \mathrm{LOG}(x) - \mathrm{LOG}(x_{-1})$
$\mathrm{DIFF}(x) = x - x_{-1}$

D3 Mortgage arrears rate (%) (*ARREARS*)

$$ARREARS = \mathrm{EXP}(-13.189 + 0.983*\mathrm{LOG}(RS_{-4}) - 0.035*((PHSE/PHSE_{-4} - 1)*100) + 2.491*\mathrm{LOG}(MORTH\%_{-4}) + 0.18*UR_{-4})$$

PHSE = relative price of housing (adjusted for trend productivity)
MORTH = mortgage debt as percentage of GDP
UR = unemployment rate (%)

Banking sector model equations

B1 Corporate write-off rate (*BWRCORP*)

$$BWRCORP = \mathrm{EXP}(-1.852 - 3.1*((CAPITAL - CAPITAL_{-1})/CAPITAL_{-1}) + 1.66*\mathrm{LOG}(4*LQRQ_{-4}))$$

B2 Mortgage write-off rate (*BWRMG*)

$$LTV_i = LTV_{i,-1}*PHSE_{-1}/PHSE \qquad i = 1\ldots12$$

Forecast of current loan to value (*LTV*) ratio of average mortgage arrears based on previous LTV ratio (in twelve buckets) and relative price of housing.

$$LGD_i = \mathrm{MAX}\ [0;100-(80/LTV_i)]$$

Expected loss given default (*LGD*) based on LTV ratio and taking into account a 20% 'haircut' to reflect repossession costs and lost interest on loans in arrears.

$$MGREP = 0.11*(ARREARS_{-4}/100)$$

$$BWRMG = \sum_i \omega(LTV_i)*LGD*MGREP*MGEXP$$

LTV = loan to value ratio
LGD = loss given default
MGREP = mortgage repossession rate
MGEXP = mortgage exposures
$\omega(LTV)$ = relative propensity to default estimated from disaggregated model (increasing with *LTV*)

B3 Credit card write-off rate (*BWRCC*)

$$BWRCC = \mathrm{EXP}(0.127 + 0.474*\mathrm{LOG}(BWRCC_{-1}) + 0.84*\mathrm{LOG}(CREDARR_{-4}))$$

Income generation or business risk

An important channel of impact can arise from a general weakening in the operating environment that reduces banks' capacity to generate income. At present, the major UK banks earn approximately 43% of their income from net interest and the remainder from fees. The Bank models the net interest income component by making a simple assumption that such income rises in line with GDP growth.[1] This approach has relatively low explanatory power, so estimation uncertainty is high. Fee income is not modelled at this stage. The Bank is developing a more sophisticated approach in order to capture the effect of changes in official interest rates on net interest income. One improvement is to take into account the speed at which banks' assets and liabilities are re-priced following interest rate changes.[2] The analysis of the low risk premia vulnerability is a first development of this approach (see Annex 1).

Funding risk

In stressed conditions banks may face an increase in the price, or a reduction in the availability, of their wholesale

(1) $NII = NII_{-1} * (0.995 + (GDPGR * 0.202))$, where *NII* = real net interest income and *GDPGR* = annual real GDP growth.
(2) Drehmann *et al* (2006) suggest a potential approach.

Box C
Estimating market risk exposures

Banks' trading book exposures to bonds and equities can be estimated using publicly available VaR data, covering both on and off balance sheet exposures, which record the losses that would be generated if financial markets moved over a particular holding period as sharply as they have in the past with some probability. For example, a ten-day, 99% VaR records the minimum loss that would be incurred by a bank if financial market movements over a ten-day window were as large as they had been for 1% of the time in the past.

To infer the exposure of a bank to an asset class, it can be assumed that the historical daily returns generated by the asset class are independent and normally distributed. The former implies that if the standard deviation of the daily returns were σ, then the standard deviation of returns over a h-day holding period would be $\sqrt{h}\sigma$. VaR is then given by:

$$VaR(\alpha, h) = \Phi^{-1}(1-\alpha)\sigma\sqrt{h}E$$

where α denotes the confidence level of the VaR, eg 99%, Φ denotes the cumulative normal distribution function and E denotes the exposure, which may be obtained by rearranging the above expression. For example, if a bank's VaR due to potential movements in equity prices were £6 million (with $\alpha = 98\%$ and $h = 1$ day) and σ were estimated as 0.57% over the past two years based on the standard deviation of returns to the S&P 1200 index of global equity prices, then the estimate of the bank's exposure to equities would be £0.5 billion.(1)

(1) Two years is a popular choice of period over which to compute standard deviations among UK banks.

funding.(1) For example, a bank's funding costs would be likely to rise if it were to suffer a downgrade in its credit rating.(2) In the stress-test scenarios, these increased costs are quantified in broad terms by studying previous episodes of banking sector stress and differences in credit spreads across credit ratings. In particular, several UK and German banks made losses during the early-1990s recession and in the period between 2001 and 2003 and were downgraded. By comparing these actual losses with those estimated in the stress scenarios, it is possible to gauge the potential deterioration in bank credit ratings in these scenarios.(3) The effect of any downgrade on the cost of funding can then be approximated using the differences in sterling credit spreads across different credit ratings during a period of relative market turbulence (late 2002). Finally, the amount of wholesale funding that banks would need to roll over at higher prices can be estimated from the maturity breakdown of debt securities and interbank deposits reported in banks' published accounts. This simple methodology assumes that banks are able to meet their funding needs, albeit at a higher price, and therefore only partially models funding risk. It does not capture any additional (potentially more serious) risks that might arise if certain sources of funding are withdrawn from troubled institutions completely. Improved understanding of this channel is a priority for future work.

Operational risk

Operational risk is a broad concept describing the risk of an institution experiencing losses as a result of inadequate or failed internal processes (eg internal fraud) or external events. As such, stress scenarios can be presented in a variety of forms. The infrastructural disruption scenario — illustrated by an outage of SWIFT messaging services on which UK financial firms and the major UK market infrastructures depend — included an estimate of losses to financial firms arising from this category of risk. This estimate was based on responses by these firms to the FSA Benchmark Resilience Survey (2005), which showed the costs, claims and charges likely to arise in the event of key wholesale market functions being disabled.(4) The figures used were based on firms' estimates of daily costs if clearing, custody, settlement, wholesale payments and trading functions were unavailable. To some extent these estimates of operational risk also include a funding risk element, in that they include carry costs across markets if settlement and clearing functions are unavailable. These estimates by their nature do not include broader costs of financial infrastructure disruption — for example, to non-financial firms and individuals.

Assessing overall impact and probability

Charts 5 and **6** show aggregate estimates of the scale of impact of scenarios in which the key vulnerabilities are triggered individually as quantified for the July 2006 *FSR*. The impact is measured over a three-year horizon to allow the full effect of shocks to be felt. Some shocks may have a rapid impact on firms, for example through sharp falls in asset prices. The effect of other shocks, affecting banks mainly through credit losses, tends to emerge more gradually as economic conditions deteriorate, financing difficulties build and borrowers move into arrears and default.

For each vulnerability, impact estimates are shown for the two scenarios — moderate and severe. Central estimates of impact are indicated by darker bands, with the lighter bands indicating possible biases and uncertainties around these calibrations.

(1) Customer deposits tend to be a more stable source of funding than wholesale funding, with retail funding less sensitive to financial news and its cost often below risk-free rates.
(2) Although some banks will suffer increased funding costs, others may benefit from a flight to quality, leaving the system-wide effect uncertain.
(3) In several of the moderate stress scenarios, banks' losses were judged to be too low to trigger an increase in funding costs.
(4) See FSA Resilience Benchmarking Project (2005).

Chart 5 Impact and likelihood of 'moderate stress scenarios' affecting vulnerabilities[(a)] — July 2006 *FSR*

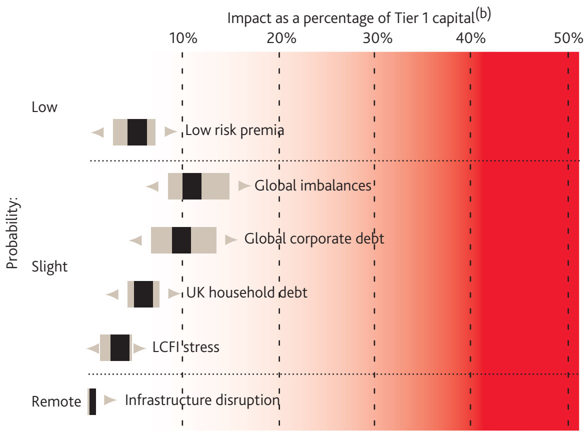
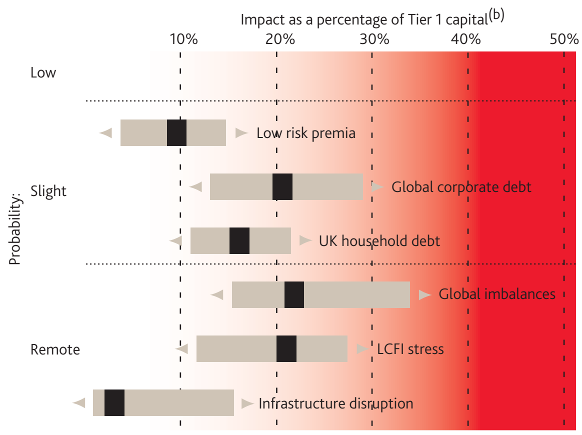


Chart 6 Impact and likelihood of 'severe stress scenarios' affecting vulnerabilities[(a)] — July 2006 *FSR*



Source: Bank calculations.

(a) Central band shows best current quantified estimate of scale of loss under each scenario; wider bands include allowances for some uncertainties around these calibrations. A number of potential channels are not included in the bands.
(b) Total impact for major UK banks of individual scenarios over a three-year horizon, relative to base. The impact is expressed as a percentage of current Tier 1 capital but, given UK banks' current profits, does not necessarily imply a loss of capital.

The uncertainty bands are a first pass, which seeks to calibrate uncertainties around individual transmission channels using a combination of model estimation error bounds, historical experience and judgement. They are unlikely to capture the full range of uncertainties around impact. The potential for other impacts, which are not currently quantified, is indicated by the arrows. In the charts, impact is shown using the metric of losses to the major UK banks, scaled by their reported Tier 1 capital. Given the buffer provided by banks' profits (of around £40 billion in 2005), the results did not imply that Tier 1 capital would necessarily be eroded from its high levels of around 8% at end-year 2005.

The charts also show a preliminary judgement on the likelihood of these alternative scenarios over the following three years. Estimating these low probabilities is very challenging. To simplify matters, each vulnerability was placed into one of three broad ranges — low, slight and remote. These aim to correspond to probability ranges of: more likely than 1 in 10, 1 in 10 to 1 in 30 and less likely than 1 in 30. The likelihood of any specific scenario is close to zero, so the probabilities are broad judgements on the chance of a comparable event occurring. These judgements are informed by historical experience and statistical analysis of macroeconomic and financial market data. The estimation of the impact and probability of each of the individual vulnerabilities is discussed further in the annexes.

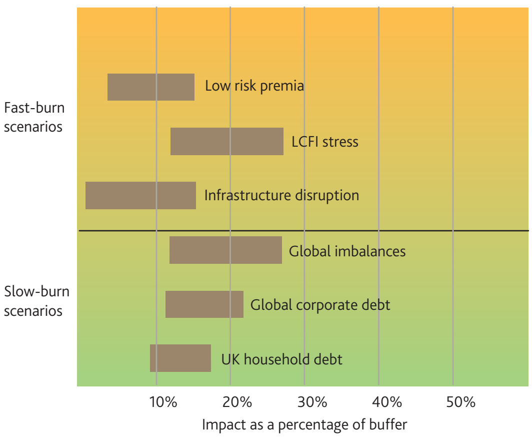
A motivation for this approach is to identify vulnerabilities which, if exposed, could lead to severe losses for firms. That might in turn induce more widespread distress across the financial sector. One source of amplification of these initial impact estimates is that banks might start experiencing cuts in their credit ratings and increased funding costs if their Tier 1 capital ratios fell sharply.[(1)] The precise level at which these effects might take hold is hard to assess *ex ante*, as it would depend on the speed with which the impact was felt and its concentration across individual banks. Some of the stress scenarios, such as those associated with corporate debt, household debt and global imbalances, may evolve relatively gradually, providing time for banks to adjust — for example, by changing lending criteria or margins or by strengthening financial buffers. This might cushion the impact of these vulnerabilities if they crystallised. A relevant buffer against losses for such 'slow burn' risks may be Tier 1 capital plus a measure of ongoing profits.

By contrast, the scenarios whose epicentre is located more directly within the financial sector, such as adjustments in risk pricing, LCFI stress and disruptions to market infrastructure, are likely to evolve much more rapidly. In these cases, sharp adjustments in asset prices, perhaps exacerbated by a reduction in market liquidity, could amplify their impact. Ongoing profit generation may not be available to offset those losses, so they may have a more immediate impact on banks' capital. Large falls in capital might also lead to increases in an institution's funding costs and higher collateral requirements in secured funding and trading activities. The immediacy of losses incurred under a 'fast burn' risk means that banks' effective buffers may be just their Tier 1 capital.

Chart 7 shows how the impacts in the severe stress scenarios would look when scaled by buffers that might be relevant to their speed of crystallisation — as an illustrative example, Tier 1 capital plus a year of profits for the slow-burn risks and Tier 1 capital alone for the fast-burn risks.

(1) The rationale is that counterparties in financial markets typically restrict banks' access to wholesale funding (and credit agencies usually downgrade their ratings) as Tier 1 capital falls.

Chart 7 Fast and slow-burn severe stress scenarios as a percentage of alternative buffers(a)(b) — July 2006 *FSR*



Source: Bank calculations.

(a) Total impact for major UK banks of individual scenarios over a three-year horizon, relative to base, as a percentage of the alternative buffers.
(b) Buffers are: Fast-burn scenarios = Tier 1 capital; Slow-burn scenarios = Tier 1 capital plus one year of profits.

Assessing aggregate financial system risk

In practice, one or more of the key vulnerabilities could be exposed simultaneously (if triggered by a common shock) or sequentially (if vulnerabilities are interrelated). Taking account of these types of interdependence between vulnerabilities is important when attempting to gauge the overall level of risk within the system, but is far from straightforward to implement in practice. As a first step towards that goal, in the July 2006 *FSR* two generalised stress scenarios were considered in which more than one of the vulnerabilities were triggered.

A large supply-side shock

This stress scenario involves a stylised severe supply-side shock to the global economy, which results both in a broad-based slowdown in real activity and at the same time higher inflation and interest rates. The stress scenario represents a global economic slowdown that is calibrated to resemble, in terms of its severity, the early-1990s UK recession — so is similar in scale and nature to that which triggers the global corporate debt vulnerability (see Table A). This puts pressure on a number of vulnerabilities simultaneously — for example, those relating to UK household debt, global corporate debt and some elements of the global imbalances vulnerability. The channels through which the global shock propagates are the same as those in these vulnerabilities and are quantified in the same way. The severe recession triggers losses for UK banks as write-off rates on household and corporate debt rise in the United Kingdom and abroad. The slowdown in economic activity reduces banks' income. As a result of these losses, banks' creditworthiness falls and their funding costs rise. The illustrative calibrations pointed to total losses over three years (relative to base profits) equivalent to around 40% of major UK banks' Tier 1 capital.

A generalised adjustment in asset prices

This scenario involves a sharp increase in long-term interest rates and risk premia in the United Kingdom, United States and the euro area. Output growth falls alongside asset prices. So, for example, nominal UK long rates are modelled to increase by around 150 basis points and the spread on high-yield corporate bonds rises by around 500 basis points. The rise in long-term interest rates and the consequent fall in the price of risky assets induce a sharp fall in output. Annual real GDP growth in the United Kingdom becomes negative for two quarters and on average is about 2.5 percentage points lower than the base case in the first year of the scenario. These developments trigger a number of the vulnerabilities, particularly the low risk premia, household and corporate debt vulnerabilities. Losses crystallise through a range of channels, including trading losses, rises in credit write-offs on corporate and household exposures (both domestic and overseas), higher funding costs and income losses. The illustrative calibrations pointed to overall losses equivalent to around 30% of major UK banks' Tier 1 capital.

Going forward, these (and other) combined vulnerability scenarios can be used to track the potential impact of similar scenarios over time, to develop a better understanding of the potential for interactions among vulnerabilities and as a guide to the thorny question of the overall level of risk to the financial system.

Errors and uncertainties

There are a wide range of potential sources of error and uncertainty associated with these preliminary quantitative impact estimates. These include:

(i) *Lack of data*: This is an acute problem for quantitative financial stability analysis. Significant data gaps became apparent during the course of the quantitative work described above including: lack of sectoral data on the composition of UK banks' overseas exposures; lack of detailed data on the trading book exposures of UK banks; and lack of data on the off-balance sheet exposures of UK banks.

(ii) *Estimation uncertainty*: This refers to the uncertainty around reduced-form model-derived estimates. Models derive parameter estimates from a sample of observations that is a subset of the full population. As such, regardless of the quality of both the model and the estimation technique, there is always a probability that the estimated parameters do not coincide with the 'true' underlying ones. The larger this probability, the stronger the uncertainty.

(iii) *Behavioural modelling*: By their nature, stress tests are drawings from the tail of the distribution of possible outcomes. In practice, there are little relevant data relating to past behaviour under stress, which is unlikely to conform closely to that during normal times. Moreover, past periods of stress have often been followed by remedial supervisory or other policy measures, so the potential impact of past stress events absent any intervention is not captured in past data. In addition, structural changes in the financial sector, including innovations in financial instruments and the entry of new participants to markets, are likely to have changed the behaviour of the financial system in response to shocks. For these reasons, it is particularly hard to capture channels of transmission where behavioural reactions are likely to play an important role. For example, liquidity effects operating on both the assets and the liabilities sides of banks' balance sheets, and feedback effects from the financial sector to the macroeconomy, are as yet not captured in the estimates. They are, however, an active area of work.

(iv) *Behavioural assumptions*: More broadly, simplifying assumptions about the passivity of the financial sector in response to extreme shocks are almost certain to be invalidated in practice. This is a potentially important omission. Financial firms' responses, such as raising new capital, may mitigate the balance sheet impact. On the other hand, uncoordinated actions by financial sector participants that aim to protect their own balance sheets — for example, by selling positions in risky assets — collectively may exacerbate the adverse impact on the system as a whole. Not taking account of these interactions represents a further source of uncertainty.

Taken together this implies that there is a high degree of intrinsic uncertainty about many of the quantitative measures. This is mirrored in the wide ranges around estimates and is indicated by the directional arrows shown in **Charts 5** and **6**. These uncertainties help define the Bank's future work agenda in the risk assessment area, the aim of which is to improve the accuracy and comprehensiveness of the qualitative and quantitative assessment of transmission channels and impacts.

3 Next steps in developing this new approach

This new approach to risk assessment, which was used as an input to the July 2006 *FSR*, is a first step in a longer-term agenda. This agenda seeks to strengthen the analytical and quantitative underpinnings of the assessment of risks to the financial system, so as to improve the identification and management of these risks. The agenda has the following key elements:

An improved data set

A number of the uncertainties which surround the quantification of risks are a reflection of data inadequacies. In part, this reflects the dynamic and changing nature of financial markets and instruments, which mean it is difficult for data collection to keep pace. But more fundamentally, it is because financial stability data requirements have not really been assessed from a first-principles perspective. Financial stability data have typically emerged as a by-product of other policy requirements — for example, data for monetary, fiscal or prudential policy purposes. The Bank is working to identify its data needs for effective systemic risk assessment, with a view hopefully to filling the most important gaps over time.

Quantifying missing channels

The existing quantitative estimates are often partial and some channels are left unquantified. In general, most progress has been made in the modelling of credit and market risk and least in the area of liquidity and operational risk. Liquidity risk is a clear priority area for future work. Liquidity effects operate on both the liabilities ('funding liquidity risk') and assets ('market liquidity risk') sides of banks' balance sheets. These two risks are often closely interconnected — for example, the realisation of funding liquidity risk may induce banks to liquidate assets, thereby pushing down asset prices and placing further pressure on balance sheets. And these two risks are likely to be especially virulent if they are operating across the balance sheets of several institutions at the same time. The modelling and measuring of such liquidity effects has been the subject of considerable academic work over the past few years.(1)

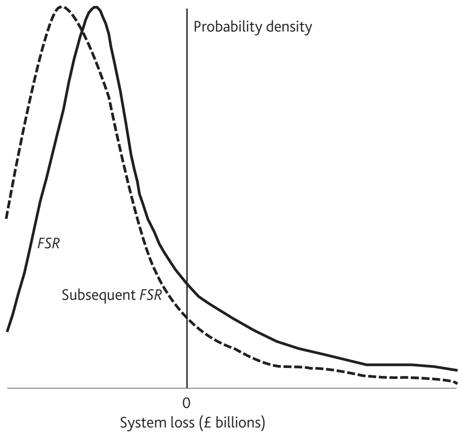
A second, and related, area requiring further quantitative work is the effect of behavioural interactions among participants in a financial network. Defaults by important participants can set in train complex sequences of knock-on effects on other participants. And the optionality embedded in certain financial instruments, such as some derivatives, can amplify the impact of relatively small changes in underlying conditions. These effects can give rise to highly non-linear reactions within the system as a whole.(2) Neither of these effects is adequately captured by the Bank's existing models and work is under way to plug these gaps too.

A hybrid suite of models

One of the longer-term aims is to develop an integrated suite of models that allow the transmission channels for UK financial system stress to be mapped out more accurately and comprehensively. The outputs from this modelling suite could then be compared with measures of system-wide resilience, such as profits and capital, to provide a summary statistic of risk to the UK financial system. Among the relevant outputs from this framework would be measures of the aggregate expected loss distribution of the UK financial system, which could be tracked over time. **Chart 8** provides an illustration of how this updating might work. This modelling suite could also be used to look at the effects on the system of specific vulnerabilities, by considering a set of 'what if' experiments involving a subset of the channels of transmission.

(1) See, for example, Shin (2006) and Cifuentes *et al* (2005).
(2) See, for example, Alentorn *et al* (2006).

Chart 8 Aggregate loss distribution of the UK banking system



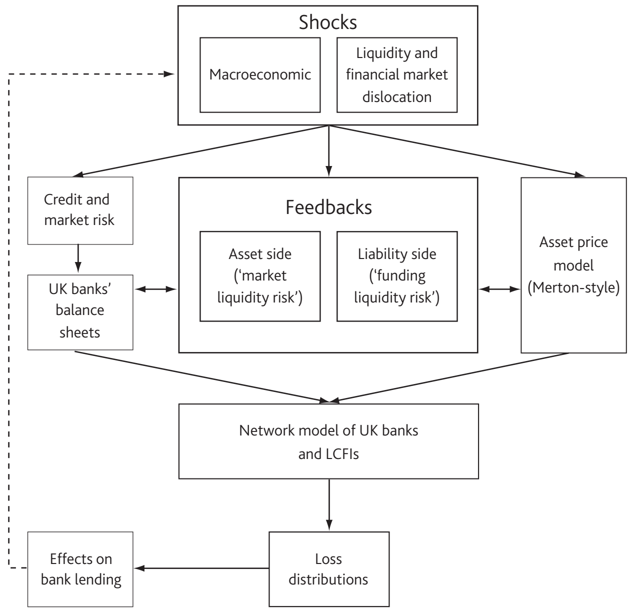
What are the primary ingredients of this suite of models? Currently, there is no off-the-shelf model (or set of models) for financial stability analysis, so the approach taken will be an eclectic one comprising two distinct modelling approaches.(1) The first approach relies on asset-pricing methods to extract information about system-wide default characteristics, using an extension of the work by Merton (1974). In parallel, a structural macroeconomic approach is being developed. The centrepiece of this will be the balance sheets of UK banks, with assets and liabilities modelled in a disaggregated fashion (see Drehmann, Sorensen and Stringa (2006)). Both sets of models would be augmented with (asset and liability) liquidity effects, network dynamics and, ultimately, feedbacks to the macroeconomy.

Figure 1 provides a schematic representation of the proposed modelling suite. The sources of potential disturbance to the financial system are contained in the box marked 'shocks'. These shocks can be either real or financial in nature and a model is needed to capture these disturbances, and their interaction, in a coherent fashion. To the left-hand side of the diagram runs the structural model, taking us from shocks to the system through to their impact on banks' balance sheets, through the conventional channels of credit and market risk. To the right-hand side of the diagram lies the asset-pricing framework, which makes inferences about balance sheet positions from banks' equity prices. Both approaches then come together when modelling factors which may amplify the first-round balance sheet impact, in particular liquidity and network effects. Taken together, all of these channels then translate into a final impact on balance sheets, as reflected in an aggregate loss distribution. This loss distribution, in turn, can then be mapped back into the impact on the macroeconomy resulting from any potential balance sheet impairment.

An increased systemic focus in firm stress-testing work

A final stage of the process involves making the quantitative approach to risk assessment operational, by helping improve

Figure 1 Proposed suite of models



the focus of risk mitigation work and crisis management preparations. One important element of this risk mitigation work is influencing the behaviour of financial firms. Risk management decisions in firms are increasingly being influenced by the results of stress-testing exercises.(2) While firm-level (or 'bottom up') stress-testing practices appear to have developed rapidly over recent years, there may be important gaps, including in capturing macroeconomic and financial sector feedbacks and interactions between firms.(3) This is not entirely surprising as it is hard for individual firms to gauge the knock-on effects of other firms' actions on their own balance sheets. So firm-level stress tests may underestimate the possible impact of stress events on their balance sheets and hence the system as a whole.

Some of these potentially missing effects would be captured by the Bank's suite of models, which provide a 'top down' view on risks to the system. There may be value over time in more structured comparisons of the results of 'top down' and 'bottom up' stress-testing exercises. To conduct such a comparison, common scenarios would need to be used as inputs to individual firms' risk models, so that the aggregated results of these bottom-up exercises could be compared with the top-down results and the differences explored.

A stress-testing approach along these lines is similar to that used during the course of the IMF's Financial Sector Assessment Programme for the United Kingdom in 2001.(4) It

(1) The closest precedent for the planned approach is the model developed by the Austrian central bank. This is described in Boss *et al* (2006).
(2) For example, see the discussion of the FSA's stress-testing thematic review at www.fsa.gov.uk/pubs/ceo/ stress_testing.pdf.
(3) See CGFS (2005).
(4) See Hoggarth and Whitley (2003) for a description of the exercise.

is also similar to the process used by the Dutch central bank in its recent stress-testing work.[1] Over time, an interactive stress-testing process of this type, involving the official sector and financial firms, could encourage better risk pricing and modelling across the system as a whole and would be a natural evolutionary step in developing the quantitative approach to risk assessment more generally.

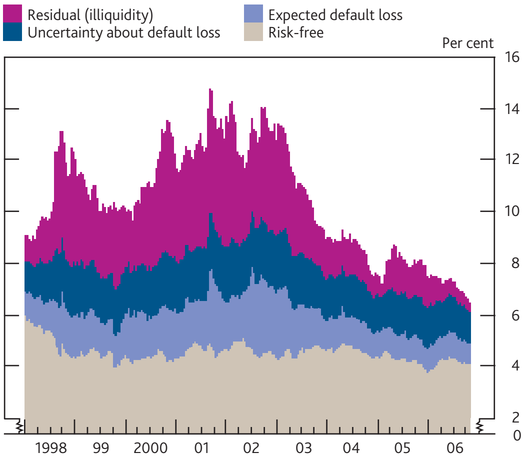
(1) See De Nederlandsche Bank (2006).

Annex 1
Low risk premia vulnerability[1]

(a) Vulnerability description

Measures of risk premia, such as credit spreads or those inferred from equity prices, are presently low by historical standards and relative to values implied by some models. For example, spreads on high-yield corporate debt have narrowed sharply in recent years, to the point where there seems little compensation for credit risk, and almost none for liquidity risk (**Chart A1.1**).

Chart A1.1 Credit spreads[a]



(a) Twenty-year cost of borrowing for UK high-yield corporates.

It is hard to predict how risk premia will evolve because it is unclear which factors have driven the recent falls. Structural factors like strengthened macroeconomic policy frameworks and greater flexibility in corporate supply chains, for example, may have reduced macroeconomic volatility; this could have boosted investors' appetite for financial risk and, hence, reduced the premia required on investments. And financial innovations that repackage risk to match investors' preferences could also have reduced the premia demanded by investors to take financial risks. To the extent that structural factors have been important in explaining the compression of risk premia, a sharp reversal would seem unlikely. On the other hand, cyclical factors could also explain the compression of risk premia in recent years. One such factor is a 'search for yield', whereby low yields on safe instruments lead to increased demand by investors for riskier assets to maintain portfolio returns. This factor could unwind as global risk-free interest rates rise, or if large adverse shocks result in an abrupt reassessment of risk.

An increase in risk premia would impose costs on UK banks directly by reducing the market value of their holdings of securities that are marked to market. And losses could arise indirectly if the wealth effects of lower asset prices undermined economic growth, increasing household and corporate write-offs and lowering net interest income. Net interest income might also be affected as risky assets and liabilities are rolled over at the increased interest rate in different proportions for different maturities (a key feature of banks' role being maturity transformation, eg transforming short-term deposits into longer-term lending).

(b) Description of stress scenarios

The risk premia stress scenarios were constructed using information about the past variation in asset prices. The moderate stress scenario involved risk premia across a range of asset markets converging towards their historic average values. The severe scenario represented a sharper correction, with each risk premium measure overshooting its average by the end of a three-year forecast horizon. The risk premia scenarios are summarised in **Table A1.1** below.

Table A1.1 Details of scenarios

Variables: Monthly risk premium on...	Initial value (basis points)	Increase after number of months (basis points) Moderate scenario 12	24	36	Severe scenario 12	24	36
Global investment grade bonds (IG)	37	7	11	14	38	56	68
High-yield bonds (HY)	276	79	120	140	259	375	453
Emerging market bonds (EM)	207	244	326	355	729	1012	1195
Equity risk premium S&P 500 (ERP)	198	31	42	44	110	156	185

Potential paths for risk premia were generated using the following error-correction model:

$$\Delta\rho_t = \beta_0(\rho_{t-1} - \bar{\rho}) + \sum_{j=1}^{J} \beta_j \Delta\rho_{t-j} + \varepsilon_t$$

where ρ_t denotes the value of each risk premium at time t, $\bar{\rho}$ is the average value of the risk premium, β_0 and β_j are estimated by fitting the model to the data and $j = 1...J$ are lags, where the choice of lag length, J, was based on the Schwarz information criterion. Monthly yield spreads on global investment grade (IG), high-yield (HY) and emerging market (EM) bond indices from Merrill Lynch and JPMorgan were used as proxies for risk premia in the respective markets.[2] An estimate of the equity risk premium (ERP) on the S&P 500 index constructed by the Bank of England was used as a proxy for the risk premium on global equities.[3]

The errors ε_t were assumed to be stationary and to follow a normal distribution, with variance σ_ε^2. Projections of possible future values of risk premia and their associated probabilities of occurrence were then constructed by rolling the model forward:

(1) This annex was prepared by Nick Vause of the Bank's Systemic Risk Assessment Division.
(2) In particular, spreads over swap rates were used for IG and HY bond indices and spreads over US Treasury bill yields were used for EM bond indices.
(3) See Panigirtzoglou and Scammell (2002).

$$\rho_{t+1} = \rho_t + \Delta\rho_{t+1} = \rho_t + \beta_0(\rho_t - \bar{\rho}) + \sum_{j=1}^{J} \beta_j \Delta\rho_{t-j+1} + \varepsilon_{t+1}$$

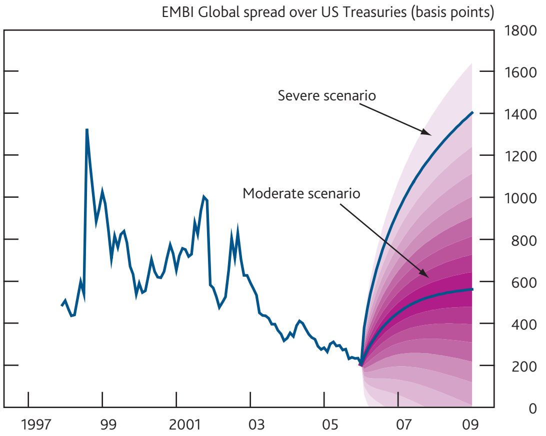
Selecting the α percentile of ε_{t+1} gives the α percentile of the risk premium forecast:

$$\rho_{t+1}(\alpha) = \rho_t + \beta_0(\rho_t - \bar{\rho}) + \sum_{j=1}^{J} \beta_j \Delta\rho_{t-j+1} + \varepsilon_{t+1}(\alpha)$$

where $\varepsilon_{t+1}(\alpha) = \sigma_\varepsilon \Phi^{-1}(\alpha)$ and Φ denotes the cumulative standard normal distribution function.

This procedure was iterated forward for 36 months, generating a 'fan chart' that illustrates potential paths that risk premia could follow. The 50th percentile of this fan chart was chosen

Chart A1.2 Emerging market spreads



Sources: JPMorgan Chase and Co. and Bank calculations.

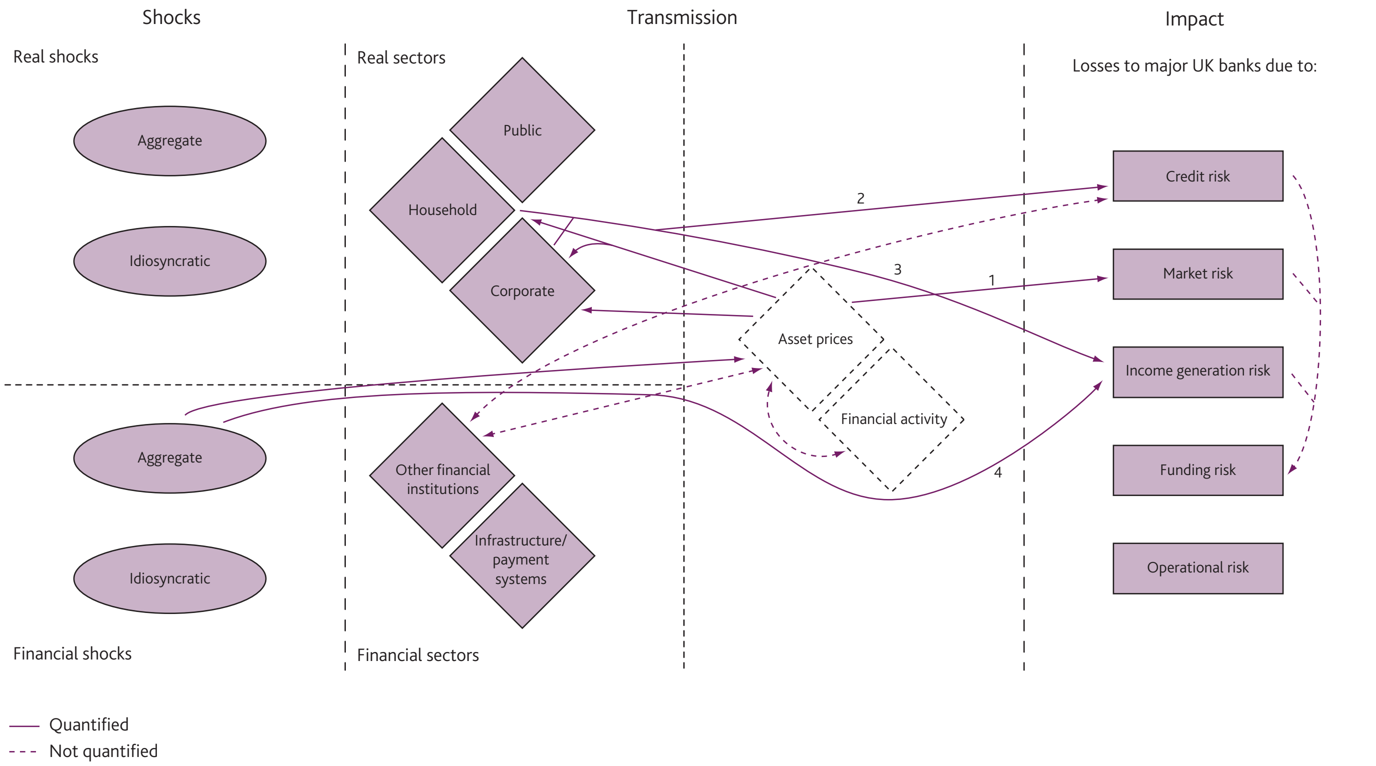
to represent the moderate stress scenario and involves the risk premium converging towards its average value in each market. The 90th percentile was chosen to represent the severe stress scenario. **Chart A1.2** illustrates the approach in the case of emerging market spreads.

(c) Risk transmission map

The impact of the moderate and severe stress scenarios on UK banks could arise via a number of channels as shown in the risk transmission map (**Chart A1.3**). At present, four distinct channels have been estimated:

- *Market risk*: Increased risk premia reduce the market value of risky assets, generating mark-to-market losses in banks' trading books (1).
- *Credit risk*: The scenario does not model explicitly the underlying trigger for an adjustment in asset prices. But it is possible that lower asset prices would have adverse wealth effects that undermined economic growth, leading to higher write-off rates on credit extended to corporates and households (2).
- *Income generation risk*: The economic slowdown also reduces net interest income generated by banks (3). Net interest income is also affected by higher interest rates paid and received on liabilities and assets that are rolled over during the three-year horizon (4).

Chart A1.3 Low risk premia transmission map



(d) Estimated impact of the scenarios on UK banks in July 2006

Market risk

The changes in risk premia detailed in **Table A1.1** were mapped to changes in asset prices, P, using different formulae for bonds and equities. The bond formula is an approximation that involves a modified duration measure, D_M, as provided by Merrill Lynch.(1)

$$\frac{\Delta P}{P} = -D_M \Delta \rho$$

Changes in equity prices were computed using a one-stage dividend discount model maintained in the Bank of England, as in the formula below.(2)

$$\Delta P = \left(\frac{E}{r + \rho + \Delta\rho} + E - D \right) - \left(\frac{E}{r + \rho} + E - D \right)$$

The results are summarised in **Table A1.2**.

Table A1.2 Changes in asset prices

	Change in price after given number of months (percentage changes)					
	Moderate scenario			Severe scenario		
Asset	12	24	36	12	24	36
Global investment grade bonds (IG)	-0.4	-0.6	-0.8	-2.1	-3.1	-3.8
High-yield bonds (HY)	-4.0	-6.0	-7.0	-13.0	-18.9	-22.8
Emerging market bonds (EM)	-15.8	-21.2	-23.0	-47.3	-65.7	-77.5
Equities	-3.6	-4.9	-5.2	-12.8	-18.2	-21.6
Memo: Average bonds[a]	-1.5	-2.2	-2.5	-5.5	-7.8	-9.4

(a) Weighted average of IG, HY and EM, with respective weights of 88%, 6% and 6% based on global notional amounts outstanding.

Changes in bond and equity prices were then applied to estimates of banks' trading book exposures to bonds and equities. These exposure measures were derived from publicly available Value-at-Risk (VaR) data, using the approach described in Box C.

The resulting mark-to-market losses for major UK banks in aggregate were relatively small, even in the severe scenario (**Table A1.3**), reflecting the relatively limited importance of trading as a business line for most UK banks. Within the total it is likely that losses would be concentrated at those banks with significant proprietary trading operations.

Credit risk

The extent of the macroeconomic slowdown that might be induced by wealth effects as risk premia rise, and asset prices fall, was computed using the National Institute Global Economic Model (NIGEM) and the Bank of England Quarterly Model (BEQM). The deterioration in the global and UK economies was then mapped to higher corporate and household write-off rates using a model of banks' balance sheets maintained in the Bank of England, as described above. Estimated losses to UK banks through this channel are reported in **Table A1.3**.

Table A1.3 Decomposition of total impact on UK banks by source (£ billions)

	Moderate scenario	Severe scenario
Market risk:		
Trading book losses due to reduced market value of assets	1.0	3.7
Credit risk:		
Write-offs due to slower economic growth	2.7	4.5
Income generation risk:		
Reduced net interest income due to higher interest rates	1.6	5.2
Reduced net interest income due to slower economic growth	0.2	0.6
Total losses	6	14
As a percentage of Tier 1 capital	4%	9%

Income generation risk

The estimated direct impact of higher interest rates on net interest income was computed by estimating the higher interest received and paid on assets and liabilities likely to be rolled over. Among assets and liabilities, all interbank claims, marketable securities and claims on the non-bank financial sector were assumed to be rolled over (ie replaced at maturity by new claims paying a new rate of interest). For example, assets and liabilities maturing within three months were grouped together and assumed to roll over completely every two months, increasing the interest earned and paid on these obligations according to the change in risk premia. Similarly, assets and liabilities maturing in three-six months were assumed to be repriced every four months, while assets and liabilities maturing in six-twelve months were assumed to be repriced every nine months. Assets and liabilities with longer maturity windows (one-five years and beyond) were assumed to be repriced only beyond the three-year horizon over which impact is calculated. While for all maturities beyond three months the impact of repricing of UK banks' assets exceeded that for liabilities, the opposite was true for the zero-three month category, and this dominated the impact calculation.

The impact of slower UK and global growth on income generation was derived using an equation linking net income generation to GDP, as set out earlier. Losses through this channel were relatively small.

(1) The approximation is known to underestimate the size of price changes for large changes in yields/risk premia, but it is a good approximation for smaller changes in yields.
(2) The model employs an endogenous growth rate of dividends per share, which is why the formula differs from the more familiar Gordon dividend discount model. For more details on the endogenous growth rate, see Panigirtzoglou and Scammell (2002).

Total losses

Table A1.3 summarises the main estimated impacts after three years. The negative impact on UK banks' profits was estimated at around £6 billion, or 4% of Tier 1 capital, in the moderate scenario and £14 billion, or 9% of Tier 1 capital, in the severe scenario.

(e) Probability of scenarios

According to the model outlined in Section (b), the probabilities of risk premia following paths corresponding to the moderate and severe stress scenarios (or even more unfavourable ones) were 50% and 10% respectively. However, the error correction approach used was based on the assumption that previous average values of risk premia were also equilibrium values, implying that assets were overvalued. The probability of the scenarios identified would be lower to the extent that structural factors, discussed in Section (a), have raised the equilibrium level of asset prices.

(f) Key uncertainties and biases

The estimated impact of a given scenario is likely to be inaccurate and/or biased, in part due to judgements made in calibrating the transmission channels. The main uncertainties and biases that arise in the low risk premia scenario quantification are listed below. Judgements on their possible scale are included in **Table A1.4**. The list below does not include uncertainties and biases related to channels that have not yet been quantified, such as any amplification of asset price falls resulting from market disruption.

- Banks' trading book exposures estimated from VaR disclosures were assumed to be long positions for each bank. It is possible, however, that some banks may have short positions. Indeed, if the major UK banks had a mixture of long and short positions, the net exposure of the UK banking system to market risk factors could even be zero.

Table A1.4 UK banks' losses under low risk premia stress scenarios in July 2006

	£ billions		As a percentage of UK banks' Tier 1 capital	
	Moderate	Severe	Moderate	Severe
Lower bound	2	5	1	3
Impact estimate	6	14	4	9
Upper bound	9	21	6	13

- It was assumed that banks' assets and liabilities that are regularly rolled over consist of interbank assets, marketable securities and claims on the non-bank financial sector. If this is inaccurate and only interbank assets and marketable securities are regularly rolled over, for example, this would reduce the impact of the third channel in **Table A1.3** (reduced net interest income due to higher interest rates) by £1.1 billion in the moderate scenario and by £3.3 billion in the severe scenario.

- It was also assumed that banks' assets and liabilities that are regularly rolled over do so, on average, at a date near the middle of their respective maturity buckets. Varying these rollover dates towards either the near or long-dated ends of these buckets would affect the computed impact of the third channel by +/-£0.2 billion in the moderate scenario and by +/-£0.5 billion in the severe scenario.

The vast majority of the computed impact of higher write-off rates in the risk premia scenarios resulted from corporate, rather than household, write-offs. A number of judgements were made in computing the impact of higher corporate write-offs and these are discussed in Annex 3. To reflect this uncertainty, +/-70% was added to the central estimate of international corporate write-offs and -20% to +35% to domestic corporate write-offs.

Annex 2
Global imbalances vulnerability[1]

(a) Vulnerability description

International financial imbalances have grown significantly over the past four years. The US current account deficit reached 6.5% of GDP in the first half of 2006. The main counterpart has been large and growing surpluses in Asia and in oil-exporting countries. These continuing current account imbalances have resulted in a large accumulation of liabilities in the United States and a correspondingly marked build-up of assets in creditor countries. In China, for example, foreign exchange reserves increased from $240 billion (17% of GDP) in mid-2002 to $1,066 billion (over 40% of GDP) in December 2006.

Going forward, it seems unlikely that investors will be willing to finance the US current account deficit on its present scale indefinitely.[2] It is quite possible that any future adjustment to more balanced global capital flows would be smooth, particularly if accompanied by policy actions by both debtor and creditor countries.[3] But it is also possible that global imbalances could unwind in a disorderly manner, potentially causing a slowdown in world GDP growth, including in the United Kingdom, and a fall in global asset prices. This, in turn, could significantly reduce UK banks' profits.

(b) Description of stress scenario

Two stress scenarios were considered. The moderate stress scenario featured a modest narrowing in the US current account deficit over the next three years to $4^1/_2$% of GDP and the severe scenario a more marked reduction to 2%. A number of commentators have argued that the latter is around the level at which the US deficit is likely to be sustainable over the medium term.[4] There are many possible combinations of adverse macroeconomic and financial shocks that could result in a disorderly unwinding of the US current account deficit. So the specific stress scenarios chosen should be thought of as illustrative examples. The scenarios aim to capture the combined effect of two shocks: a reduction in investors' appetite for US dollar assets; and an unexpected slowdown in real activity, perhaps induced by a fall in US house prices or residential investment. In the severe scenario, equity prices also fall. The scenarios were derived using the National Institute Global Economic Model (NIGEM) and, for the UK-specific effects, the Bank of England Quarterly Model (BEQM).

In the moderate stress scenario (**Table A2.1**), the US dollar falls by 15% (relative to base) against all major currencies (including the renminbi) after four quarters and is assumed to stay there for the remainder of the three-year scenario.[5] This is accompanied by a rise in US long-term nominal bond yields (of $1^1/_2$ percentage points (pps) relative to base after the first year). US house prices fall (relative to base) by 13% after two years. House prices in the United Kingdom are assumed to fall by a similar amount.

Table A2.1 Details of scenarios

Variable	Difference from base[a] Moderate	Severe
US nominal effective exchange rate	-14% after four quarters	-28% after four quarters
US real GDP	-2.5% in eight quarters	-7% in eight quarters
US house prices	-13% after eight quarters	-16% after eight quarters
US ten-year yields	+1.5pp after four quarters	+2.8pp after four quarters
Euro real GDP	-0.7% in eight quarters	-2% in eight quarters
Euro-area ten-year yields	-0.1pp after four quarters	-0.3pp after four quarters
US equity prices	-3% after four quarters	-20% after four quarters
Global credit spreads	+85bps after twelve quarters	+225bps after twelve quarters
UK commercial property prices	-19% after eight quarters	-32% after eight quarters

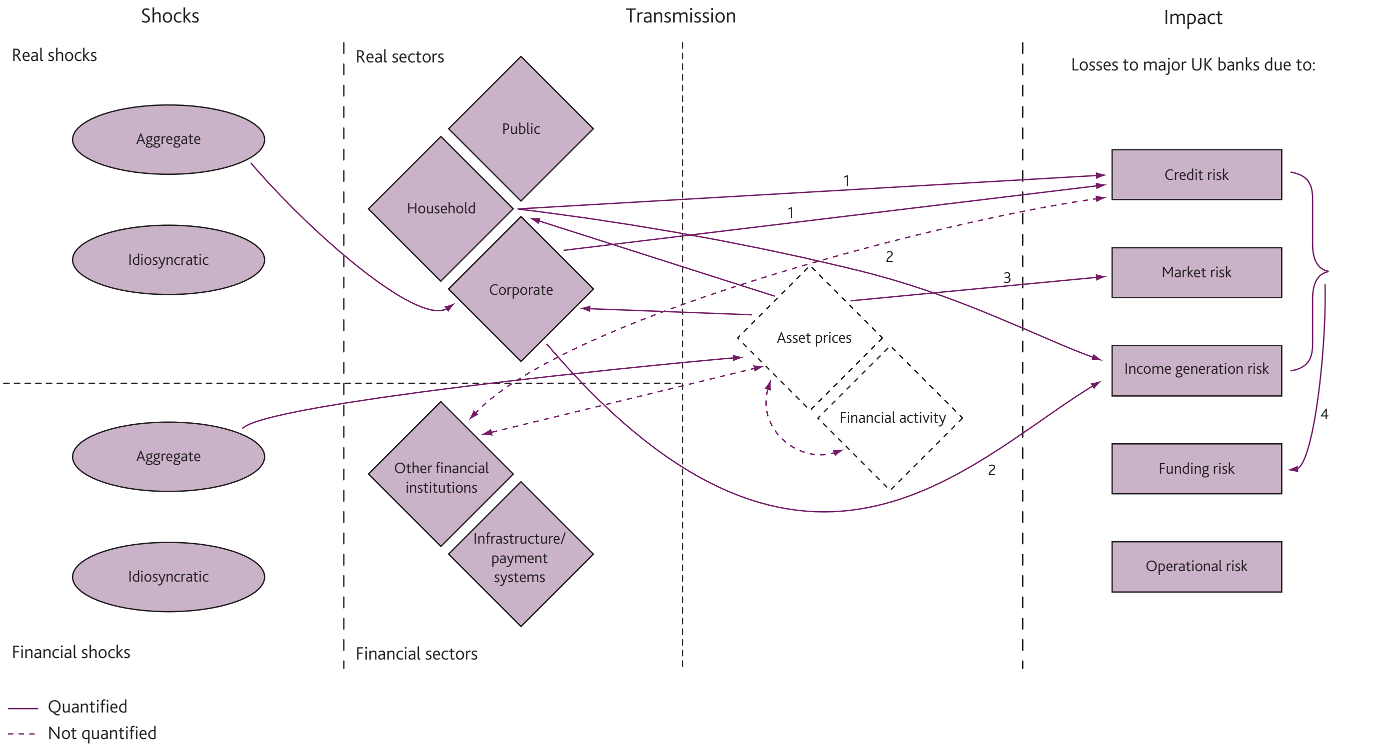
(a) All variables expressed in nominal terms except where stated. The base profiles are taken from the projections underlying the Bank of England's May 2006 *Inflation Report*.

In the severe scenario, the US dollar falls by 30% against other major currencies (relative to base) in the first year and US long-term yields rise by almost 3 pps.[6] US house prices decline by 16% after two years. In this scenario it is also assumed that global equity prices fall sharply (relative to base) — by 20% in the United States and Europe after one year. Credit spreads rise in the scenarios by 85 basis points (bps) and 225 bps respectively.[7] So the scenario assumes that an unwinding of global imbalances also partially reverses current low risk premia.

An important feature of the scenarios is the monetary policy response. In line with stress scenarios for other vulnerabilities,

(1) This annex was prepared by Glenn Hoggarth and Guillermo Felices of the Bank's International Finance Division.
(2) Not all commentators believe that the current US deficit is unsustainable. Dooley *et al* (2005) suggest that current external imbalances partly reflect the deliberate policy actions of East Asian countries, seeking export-led growth as a development strategy. Others refer to the better investment opportunities available in the United States than elsewhere because of its deeper and more sophisticated financial markets (Caballero *et al* (2006) and Cooper (2006)). And Hausmann and Sturzenegger (2005) suggest that, when properly measured, the United States is actually a net creditor rather than a debtor.
(3) Possible policy changes are discussed in the *World Economic Outlook* (2006) and include a reduction in the fiscal deficit and an increase in the personal sector savings rate in the United States, structural reforms in the euro area and an increase in domestic demand growth and exchange rate flexibility in Asia and the Middle East. The IMF has recently launched a multilateral consultation which aims to look at how co-ordinated policy actions could help to address global imbalances. See www.imf.org/external/np/sec/pr/2006/pr06118.htm for more details.
(4) See for example Mussa (2004), Wren-Lewis (2004) and O'Neill and Hatzius (2004).
(5) In the scenario the dollar effective rate falls by 14% since it is assumed that the Hong Kong dollar stays pegged to the US dollar.
(6) The dollar depreciation required to reduce the US current account deficit to a sustainable level will depend on the precise features of any scenario. For example, and partly because of the low share of US trade relative to GDP, according to Obstfeld and Rogoff (2005) a 30% fall in the real effective dollar exchange rate would be needed to eliminate completely the US current account deficit. Blanchard *et al* (2005) estimate that, if the current account deficit was closed by movements in relative prices alone, the dollar would need to fall over time by 40%–90% in real terms. Barrell and Holland (2006) simulate that a 30% fall in the nominal effective dollar exchange rate induced by an increase in the risk premium required to hold dollars would reduce the deficit by 3% of GDP. But the required dollar depreciation would be smaller if the adjustment occurred through lower domestic demand growth in the United States and faster growth in surplus countries.
(7) Credit spreads play no formal role in the macroeconomic models used but affect the estimated market risk losses on the trading book discussed below.

Chart A2.1 Global imbalances risk transmission map



this is assumed to follow a Taylor interest rate rule (see footnote 1 on page 10). Since the dollar depreciation increases inflationary pressure in the United States but reduces it elsewhere, the scenarios include a tightening in US monetary policy and looser monetary policy in the euro area and the United Kingdom.

In the United States, sharp rises in long-term and short-term interest rates (relative to base) have a negative impact on GDP. This, coupled with the impact of the fall in house prices on consumption, causes output growth to fall markedly notwithstanding the positive effect on net trade volumes of dollar depreciation. US GDP (volume) is $2^1/_2$% and 7% lower than base after two years in the moderate and severe scenarios respectively. So in both scenarios, the US current account deficit falls over the three-year horizon due to a combination of a reduction in domestic expenditure, a change in its composition (switching from tradables to non-tradables) and an increase in exports.(1)

GDP growth also falls (relative to base) in the euro area and United Kingdom, albeit less markedly. In part this reflects exchange rate appreciation against the dollar: the nominal sterling trade-weighted index appreciates in the moderate and severe scenarios by around 5% and 10% respectively relative to base. Domestic demand growth also falls as a result of falling house and equity prices. However, the impact on growth is mitigated to some extent by the loosening in monetary policy.

(c) Risk transmission map

The impact of a disorderly unwinding of global imbalances on UK banks may arise via four channels identified in the risk transmission map (**Chart A2.1**):

- *Credit risk*: Through increasing write-offs on credit exposures, in particular to the UK and overseas household and corporate sectors (1).
- *Income generation risk*: Through slower economic activity reducing net interest income generated by banks in the United Kingdom and abroad (2).
- *Market risk*: Through mark-to-market losses sustained on trading book exposures (3).
- *Funding risk*: Falling profits may affect the credit rating of banks and hence their cost of funding (4).

The main links estimated by the model are illustrated by the bold lines in **Chart A2.1**. The dashed lines show links which have not currently been quantified.

(d) Estimated impact of the scenarios on UK banks in July 2006

Credit risk

Table A2.2 shows estimated credit losses for major UK banks, relative to base in the moderate and severe scenarios after three years.

(1) Note that the last time the dollar fell sharply — by almost 40% in nominal terms on an effective basis between 1985 and 1987 — it was associated with a decline in US interest rates and continued fast growth in real estate and equity prices. Consequently, domestic demand growth remained strong and the current account deficit widened initially rather than narrowed.

Corporate write-offs accounted for a substantial share of total credit losses. Write-offs increased both because of the deterioration in GDP growth — which increased the probability of corporate default — and falls in commercial real estate prices — which, as a proxy for loan collateral, increased loss given default. In both scenarios, major UK banks suffered larger loan losses from their exposures to corporates operating abroad than in the United Kingdom. This reflects the fact that UK banks' corporate foreign exposures were estimated to be bigger than their domestic ones, especially for the larger UK banks.(1)

Household credit losses were smaller. Secured write-offs rose moderately, with the impact of lower house prices and higher unemployment (relative to base) on mortgage arrears (and thus write-offs) partly offset by the impact of lower interest rates in the United Kingdom (and the euro area), which reduced mortgage interest payments. In the case of unsecured write-offs, the loosening in monetary policy almost fully offset the fall in GDP growth (relative to base), implying only a modest rise in unsecured arrears (and thus write-offs).

Income generation risk

Lower GDP growth in the two scenarios reduced net interest income generation: losses were larger in the severe scenario as GDP growth fell more sharply (relative to base) than in the moderate case over most of the three-year horizon. The impact of lower activity levels on other income, including fees and commissions, was not estimated.

Market risk

A disorderly unwinding of global imbalances may also affect the trading book exposures of major UK banks. Losses on such exposures would be expected to vary markedly across major UK banks, depending on the extent of their trading activities and whether their trading books contain short or long positions in different financial asset classes. As discussed in Box C on page 13, estimates of trading book exposures were based on VaR disclosures of the major UK banks. Losses were derived by applying asset prices falls to these exposures, as set out in Annex A. Since the estimates assumed that banks were long in all asset markets where prices fall (and short where market prices rise) they should be thought of as an upper bound. Bearing this limitation in mind, the market risk losses were estimated at £3.2 billion and £5.5 billion in the moderate and severe scenarios respectively — about 17% and 30% of major UK banks' 2005 trading income.

Funding risk

The prospect of losses through credit and market risk channels could increase banks' credit spreads and raise their funding costs, particularly in the severe scenario. Funding costs in the severe scenario were assumed to increase by £2 billion.

Table A2.2 Decomposition of total impact on UK banks by source (£ billions)

	Moderate scenario	Severe scenario
Credit risk:		
Household credit write-offs	1	1
Corporate credit write-offs	7	14
Income generation risk:		
Reduced net interest income due to slower growth	6	11
Market risk:		
Market risk in the trading book	3	6
Funding risk:	0	2
Total losses	17	34
As a percentage of Tier 1 capital	11%	22%

Total losses

A summary of the main estimated impacts after three years is provided in **Table A2.2**. The negative impact on UK banks' profits was estimated at around £17 billion, or 11% of Tier 1 capital, in the moderate stress scenario and almost twice as large (£34 billion, or 22% of core capital) in the severe scenario. This impact was large relative to some other vulnerability scenarios, though still smaller than the pre-tax profits of the major ten UK banks in 2005 (around £40 billion). Its impact, however, may be concentrated among banks that were most active in corporate lending, international banking and capital market activities.

(e) Probability of scenarios

The probability of a combination of events occurring in precisely the way described above in the moderate and extreme scenarios is close to zero. However, some quantification can be made of the likelihood that the main inputs (the dollar exchange rate and US long-term interest rates) and output (the US current account deficit) change broadly in the way suggested in the scenarios.

One approach was to use option prices to derive market expectations of a sharp dollar fall and rise in longer-term US yields.(2) At end-June 2006, financial markets attached a 10% probability to a depreciation of the nominal dollar effective exchange rate of at least 15% within twelve months — as assumed in the moderate scenario — but almost zero probability to a depreciation of 30% or more (used in the severe scenario). Similarly, financial markets attached a 10% probability to a rise in US long yields of 0.8% points — as assumed in the moderate scenario — over the following six months.(3)

(1) Drawing on a range of sources, including BIS international financial statistics and company accounts, major UK banks' exposures to corporates outside the United Kingdom are judged to be around 60% of their total corporate exposures.
(2) Some caution is needed in interpreting market expectations this way, because options tend to become more illiquid at the tails of the distribution.
(3) Option markets for long US yields are very illiquid beyond a six-month horizon.

An alternative approach was to use past movements in the US current account deficit as a guide to the likelihood of an adjustment towards a particular level. A central estimate and probability distribution ('fan chart') for the US current account deficit was derived from an error correction model (ECM) using a similar approach to that outlined in Annex 1. This suggested that the probability of the US current account deficit falling in the following three years to 4½% of GDP — the outcome of the moderate scenario — is around a 1 in 10 to 1 in 30 event. The probability of the deficit falling to 2% — as in the severe scenario — was less than 1 in 50.

(f) Key uncertainties and biases

The estimated impacts of the scenarios are subject to considerable uncertainties and biases. Some of the main sources are:

- Uncertainties around estimates of banks' UK household and corporate credit losses (as discussed in Annexes 3 and 4).
- On the upside, actual write-offs on foreign exposures may be higher and foreign net interest income lower than estimated because changes in these factors are based on UK variables. In particular, this is likely to understate the increase in write-offs and fall in net interest income in the United States. This is a clear limitation of the present methodology that will be addressed in future work.
- No account was taken of the potential for widespread market dislocation that could amplify the impact of an adjustment on asset prices. The risk appetite of financial market participants could fall precipitously as occurred, for example, in Autumn 1998 during the Russian and LTCM crises.(1)
- On the downside, it is possible that the US authorities would not increase interest rates as assumed in the scenarios by imposing a Taylor interest rate rule. The authorities may believe that any rise in inflation would be temporary and put more weight instead in their policy decision on a fall in US growth.
- The scenario also assumed that the falls in risky asset prices in the United States spilt over to global markets. If they do not, credit and market losses would be smaller.
- It is possible that sterling appreciation against a falling dollar would be less than that of other major currencies. Historically, at least, sterling has been more closely correlated with the dollar than with European currencies.(2)
- Market risk in the trading book was based on banks' disclosed VaRs and assumed that banks were long on all assets whose prices fell and short on assets whose prices rose. This is a strong assumption.
- As in other vulnerability scenarios, it was assumed that bank behaviour is passive. No allowance was made for banks changing their lending and deposit rates, or other terms and conditions, in the light of changes in the demand for their products.

Overall the losses to UK banks in the moderate stress scenario were judged to lie within a range of uncertainty of 25% either side of the central estimate (ie £13 billion–£22 billion — see **Table A2.3**). Those in the severe scenario were judged to be within a range of 30% on the downside and 50% on the upside of the central estimate (ie £24 billion–£52 billion).

Table A2.3 UK banks' losses under global imbalances stress scenarios in July 2006

	£ billions		As a share of UK banks' Tier 1 capital	
	Moderate	Severe	Moderate	Severe
Lower bound	13	24	8%	15%
Impact estimate	17	34	11%	22%
Upper bound	22	52	14%	33%

(1) See 'Risk transmission in the Russian and LTCM crises', Box 7 in *Financial Stability Report* (2006), July.
(2) So the sterling trade-weighted exchange rate could instead depreciate rather than appreciate as is assumed in the scenarios.

Annex 3
Global corporate debt vulnerability[1]

(a) Vulnerability description

The global corporate debt vulnerability encompasses two distinct trends: first, the rapid growth in the exposures of UK banks to UK commercial property; second, the loosening of terms and conditions in the wholesale corporate lending markets.

Lending by the major UK banks to the UK commercial property sector has grown rapidly over the past six years. At end-June 2006, direct exposures totalled £125 billion, 2.7% of assets. This understates the importance of commercial property because a significant proportion of lending to non-financial companies is secured on commercial property.

Historically the UK commercial property sector has been more cyclical than the rest of the corporate sector and at times has been a major source of credit losses for UK banks. Commercial property price inflation has picked up over the past two years, reaching 15% in the year to May 2006, though it remains modest relative to the late 1980s. However, recent Bank analysis suggests that the implied commercial property risk premium is currently low relative to its 1998–2005 average.[2]

At the same time, while corporate sectors in the United States, United Kingdom and major European countries are in relatively good shape after several years of balance sheet restructuring, recent *FSRs* have identified a number of areas of potential concern, including:

- Rapid growth in the leveraged syndicated loan market, partly associated with leveraged buyout activity. This has been accompanied by some dilution in loan covenants. In the United States, for example, there has been an increase in the proportion of new loans where covenants allow 'leverage' multiples, as measured by debt to earnings ratios, of over seven. Underwriting league tables suggest that some of the major UK banks are significant players in this market.

- The rapid growth in markets for structured products such as collateralised debt obligations (CDOs) and commercial mortgage-backed securities (CMBS). In 2005, global issuance of CDOs increased by two thirds while CMBS issuance nearly doubled. While credit structuring can play a beneficial role in the efficient allocation of risk in the financial system by breaking down and redistributing the credit risk of the underlying debt claims, it also has the potential to lead to excessive concentrations of credit exposures.

UK banks' domestic corporate exposures, other than commercial property, account for around 4% of global assets. Overseas exposures to non-financial companies are estimated to account for 10% of their worldwide consolidated assets. These corporate exposures vary in nature from the conventional commercial exposures to capital market-related exposures.

(b) Description of stress scenarios

The corporate stress scenarios involve significant global macroeconomic slowdowns that affect the domestic and international corporate exposures of UK banks. They seek to provide a gauge on the potential impact of such events on overall corporate exposures, rather than a specific measure of the impact of a particular problem arising from the commercial property sector, leveraged lending or structured credit exposures.

The scenarios model stylised supply-side shocks, which reduce economic activity but raise inflation. **Table A3.1** describes key features of the scenarios for the UK economy. The macroeconomic developments in the severe scenario are similar to those in the early-1990s UK recession, although lower current inflation means that a given real asset price adjustment necessitates greater nominal price falls. House prices fall, returning the house price to earnings ratio to its average over the past two decades, while unemployment rises to levels experienced in the 1990s recession. The moderate stress scenario was designed to capture a less unlikely, and also less extreme, event — with the economy not falling into recession and nominal property price falls similar in magnitude to those experienced in the early 1990s.[3] In both scenarios, monetary policy is assumed to tighten, because the effect of higher inflation outweighs that of slower growth given the assumed Taylor interest rate rule (see footnote 1 on page 10).

Table A3.1 Details of the UK scenarios

Variable	Moderate scenario	Severe scenario
Trough in real GDP growth	1.5%	-1.4%
Peak in unemployment	6%	10%
Peak in nominal interest rates	8%	11%
Peak in inflation	3.6%	5.3%
Fall in commercial property prices[a]	21%	34%
Fall in house prices[a]	10%	23%
Peak in secured arrears (quarterly)[b]	1.6%	2.9%
Peak in unsecured arrears (quarterly)[c]	1.4%	1.8%

(a) Measured at peak to trough in nominal prices over the three-year horizon.
(b) Secured arrears measured as arrears of six months and above.
(c) Unsecured arrears measured as arrears of three months only.

(1) This annex was prepared by Alistair Barr of the Bank's Systemic Risk Assessment Division.
(2) See Box 1 in the *Financial Stability Review* (2005), December, which describes the application of a three-stage dividend discount model to commercial property values.
(3) For technical convenience, the shocks are modelled by using the combination of scenarios investigated by the IMF in the 2002 FSAP. See Hoggarth and Whitley (2003) for a description of the exercise.

The global scenarios are based on a simple assumption that all other countries to which the major UK banks have exposures experience a shock of equivalent magnitude to that faced by the United Kingdom.

(c) Risk transmission map

Three main channels through which corporate debt problems might lead to material costs for major UK banks were considered (numbered in **Chart A3.1**):

- *Credit risk*: Increased corporate write-offs, reflecting a deterioration in the ability of some corporates to service their debts. A fall in commercial property prices would be likely to amplify write-offs by increasing loss given default by non-financial companies (1).

- *Income generation risk*: A reduction in banks' net interest and fee income, a significant portion of which is associated with corporate lending (2).

- *Funding risk*: Reduced profitability of corporate lending might lower a bank's creditworthiness and raise the cost of external finance (3).

Data and modelling limitations mean that a number of potentially important financial propagation/amplification channels could not be quantified (as shown by dashed lines in **Chart A3.1**).

(d) Estimated impact of the scenarios on UK banks in July 2006

Credit risk

The effect of the macroeconomic downturn on corporates' financial health, and thereby on banks, was evaluated by using BEQM. In both scenarios inflation increases led to a sharp rise in interest rates and hence corporate income gearing. In the moderate downturn, the UK corporate liquidations rate was estimated to double by the end of the projection period, while in the severe downturn it matched its early-1990s peak by the end of the period. The UK write-off rate doubled relative to base in the moderate downturn and tripled in the severe downturn, in both cases leaving write-off rates below early-1990s levels. In the absence of data on the write-off rates on UK banks' overseas exposures, or a model of corporate write-off rates in other countries, it was assumed simply that the increase in the write-off rate on overseas exposures would be the same as on UK exposures. Overall, over the two years following the moderate (severe) stress scenarios, rising write-offs on the major UK banks' domestic and overseas corporate exposures led to losses of £13 billion (£25 billion) relative to base (**Table A3.2**).

Income generation risk

An increase in the financial pressures on corporates would also lead to a reduction in banks' net interest income, approximately 25% of which is associated with corporate lending. Margins, on both new and existing lending, would be likely to fall. There is also likely to be a reduction in the

Chart A3.1 Corporate debt transmission map

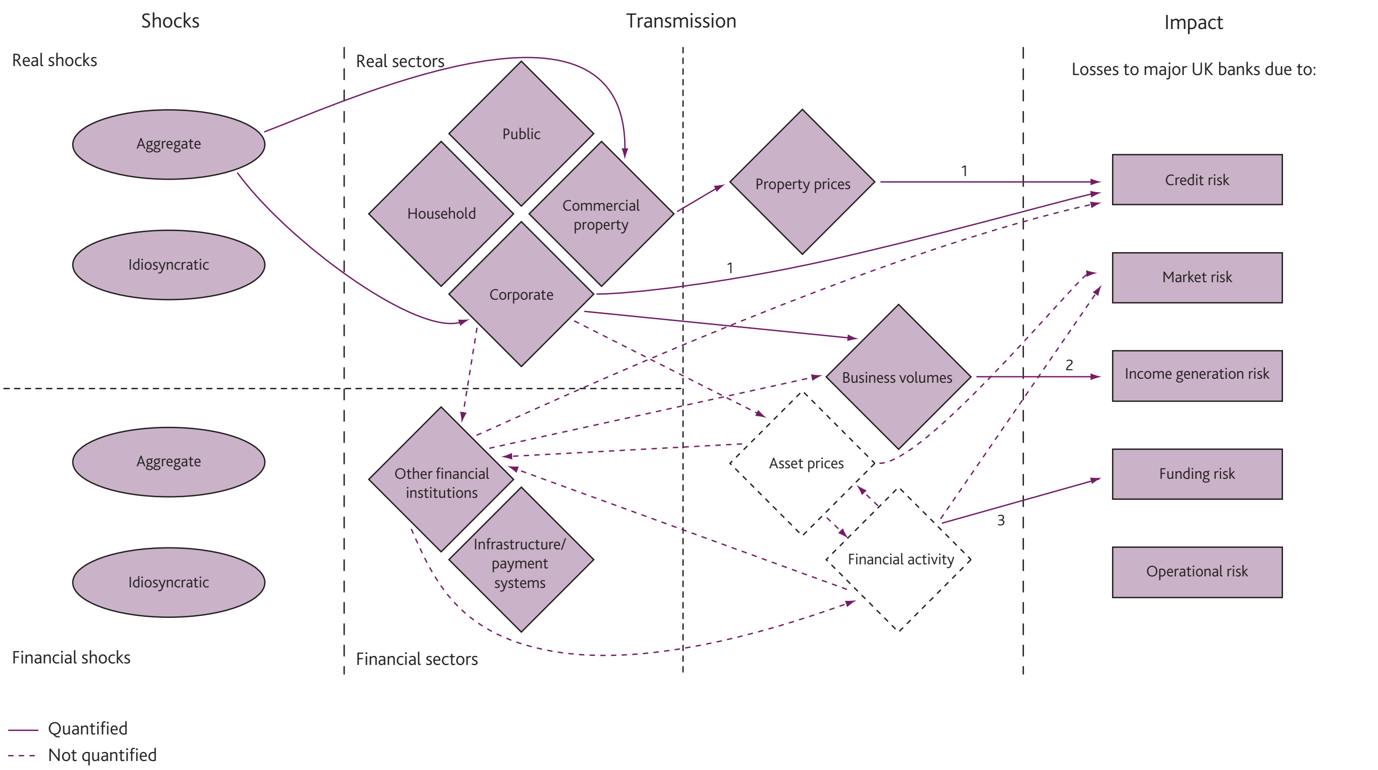


Table A3.2 Decomposition of total impact on UK banks by source (£ billions)

	Moderate scenario	Severe scenario
Credit risk:		
Write-offs on UK banks' corporate exposures	13	25
Income generation risk:		
Reduced net interest income due to slower growth	2	5
Funding risk:	0	2
Total losses	15	32
As a percentage of Tier 1 capital	10%	21%

volume of new lending. Using the simple model described in footnote 1 on page 12, this effect was estimated at £2 billion in the moderate stress scenario and £5 billion in the severe scenario.

Funding risk

It was judged that the losses arising in the moderate scenario would have no significant effect on banks' funding costs. In contrast, the reduction in profitability associated with the severe scenario may have a greater impact. Based on a rule of thumb, it was estimated that funding costs could rise by about £2 billion over the duration of the severe scenario.

Total losses

Although subject to large error bounds, the moderate stress scenario was estimated to reduce major UK banks' profits in the three years of the stress scenario by about £15 billion (or 10% of Tier 1 capital) (**Table A3.2**). The effect of the severe scenario was much larger, with cumulative costs of around £32 billion (21% of Tier 1 capital).

(e) Probability of scenarios

The probability of outturns being at least as bad as in the scenarios was calculated by initially looking at the frequency with which similar developments have occurred in the past. **Table A3.3** shows the 'bottom-up' probability of the key individual components of the UK scenarios occurring in the next three years. The probabilities were calculated by looking at the number of times that past outturns have been at least as bad as in the scenarios, or by using statistical inference from the volatility of the series.

Table A3.3 Three-year probability of scenarios[(a)(b)]

	Calculated using:					
	GDP growth	Unemploy-ment rate	Inflation	House price/ earnings ratio	Commercial property prices	Write-off rates[(c)]
Moderate stress scenario	35%	31%	18%	7%	12%	12%–20%
Severe stress scenario	13%	3%	10%	1%	1%	2%–6%

(a) Unconditional probability of variables changing by amount considered in scenario in next three years.
(b) Probabilities based entirely on statistical methods (eg frequency of events having occurred since the mid-1970s, or historical volatility); these probabilities do not take judgements into account.
(c) The values are reported as a range because different write-off rates were examined on both corporate and household exposures.

An overall assessment of probability also requires a number of other subjective judgements. One of the most important is making the probability conditional on the current environment — eg the current high level of UK commercial property prices relative to historical fundamentals is assumed to make prices more susceptible to a sharp fall in a severe downturn. It is also necessary to judge the probability of the overall scenario, and not just components. Self-evidently, the joint probability is lower than the probability of any individual component. But stress scenarios could also materialise with other combinations of adverse outcomes for component variables. To gauge this, a 'top-down' probability of an adverse scenario was also considered, by conducting analysis on UK banks' write-off rates in the past (final column in **Table A3.3**).

The overall judgement was that the probability of events being at least as bad in the next three years as those in the UK corporate stress scenarios was between 1 in 10 and 1 in 30. Within that broad range, the severe scenario was, of course, the less likely of the two. A simple assumption was made that the likelihood of a similar scenario occurring in the United States and euro area was broadly the same as in the United Kingdom. So the overall probability of events at an international level being at least as bad in the next three years as those in the global corporate scenario was judged to be in the same range.

(f) Key uncertainties and biases

The probability and impact calculations are subject to a number of uncertainties and biases.

- The scenarios assume that the probability of severe adverse events has remained broadly unchanged over time, despite structural changes to the economy; hence, that historical outcomes can be used to assess the probability of what might occur in the future.[(1)]

- Estimation error in the write-off equations is a significant source of uncertainty for the impact assessment.

- It is also possible that there is bias in these estimates of uncertainty, because many of the behavioural relationships were calibrated over a relatively benign period and do not capture the non-linearities that may develop in times of stress. In addition, they will not reflect possible structural shifts in these relationships over time.

- As with other vulnerabilities, results were derived assuming that monetary policy in the United Kingdom and elsewhere follows a Taylor rule. In addition, banks' portfolio

(1) See the speech by the Governor to the CBI North East Annual Dinner, 11 October 2005 (www.bankofengland.co.uk/publications/speeches/2005/speech256.pdf).

composition was assumed to be constant over the duration of the stress test. Banks do not therefore reduce exposures as conditions start to worsen. While this could mitigate losses, system-wide reductions in lending or asset sales could amplify the impact.

- The risk characteristics of the banks' overseas corporate exposures were implicitly assumed to be the same as those of the banks' UK corporate exposures.

These uncertainty bounds will be large. **Table A3.4** reports some rough judgements on their possible scale, inferred largely from examination of estimation uncertainty in the relevant equations.

Table A3.4 UK banks' losses under global corporate debt stress scenarios in July 2006

	£ billions		As a percentage of UK banks' Tier 1 capital	
	Moderate	Severe	Moderate	Severe
Lower bound	10	21	7	13
Impact estimate	**15**	**32**	**10**	**21**
Upper bound	21	45	13	29

Annex 4
UK household debt vulnerability[1]

(a) Vulnerability description

Lending to UK households has risen rapidly in recent years and the ratio of household debt to post-tax income has increased from 100% in the mid-1990s to about 150% in 2006.[2] UK household lending, at £865 billion in June 2006, is the largest single category of exposure for the major UK banks.

Banks can limit risks to their balance sheets from household lending through careful vetting of potential borrowers and by charging a suitable margin on their lending. But household debt portfolios may be vulnerable to a severe generalised reduction in credit quality resulting from a macroeconomic downturn. A number of potential co-ordination failures limit banks' ability to insure themselves fully against loss. For example, lending to a client by one bank may increase the risk of default on another bank's lending to that same client. And individual institutions' attempts to limit losses may exacerbate system-wide losses. For example, a reduction in the aggregate supply of credit may further strain households' financial positions, while a large number of house repossessions by lenders could amplify downward pressure on house prices, reducing the value of collateral and potentially increasing losses for all lenders.

The majority of UK household lending is secured on property, where loss rates in the event of default would be low. But since the early 1990s, the higher growth rate of unsecured lending has increased its share of total household lending from 15% to 20%.[3] Credit card lending — which has the highest and most volatile write-off rate — is making up an increasing share of this component.

In recent years there has been a deterioration in the ability of some households to repay their debts. Personal insolvencies have increased by over 60% in the past year, and their level (excluding the self-employed, where trends follow corporate conditions) is over three times as high as their early-1990s peak. Write-offs on banks' unsecured household lending have also increased, accounting for about three quarters of major UK banks' total domestic write-offs in 2005.

Household write-off rates could rise substantially further if there were a severe macroeconomic downturn. The potential for pronounced cyclicality was recently illustrated in Hong Kong, where rising unemployment, and a doubling in the number of personal bankruptcies, contributed to the credit card write-off rate reaching a record high of 13.3% in 2002, compared with 5.5% a year earlier.

(b) Description of stress scenarios

The UK household debt stress scenarios investigate the potential effect on UK banks of a significant economic slowdown in the United Kingdom. The scenarios were designed in exactly the same manner as described in the corporate debt vulnerability annex (see Annex 3 and **Table A3.1** for details) and adopt identical assumptions about the behaviour of monetary policy makers and banks. So the macroeconomic developments in the severe scenario are similar to those in the early-1990s downturn, while the moderate stress scenario captures a more likely, but less extreme, slowdown in the economy.[4]

(c) Risk transmission map

The main channels through which household debt problems might lead to material costs for major UK banks (numbered in **Chart A4.1**) are similar to those described in Annex 3:

- *Credit risk*: Increased write-offs on lending, reflecting a deterioration in some households' ability to repay their debts. Falling house prices would be likely to amplify write-offs by increasing loss given default (1).

- *Income generation risk*: A reduction in banks' net interest and fee income, a significant portion of which is associated with household lending (2).

- *Funding risk*: Reduced profitability of household lending might lower a bank's creditworthiness and raise the cost of external finance (3).

(d) Estimated impact of the scenarios on UK banks in July 2006

Credit risk

Write-offs were estimated using the equations set out in Box B on page 12. Losses were estimated at around £5 billion over the three years of the moderate stress scenario, reflecting the effects of increased unemployment and higher payments on debt relative to income (**Table A4.1**). The effect of the severe stress scenario was much larger, with cumulative costs of about £10 billion.

Income generation risk

Estimates derived from a simple equation linking income generation to activity levels (see footnote 1 on page 12) were that banks' net interest income would fall by £4 billion (£13 billion) in the moderate (severe) stress scenarios.

Funding risk

It was judged that the relatively small losses (compared with annual major UK bank profits) in the moderate stress scenario

(1) This annex was prepared by Robert Hamilton of the Bank's Systemic Risk Assessment Division.
(2) In aggregate, the increase in debt has been more than offset by the accumulation of financial assets. But the wealth distribution is extremely skewed across individual households and there has been an increase in the proportion of households with negative net worth and an increase in the value of their net debt.
(3) In the past year, the growth of unsecured lending has fallen sharply, with annual growth below that of mortgage lending.
(4) For technical convenience, the combination of scenarios investigated by the IMF in the 2002 FSAP was used to model the shocks.

Chart A4.1 Household debt transmission map

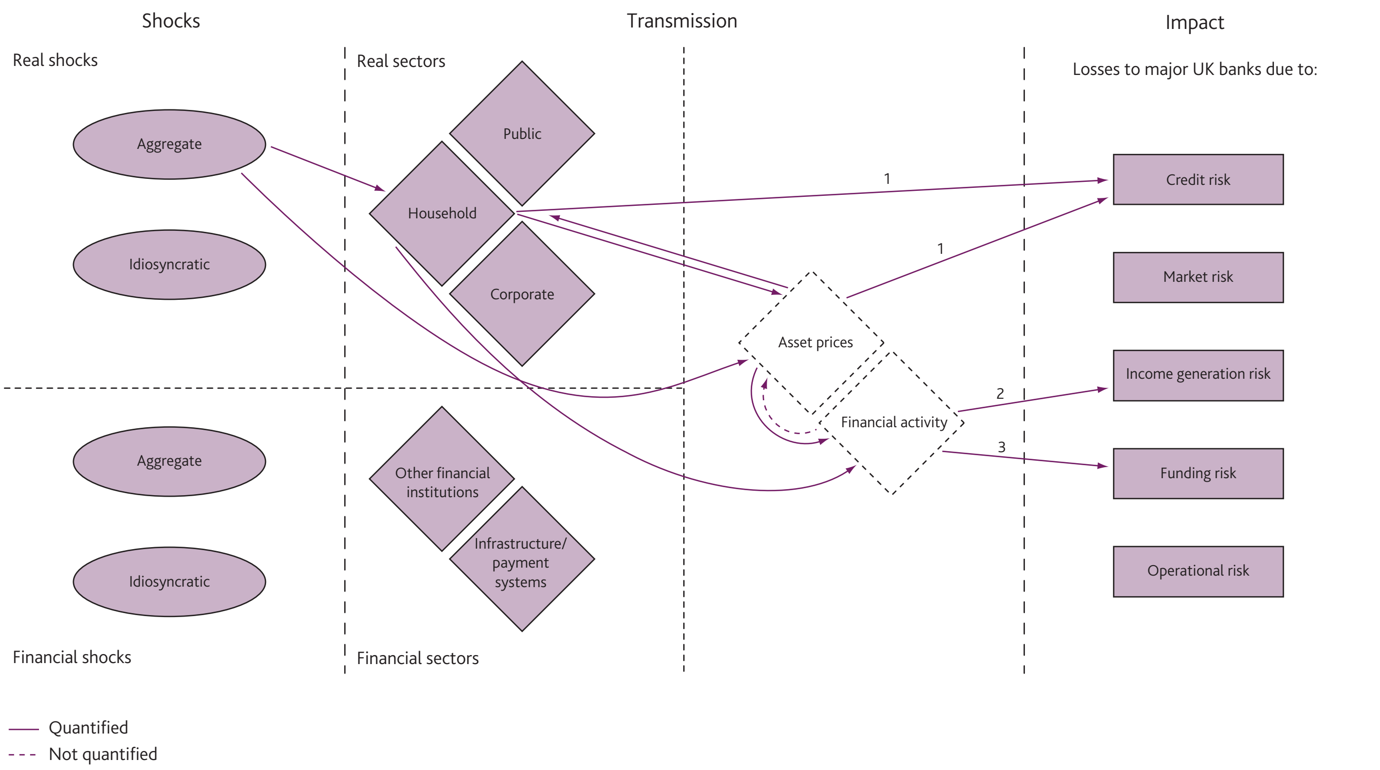


Table A4.1 Decomposition of total impact on UK banks by source (£ billions)

	Moderate scenario	Severe scenario
Credit risk:		
Write-offs on UK banks' household exposures	5	10
Income generation risk:		
Reduced net interest income due to slower growth	4	13
Funding risk:	0	2
Total losses	9	25
As a percentage of Tier 1 capital	6%	16%

would not result in any significant effect on banks' funding costs. The reduction in profitability associated with the severe stress scenario may have a greater impact. As in other vulnerability scenarios, using a rule of thumb estimate based on past experience of ratings downgrades, funding costs were estimated to rise by about £2 billion over the three-year horizon (**Table A4.1**).

Total losses

Although subject to large error bounds, the overall impact estimate was that the moderate shock would reduce major UK banks' profits over three years by about £9 billion (**Table A4.1**). The effect of the severe stress scenario was larger, with cumulative costs of around £25 billion.

(e) Probability of scenarios

The probability of outturns being at least as bad as in the scenarios was calculated by adopting an identical approach to that set out in Annex 3 and summarised in **Table A3.3**.

As highlighted in Annex 3, the overall assessment of the probability of a recession scenario requires a number of subjective judgements. One challenge is to gauge the probability of the overall scenario, and not only its components: stress scenarios could also materialise with other combinations of adverse outcomes. Another set of judgements arises when conditioning probabilities on current economic conditions.

The overall judgement is that the probability of events being at least as bad in the next three years as those in both the household scenarios was between 1 in 10 and 1 in 30, although self-evidently the severe scenario was the less likely of the two.

(f) Key uncertainties and biases

The probability and impact calculations are subject to the same general uncertainties and biases as described in Annex 3.

- The scenarios assume that the probability of severe adverse events has remained broadly unchanged over time, despite structural changes to the economy; hence, that historical outcomes can be used to assess the probability of what might occur in the future.[1] As discussed above, the probability assessment is subject to considerable judgement.

- A significant source of uncertainty surrounding the impact assessment arises from the error bounds on the write-off equations.

- A source of bias is that many of the behavioural relationships were calibrated over a relatively benign period and do not capture non-linearities that may develop in times of stress. In addition, they will not reflect possible structural shifts in these relationships over time.

- The results assumed that monetary policy follows a Taylor rule. This assumption has a quite significant impact on the estimates. The effect of switching off the Taylor rule and holding monetary policy constant would be to reduce substantially the impact of the shocks in the scenarios.

In addition, a number of specific uncertainties and biases arise.

- Household sector write-offs and bankruptcies have increased sharply over the past year, despite benign economic conditions. If this continues, write-offs in a downturn would develop from a higher base.

- As with other vulnerabilities, banks' portfolio composition was assumed to be constant over the duration of the stress test. In practice, this assumption is unlikely to hold. Indeed, a number of UK banks have tightened lending criteria over the past year with the aim of reducing their vulnerability to household credit risk.

- The model assumes that rising losses by banks do not lead to an abnormal reduction in lending ('credit crunch') or asset fire sales (property collateral sold into a falling market). By increasing loss given default, these effects could magnify the impact on banks, particularly following a severe shock — for example, a further 10% haircut on collateral values was estimated to increase banks' write-offs by £3.4 billion.

As shown in **Table A4.2**, the uncertainty bounds were large, stretching from £7 billion–£12 billion for the moderate stress scenario to £17 billion–£33 billion for the severe stress scenario, largely reflecting the estimation uncertainty in the relevant equations.

Table A4.2 UK banks' losses under UK household debt stress scenarios in July 2006

	£ billions		As a percentage of UK banks' Tier 1 capital	
	Moderate	Severe	Moderate	Severe
Lower bound	7	17	4	11
Impact estimate	9	25	6	16
Upper bound	12	33	7	21

(1) See the speech by the Governor to the CBI North East Annual Dinner, 11 October 2005 (www.bankofengland.co.uk/publications/speeches/2005/speech256.pdf).

Annex 5
LCFI stress vulnerability[1]

(a) Vulnerability description

Severe stress at an LCFI, or in an extreme scenario a sudden failure, could have far-reaching implications given LCFIs' central role in financial intermediation and market-making. The cause of such stress could be idiosyncratic, for example arising from a massive internal fraud, or a wider systemic event. Both systemic and idiosyncratic events are likely to be related. A wider systemic event could reveal excessive exposure concentrations or other operational weaknesses at an LCFI. An idiosyncratic problem at an LCFI could well be a trigger for more widespread stress or significantly aggravate problems arising for the system from another source.

The likelihood of sudden idiosyncratic default by large, well-diversified and well-capitalised institutions, that have sophisticated internal risk management systems and are subject to close supervision at both regulated entity and consolidated group levels, seems remote. But it cannot be ruled out. A more likely — although still remote — possibility is the development of severe problems at one or more LCFIs arising from more generalised severe system stress. Such an event could have the effect of transforming seemingly well-diversified portfolios into unexpectedly concentrated positions that are subject to heightened market or default risk. Liquidity might dry up in markets used by market-makers for dynamic hedging strategies. Such difficulties could be further intensified by operational weaknesses (such as recently illustrated by the backlog in credit derivative confirmations and unnotified assignments) and by strains on the financial infrastructure as a consequence of a rapid move to collateralise or close out such exposures. These strains might lead to unexpected payment delays, thereby increasing the demand for credit. But in such circumstances lenders, faced with uncertainties over the standing of borrowers and the value of collateral, may be reluctant to meet this increased demand. Such strains on liquidity could precipitate failures among dealers or other financial intermediaries.

The possible channels for such system-wide stress are numerous and inter-related. They are very hard to quantify individually or directly given the limited data available. Moreover, the relative importance of different channels is likely to depend on the nature of the shock or combination of shocks that lead to stress at a LCFI. Current risk positions will not remain static or be unresponsive to rising stress and so may not be representative of what might be expected in a crisis.

(b) Description of stress scenarios

The LCFI stress scenarios are quite different in nature to those used to assess the materiality of other vulnerabilities. Rather than being defined by a set of specified triggering events, they are statistically based. The scenarios derive an estimate of losses arising on a portfolio of large counterparty exposures of UK banks to LCFIs. The scenarios are defined by points on portfolio loss distributions. Both the moderate and severe stress scenarios are defined by UK banks' expected portfolio losses above the 95th percentile. The loss distribution is characterised by the choice of a common default probability and correlation parameter. In the moderate scenario, the probability of default is given by the average CDS-implied probability of default (PD) as at March 2006, with the correlation parameter based on daily changes in CDS spreads over the preceding twelve months. In the severe stress scenario, the mean default probability is increased to levels implied by spreads in October 2002 (over the September 2002-September 2003 period financial markets experienced considerable stress), while an upward adjustment is made to the assumed correlation to simulate heightened sensitivity of LCFIs to a common shock.

(c) Risk transmission map

The key role played by LCFIs in intermediating credit, market and other risks and their multiple links to UK banks is illustrated by the risk transmission map (**Chart A5.1**). In addition to the fact that some of the major UK banks are LCFIs themselves, even domestically orientated UK retail banks can be affected by LCFIs' activities insofar as they draw on their services to offer sophisticated investment products and hedge the attached risk.

Quantifying the scale of these linkages, which are likely to fluctuate through time, is very hard. The level and nature of risks associated with asset holdings will vary over time. Maturities of assets and liabilities will be constantly changing. As the risk map suggests, the value of some exposures (especially complex derivatives with embedded options) will be dependent on movements in asset prices, some in a non-linear manner. A market-wide shock can cause the value of positions to swing considerably, triggering rapid adjustments to portfolios (including sales of assets to meet margin calls) which may also affect prices sharply. The initial impact of a shock may be amplified by falls in market liquidity as major market players attempt to reduce positions and leverage while retaining as far as possible their credibility as long-term market-makers.

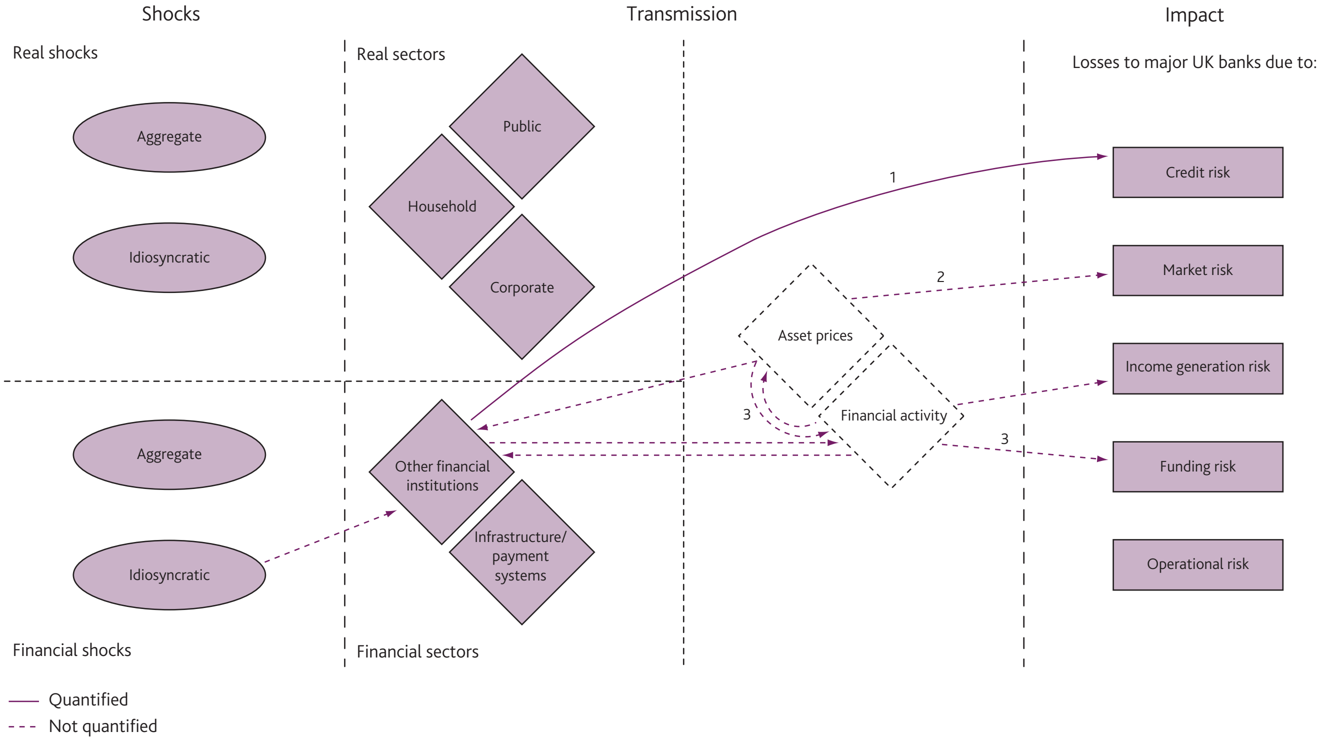
The link estimated at this stage is illustrated by the solid line in **Chart A5.1**. The dashed lines show links that have been recognised but not quantified.

(d) Estimated impact of the scenarios on UK banks in July 2006

Reflecting the difficult measurement issues described earlier, initial efforts to model the probability and impact of an LCFI

(1) This annex was prepared by Colin Miles and Tom Belsham of the Bank's Systemic Risk Assessment Division.

Chart A5.1 LCFI stress transmission map



failure on major UK banks have been limited in scope. The focus has been on losses that might arise for UK banks exclusively from counterparty exposures to LCFIs. There has been no explicit attempt to identify other channels or to capture the indirect impact of market disruption on UK banks' credit, market and operational risk exposures that might arise from system-wide stress that is unrelated to their counterparty relationships with LCFIs.

First, supervisory data on counterparty 'large' exposures were used to construct an aggregate portfolio of UK banks' exposures to LCFIs.(1) Using market information on default probabilities and correlations, probability distributions of credit losses on this portfolio could then be generated. By focusing on the adverse tail of that distribution and examining the sensitivity of losses to assumptions about default probability and correlation, it was possible to obtain an estimate of potential losses under extreme stress.

To calculate the joint loss distribution, a methodology described by Vasicek (2002), and similar to that which underlies the Internal Ratings Based (IRB) approach to generating Pillar 1 capital requirements under Basel II, was adopted.(2) Under this approach, asset values of banking book credit counterparties are assumed to be correlated with a single systemic risk factor, where both the systemic risk factor and the asset values of the individual counterparties are assumed to be (marginally) distributed as standardised normal variables. This has the implication that default correlations between different LCFIs in the portfolio are determined solely by their correlation with the single systemic risk factor.

Calculating the loss distribution then requires only estimates of (i) the correlation parameter and (ii) the probability of default of the portfolio of 'large counterparty exposures'. The correlation parameter is an important determinant of the shape of the — highly skewed — loss distribution and thus has a significant influence on the size of extreme tail losses. While under the IRB approach default correlation for non-financial corporate exposures is determined by a formula dependent on PDs, this may not be suitable for exposures to financial institutions whose market inter-linkages can be expected to be higher. This may be particularly true during a systemic crisis. Therefore, instead of adopting the Basel formula for correlation, under the moderate scenario a simple average of estimated inter-LCFI default correlations was used, derived from daily changes in CDS prices over a trailing twelve-month window. Following Vasicek, an upward adjustment was then made to reflect the highly concentrated nature of the portfolio of large exposures.(3) In addition, since historical CDS spread data provide only modest opportunities to assess the impact of market turbulence, given that they became

(1) For regulatory purposes, 'large exposures' are defined as any exposures that exceed 10% of eligible capital (Tier 1 plus Tier 2 capital, less any regulatory deductions).
(2) See BIS (2005).
(3) The IRB approach assumes a well-diversified portfolio in which the idiosyncratic risk of default of an individual borrower on the portfolio is eliminated. This is not a valid assumption in the case of a portfolio of exposures to a relatively small number of LCFIs. Vasicek addresses this issue by providing a 'granularity' or concentration adjustment to the assumed correlation which takes the form: $\hat{\rho} = \rho + \delta(1 - \rho)$ where $\hat{\rho}$ is the adjusted correlation, and

$$\delta = \sum_{i=1}^{n} w_i^2$$ where the w_i are the shares of each exposure in the portfolio. For a given number of assets n, δ will be at a minimum (equal to $\frac{1}{n}$) when the portfolio is evenly distributed, and as n increases, $\delta \rightarrow 0$. The proportional adjustment increases as ρ falls.

Chart A5.2 Cumulative probability of losses on UK banks' exposures to thirteen LCFIs: moderate stress scenario

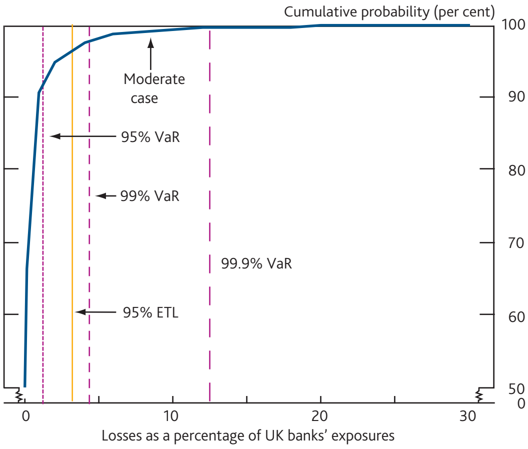
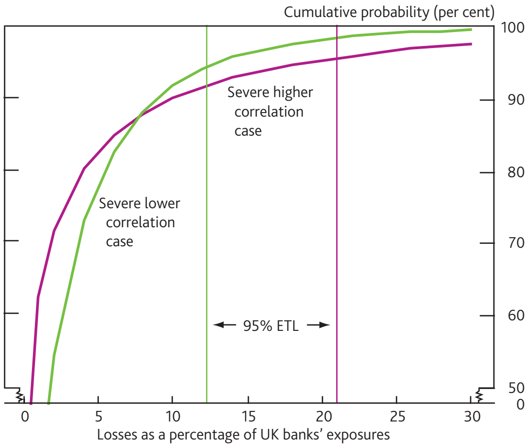


Chart A5.3 Cumulative probability of losses on UK banks' exposures to thirteen LCFIs: severe stress scenarios



Assumes loss given default of 60%. Based on estimated PDs derived from CDS spreads as at end-March 2006 ('moderate' case) and mid-October 2002 ('severe' case). For the moderate case, default correlation is based on an average of daily changes in CDS spreads over the twelve months ending 31 March 2006. In the 'severe' cases average pair-wise correlations of 0.5 and 0.2 are assumed for the higher and lower default correlation cases respectively.

The dotted, dashed and dotted-dashed vertical lines show, respectively, the 95%, 99% and 99.9% percentiles. (99.9% is the standard adopted for Basel II minimum capital requirements.) The solid vertical bands show 95% expected tail losses (or 'conditional VaRs'), ie the probability weighted mean loss given that the loss event occurred within the extreme adverse 5% tail of the distribution.

available only in 2001, to reflect priors about the likely increased co-dependence between asset prices under highly stressed conditions a further upward adjustment was made to the correlation parameter under the severe scenario.

Finally, probabilities of default under the two scenarios were derived from CDS spreads. Under the assumption that credit protection is fairly priced, the value of a CDS contract should equate the expected return in the event of default with the expected return in the event of no default. So, for firm *i*, with spread S_i, loss given default D_i, and probability of default p_i, it must be the case that:

$$p_i D_i = (1 - p_i) S_i$$

Rearranging the terms, the (CDS implied) probability of default is:

$$p_i = \frac{S_i}{(D_i + S_i)}$$

The above formula requires only an assumption about the loss given default (or recovery rate) to enable calculation of the CDS implied probability of default; this was assumed to be 60%.(1)

The model used CDS spreads as at end-March 2006 for the moderate scenario. Using this approach the exposure-weighted average PD for UK banks' LCFI portfolio was a mere 0.44%. Using these inputs, the model produced a near 'corner' rectangular default distribution (**Chart A5.2**), indicating virtually no possibility of significant loss. Also shown are the VaRs at three different confidence levels and an estimate of the expected tail loss ('ETL' — or 'conditional VaR') within the 95% tail. The expected tail loss defines the mid-point estimate of impact in the moderate scenario.

Given the current very low level of market-based PDs, the small scale of losses even in the extreme tail is unsurprising. However, one does not have to go back very far to identify a period when expected defaults for the group were significantly higher (although it is unlikely in practice that these higher PDs would persist for long given the need for remedial action, either at the initiative of the firms or in response to the demands of their regulators).

In order to understand what a severe stress scenario may look like, **Chart A5.3** compares the moderate stress case with two more extreme cases, both of which assume PDs equivalent to those prevailing in mid-October 2002, but with alternative assumptions regarding default correlation. At that time, the average three-year PD for the group was 3.5%, with a range of 1.6%–7.4%. Default correlation, before the adjustment for granularity, was assumed to be 0.5 in the higher correlation case, and 0.2 in the lower case. As can be seen, increasing the correlation raises the probability at both extremes of the distribution (ie increases the probability both of zero loss and of larger losses). Also shown are the expected tail losses within the 95% percentile for each case. The high correlation case was finally used to generate a measure of impact in the severe stress scenario.

To compute the impact under each of the two scenarios, moderate and severe, the 95th percentile loss provides the

(1) Two important caveats apply, however. The first relates to the loss given default. If market practitioners employ a given recovery rate when pricing CDS spreads, any differences in their perceptions as to the true recovery rate will be incorporated in the spread. Implied PDs will then capture the residual between the recovery rate used to price the derivative, and the counterparties' actual beliefs about the likely losses in the event of default. The second is that in setting expected returns in the default case equal to expected returns in the no-default case, this calculation of the fair value of the contract assumes that agents are risk-neutral. In reality, asset prices are likely to reflect investors' risk aversion, so implied probabilities will tend to overstate the market's true perception of credit risk.

lower bound; the probability-weighted loss in excess of that percentile gives the expected loss (where the probability mass in the tail is normalised to 1).

Table A5.1 summarises estimated losses in the moderate and severe stress scenarios as measured in July 2006.

Table A5.1 Decomposition of total impact on UK banks by source (£ billions)

	Moderate scenario	Severe scenario
Counterparty credit risk:	5	33
Total losses	5	33
As a percentage of Tier 1 capital	3%	21%

(e) Probability of scenarios

As noted above, the LCFI stress scenarios are statistically based — losses arising above the 95th percentile — conditional on a set of assumptions made in specifying the shape of the distribution of portfolio losses, with losses in the severe scenario characterised by a realisation from a more skewed distribution. Purely in that conditional sense, both the moderate and severe stress scenarios are 1 in 20 events over the three years of the scenario. But in an unconditional sense, the severe scenario will be much less likely given the extreme assumptions made about losses given default and correlation of losses.

(f) Key uncertainties and biases

The approach set out provides a helpful framework for monitoring the implications for potential losses of changes in market sentiment about LCFI default and of different assumptions regarding default probability and correlation. But the analysis is partial. In particular, the systemic implications of LCFI stress were captured only indirectly via a correlation assumption and only to this degree do the results extend to the wider impact on UK banks of the market disruption that the failure of an LCFI would seem likely to produce.

The uncertainty bounds, shown in **Table A5.2**, are broad and were gauged using sensitivity analysis on confidence intervals and correlation assumptions.

Table A5.2 UK banks' losses under LCFI stress scenarios in July 2006

	£ billions		As a percentage of UK banks' Tier 1 capital	
	Moderate	Severe	Moderate	Severe
Lower bound	2	18	1	12
Impact estimate	5	33	3	21
Upper bound	7	43	5	27

Annex 6
Infrastructure disruption vulnerability(1)

(a) Vulnerability description

In recent years global payment and settlement systems have become more sophisticated, dealing in ever greater volumes and values of transactions. Significant advances have been made in reducing risks involved in settlement, particularly compared with traditional bilateral net arrangements. These have included the introduction of new systems, for example CLS(2) to reduce Herstatt risk in FX settlement, or new approaches to enhance the risk reduction capability of existing systems, for example Delivery Versus Payment in central bank money for CREST.(3)

At the same time, the financial system has become increasingly dependent on a small number of infrastructure service providers. Alternative processes are unlikely to be implemented quickly or cheaply in the event of severe disruption. Furthermore, the interdependency of systems means that, if problems arise, they could have a wide-ranging impact across payment and settlement systems and financial firms globally.

These problems would be exacerbated if the contingency plans of providers and users of such infrastructure are either incomplete, not fully understood or inadequately tested. Responses to a recent UK survey suggest that, despite considerable investment in enhancing their business continuity arrangements, many firms are unclear as to how they would operate if there were to be a significant impairment to market infrastructure.(4)

(b) Description of scenarios

The infrastructure disruption scenario is designed to examine interdependencies between infrastructure providers, rather than focusing on one specific system. The scenarios centre on a problem emerging in the SWIFT messaging system, not because this was regarded as vulnerable but because the scenarios are illustrative of a number of potential issues. Two specific scenarios are considered, the first a SWIFT outage that lasts for one day (the moderate scenario) and the second an outage that lasts for two weeks (the severe scenario).

SWIFT provides secure messaging services to financial institutions and market infrastructures covering more than 7,500 users in over 200 countries. Many financial institutions and market infrastructures have built their IT systems around these SWIFT services in a way that makes them highly reliant on SWIFT's resilience. The UK financial system is particularly dependent on SWIFT, because major UK wholesale market infrastructures, such as CREST, CHAPS, CLS and LCH.Clearnet Ltd, all use the SWIFT system. If SWIFT is not available for a sustained period of time, many of these systems will be unable to operate given the absence of direct substitutes, severely impairing the ability of financial institutions to make payments and to settle transactions. Such unavailability is of course highly unlikely — SWIFT has never experienced a prolonged disruption and has invested heavily in backup sites and business continuity arrangements.

Table A6.1 Details of scenarios

Variable	Moderate	Severe
SWIFT outage	One-day duration	Two-week duration

(c) Risk transmission map

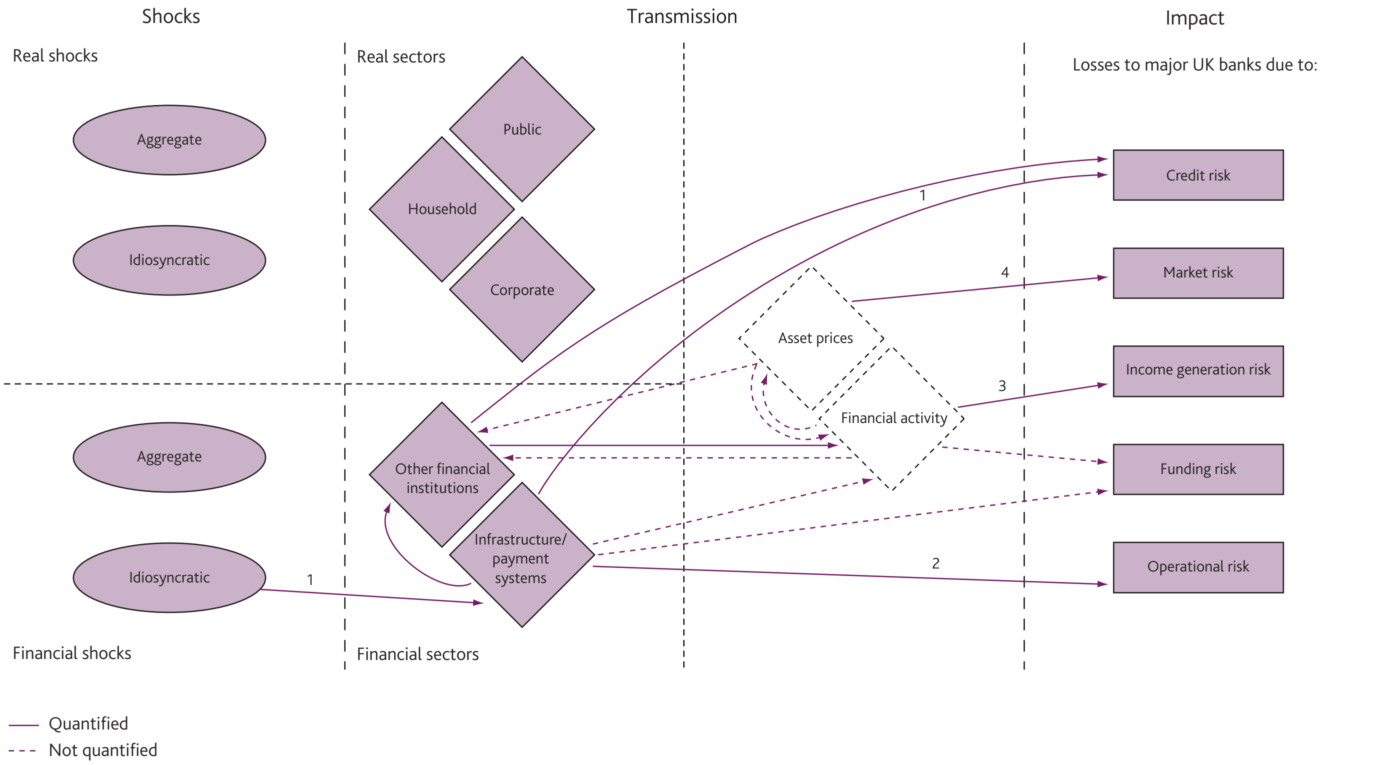
The most immediate manifestation of a SWIFT outage on the UK financial system would be the impairment of wholesale payment and settlement systems. The payment system is a complex and integrated network of component systems; the United Kingdom is no exception. Even if an individual component were not directly affected, it could face knock-on effects from problems in connected systems. Problems could also spread internationally. For example, CLS relies on a network of Real Time Gross Settlement Systems connected at the national level and a problem in any one of these, including the one in the United Kingdom, could have repercussions for CLS and for its members globally. An impairment of wholesale payment and settlement systems could affect firms across the financial sector, even those that are not direct members of these settlement systems, but who rely on members to provide payment and settlement services. In extreme circumstances, large parts of the financial sector could face liquidity shortages.

Chart A6.1 shows the risk transmission map for a SWIFT outage. Four distinct channels through which the scenarios impact on UK banks were quantified in the July 2006 *FSR*:

- *Credit risks*: The timing of any outage is an important determinant of the nature and scale of the impact, with the greatest effect likely to materialise if the outage occurred intra-day, when firms are likely to be running intra-day positions. If the payments and settlement systems were significantly impaired, such exposures may need to be extended overnight and beyond. While exposures within CHAPS are collateralised, other exposures outside this system may not be. This could lead to providers of such financing facing increased credit risks (1). Retail payment systems in the United Kingdom are less SWIFT-dependent than wholesale systems, so retail payments are likely to be relatively unimpaired. There may, however, be some delay to higher value payments and the issue of corporate

(1) This annex was prepared by David England and Garreth Rule of the Bank's Systemic Risk Assessment Division.
(2) Continuous Linked Settlement.
(3) CREST is the real-time securities settlement system for UK and Irish securities.
(4) See FSA (2005).

Chart A6.1 SWIFT outage transmission map



securities. If the outage lasted for a sustained period, this could lead to companies demanding more credit from banks than usual, perhaps further increasing credit risk.

- *Income generation, operational and funding risks*: Added settlement risks and, potentially, trading suspensions would be likely to lead to a sharp fall in trading volumes and market liquidity. While the exchanges could continue largely unimpaired, difficulties within firms' own systems, problems in confirming positions and the fear of long delays in settlement could discourage many market participants (2). Falls in trading volumes could lead to a reduction in revenue generation (3). Primary issuance would probably be affected across a range of markets, and perhaps postponed, affecting the ability of companies and banks to raise funding. This could have adverse effects on capital spending, at least for the period of the outage.

- *Market risk*: Reduced trading volumes and lower market liquidity could lead to greater volatility in asset prices and an impaired ability to close out positions (4).

Uncertainty over contingency plans of either market participants or infrastructure providers would be likely to exacerbate further many of these risks.

(d) Estimated impact of the scenarios on UK banks in July 2006

Many potential channels of impact are hard to quantify, particularly the wider costs of market disruption, lost new business opportunities and longer-term reputational costs for systems and firms. The main channels that have been quantified are:

Operational risks

Operational risk estimates were based on responses to the Tripartite Resilience Benchmarking Project, which reports firms' estimates of costs, claims and charges likely to arise in the event of key wholesale market functions being disabled.[1] The estimates cover custody, trade clearing, settlement, wholesale payment and trading functions. They are also likely to include an element of funding risk costs, though this is difficult to identify separately. Several simplifying assumptions were used in deriving quantitative operational risk estimates from firm responses. Firms' cost estimates were reported as ranges, so assumptions were made about average costs within ranges: for example, responses in £25 million-plus categories were assumed to equate to an average cost of £40 million. The survey also looked exclusively at the domestic costs of market impairment for the UK banks. To proxy for the costs of operational disruption internationally, the estimates were scaled up by the ratio of UK banks' total (domestic and overseas) assets to domestic assets, which had the effect of broadly doubling the estimates. The resulting operational risk estimates were £0.4 billion in the moderate scenario and £3.5 billion in the severe scenario (**Table A6.2**).

(1) The Tripartite Resilience Benchmarking Project. See FSA (2005).

Counterparty credit risks

Additional counterparty credit risks could arise from extended overdrafts to correspondent banking customers, from exposures to other banks more generally and from delays in settlement. A crude measure of added counterparty credit risk, as measured by expected loss on overdrafts extended by UK banks (proxied as CHAPS members) to second-tier banks, was derived by multiplying intra-day overdraft limits by an estimated 'stressed' default probability. This was based on CDS premia for the two-week period of the outage in the severe stress scenario (an unstressed default probability is used for the one-day moderate stress scenario).(1) The two-week stressed default probability was applied also to UK-owned banks' total overseas exposures to other banks to estimate the added credit risk from financial stress caused by a SWIFT outage on those exposures. The additional expected loss estimates were negligible, reflecting the short period of the outage.

Settlement delays could also add to counterparty credit risk. Due to the prevalence of 'delivery versus payment' systems in securities settlement, the cost faced by banks is one of replacement cost (the risk that a counterparty goes bankrupt before settlement of a security, and that market movements mean that a loss is involved in replacing the security). In gauging this risk, it was assumed that trading would continue at average levels over the period of the outage, and that settlement backlogs would lead to settlement delays for each day's trading equal to the length of the outage. Price volatility was scaled up by a factor of ten to proxy wider financial market turbulence. Recent, low, default probabilities were used for the one-day outage while stressed default probabilities were the basis of estimates for the ten-day outage. It was also assumed that the resulting replacement cost risks to the major UK banks resulted from delayed settlement in UK equities, gilts and bonds in CREST, and transactions in CLS with a sterling leg. Even under these generally extreme assumptions the estimated replacement costs were negligible.

Business (or income generation) risks

Market disruption might affect the major UK banks directly through lower trading revenues or losses on trading portfolios. A worst-case scenario for trading revenues would be for all trading revenue to be lost during the SWIFT outage. Scaling total annual trading profits of the major UK banks suggested minimal costs in the one-day outage and £0.3 billion for the ten-day outage.

Market risk

Volatility in financial prices could also lead to potential market losses, though the scale would be uncertain and depend on the positions of individual firms. The effects of asset price volatility were gauged using expected loss estimates derived from reported major UK bank trading VaRs from the extreme tail of the distribution (at the 99.6% level for the one-day case and the 99.96% level in the ten-day case). This resulted in cost estimates of around £0.1 billion and £0.5 billion respectively.

Total losses

Table A6.2 summarises the costs to the UK banks. The diffuse impact of a SWIFT outage means that many of the potential channels were extremely hard to quantify, so that the central estimate is likely to be too low. Although central estimates are reported, it is advisable to focus on the wide range of uncertainty around these figures.

Table A6.2 Decomposition of total impact on UK banks by source (£ billions)

	Moderate scenario	Severe scenario
Credit risks	Negligible	0.4
Market risk	0.1	0.5
Operational risk	0.4	3.5
Income generation risk	Negligible	0.3
Total losses	0.5	4.7
As a percentage of Tier 1 capital	0.3%	3.0%

(e) Probability of scenarios

Both the moderate and severe stress scenarios were judged to be remote possibilities. This reflects the fact that SWIFT has never experienced a generalised disruption and has invested heavily in backup sites and systems to recover quickly if problems were to arise.

(f) Key uncertainties and biases

There are many unknowns and uncertainties surrounding the costs of major infrastructural disruption. These include:

- Uncertainties surrounding the existing contingency plans of firms and infrastructures.

- Uncertainty about the cost of disruption increases the longer the period of disruption assessed. In a long outage, for example, the risk of longer-term costs — such as those associated with reputational risk — may rise sharply. On the other hand, workarounds may become established so that operational costs start to diminish over time. This uncertainty was quantified crudely for the ten-day outage by assuming that an upper limit to uncertainty would involve daily costs increasing by 20% per day during the outage — and from a slightly higher base than in the central estimate. The possibility that operational costs could diminish over time was modelled in the lower bound by assuming daily

(1) The one-day outage estimate uses default probabilities taken from average three-year CDS premia on non-UK LCFIs in 2005. Stressed default probabilities use average CDS premia on non-UK LCFIs from October 2002 — a period of some financial market stress.

costs would fall by 10% each day from a lower base than in the central case. The scope for costs to fall was assumed to be less because Tripartite Resilience Benchmarking Project responses suggest limited potential for costs to be mitigated: most firms would either rely on manual workarounds or have no contingency plan in the event of a SWIFT outage.

- There is also uncertainty about the extent to which infrastructures overseas would be affected by a SWIFT outage, given that, for example, US infrastructures are generally less dependent on SWIFT than those in Europe, but SWIFT has a large Asian reach. This was quantified in the 'lower bound' to uncertainty by scaling up the FSA survey's UK operational cost estimates by the ratio of UK banks' total European (including domestic) assets to domestic assets, rather than by the ratio of global assets to domestic assets.

- Uncertainty over the associated counterparty credit risks is also large. This is quantified crudely by assuming higher default probabilities for the upper-bound estimate — double that of the central case for the ten-day outage. In addition, for the upper-bound estimate of delayed settlement costs, financial price volatility was assumed to be higher than in the central case but to be lower — around average levels — in the lower-bound estimate.

- There is also uncertainty about how the associated market volatility and likely fall in trading volumes would affect market risk and banks' trading income. This was quantified in the upper case by using expected loss estimates based on major UK banks' VaRs from further along the tail of the distribution; for the lower bound no added market risk is assumed. Lost trading revenues could be partly recouped after market functioning has been restored, but equally trading might remain depressed for a time after the outage. This uncertainty was crudely estimated by doubling and halving the central case for the upper and lower cases respectively.

Overall, as shown in **Table A6.3**, the upper and lower-bound estimates of costs in the one-day outage were respectively judged to be double and half the cost in the impact estimate. For the ten-day estimates, the upper bound is about five times the size, and the lower bound is about a third, of that in the impact estimate.

Table A6.3 UK banks' losses under infrastructure disruption stress scenarios in July 2006

	£ billions		As a percentage of UK banks' Tier 1 capital	
	Moderate	Severe	Moderate	Severe
Lower bound	0.2	1.4	0.1	0.9
Impact estimate	0.5	4.7	0.3	3.0
Upper bound	1.1	24.1	0.7	15.4

These estimates of uncertainty are crude and do not cover all sources of risk. In particular, funding risk uncertainty was not separately quantified. Among other sources of unquantified uncertainty are potential feedbacks from wider costs to the major UK banks, such as from market disruption. And credit risk from non-bank financial firms and corporates may also increase, which was not quantified in either the central estimate or in the uncertainty bounds.

References

Alentorn, A, Nier, E, Yang, J and Yorulmazer, T (2007), 'Network models and financial stability', *Journal of Economic Dynamics and Control*, forthcoming.

Allen, W and Wood, G (2006), 'Defining and achieving financial stability', *Journal of Financial Stability*, Vol. 2(2), pages 152–72.

Bank of England (2005), *Financial Stability Review*, December.

Bank of England (2006a), *Financial Stability Report*, July.

Bank of England (2006b), 'A simple model for emerging market bond spreads', *Bank of England Quarterly Bulletin*, Spring, pages 14–15.

Bank of England (2006c), *Inflation Report*, May.

Barrell, R and Holland, D (2006), 'Correcting global imbalances', *National Institute Economic Review*, July.

Benito, A, Whitley, J and Young, G (2001), 'Analysing corporate and household sector balance sheets', *Bank of England Financial Stability Review*, December.

BIS (2005), 'An explanatory note on the Basel II IRB risk weight functions', available at www.bis.org/bcbs/irbriskweight.htm.

Blanchard, O, Giavazzi, F and Sa, F (2005), 'International investors, the US current account and the dollar', *Brookings Papers on Economic Activity*, 1:2005.

Boss, M, Breuer, T, Elsinger, H, Krenn, G, Lehar, A, Puhr, C and Summer, M (2006), *Systemic risk monitor — risk assessment and stress testing for the Austrian banking system*, Austrian National Bank.

Brunnermeier, M and Pedersen, L (2006), 'Market liquidity and funding liquidity', *mimeo*, Princeton University.

Bunn, P, Cunningham, A and Drehmann, M (2005), 'Stress testing as a tool for assessing systemic risk', Bank of England *Financial Stability Review*, June.

Bunn, P and Young, G (2004), 'Corporate capital structure in the UK: determinants and adjustment', *Bank of England Working Paper no. 226*.

Caballero, R, Farhi, E and Gourinchas, P (2006), 'An equilibrium model of global imbalances and low interest rates', *NBER Working Paper no. 11996*.

CGFS (2005), 'Stress-testing at major financial institutions: survey results and practice', *CGFS Publications No. 24*, January.

Cifuentes, R, Ferrucci, G and Shin, H (2005), 'Liquidity risk and contagion', *Journal of the European Economic Association*, Vol. 3 (2–3), pages 556–66.

Cihak, M (2006), 'How do central banks write on financial stability?', *IMF Working Paper no. 163*.

Cooper, R (2006), 'Understanding global imbalances', Harvard University, May.

De Nederlandsche Bank (2006), 'Financial stability: is the Dutch financial sector stress-resistant?', *DNB Quarterly Bulletin*, December.

Dooley, M, Folkerts-Landau, D and Garber, P (2005), 'International financial stability', *Deutsche Bank Global Markets Research*.

Drehmann, M, Sorensen, S and Stringa, M (2006), 'The impact of credit and interest rate risk on banks: an economic value and a capital adequacy perspective', *mimeo*, Bank of England. Available at www.bis.org/bcbs/events/rtf06stringa_etc.pdf.

FSA (2005), 'Resilience Benchmarking Project', *Tripartite Discussion Paper*, December.

Gai, P, Jenkinson, N and Kapadia, S (2006), 'Systemic risk in modern financial systems: analytics and policy design', *mimeo*, Bank of England, August.

Haldane, A, Hall, S, Saporta, V and Tanaka, M (2004), 'Financial stability and macroeconomic models', *Bank of England Financial Stability Review*, June.

Harrison, R, Nikolov, K, Quinn, M, Ramsay, G, Scott, A and Thomas, R (2005), *The Bank of England Quarterly Model*, Bank of England.

Hausmann, R and Sturzenegger, F (2006), 'Global imbalances or bad accounting? The missing dark matter in the wealth of nations', *Harvard University Working Paper no. 124*, January (revised May 2006).

Hoggarth, G and Whitley, J (2003), 'Assessing the strength of UK banks through macroeconomic stress tests', *Bank of England Financial Stability Review*, June.

International Monetary Fund (2006), *World Economic Outlook*, September.

Merton, R (1974), 'On the pricing of corporate debt: the risk structure of interest rates', *Journal of Finance*, Vol. 29, pages 449–70.

Mussa, M (2004), 'Exchange rate adjustments needed to reduce global payments imbalance', in Bergsten, C and Williamson, J (eds), *Dollar adjustment: how far? Against what?*, Institute for International Economics.

O'Neill, J and Hatzius, J (2004), 'US balance of payments. Unsustainable, but…', *Goldman Sachs Global Economics Paper no. 104*.

Obstfeld, M and Rogoff, K (2005), 'Global exchange rate adjustments and global current account imbalances', *Brookings Papers on Economic Activity*, Vol. 0(1), pages 67–146.

Panigirtzoglou, N and Scammell, R (2002), 'Analysts' earnings forecasts and equity valuations', *Bank of England Quarterly Bulletin*, Spring, pages 59–66.

Schinasi, G (2006), *Safeguarding financial stability: theory and practice*, International Monetary Fund, Washington.

Shin, H (2006), 'Risk and liquidity in a system context', *BIS Working Paper no. 212*.

Sorge, M (2004), 'Stress-testing financial systems: an overview of current methodologies', *BIS Working Paper no. 165*.

Vasicek, O (2002), 'Loan portfolio value', *Risk*, December, pages 160–62.

Whitley, J, Cox, P and Windram, R (2004), 'An empirical model of household arrears', *Bank of England Working Paper no. 214*.

Whitley, J and Windram, R (2003), 'A quantitative framework for commercial property and its relationship to the analysis of the financial stability of the corporate sector', *Bank of England Working Paper no. 207*.

Wren-Lewis, S (2004), 'The needed changes in bilateral exchange rates', in Bergsten, C and Williamson, J (eds), *Dollar adjustment: how far? Against what?*, Institute for International Economics.

Glossary of key terms

Arrears – Unpaid overdue debt. For example, a borrower who is 'in arrears' on mortgage debt is behind in interest/principal payments due.

Banking book – Contains assets and liabilities which are held to maturity, ie assets which are not traded on a frequent basis.

Basis point (bp) – 0.01%. So 100 bps = 1 percentage point.

Business risk – See **income generation risk**.

Corporate spread – The difference between the **yield** on a corporate bond and a government bond of similar duration, time to maturity and currency denomination.

Credit derivatives – Credit derivatives are instruments designed to allow the hedging and transfer of credit risk.

Credit risk – The risk that a bank will lose money as a result of the failure of a borrower (eg household, corporate) to fulfil its contractual obligations; for example, a corporate defaulting on a bank loan.

Credit spread – See **corporate spread**.

Current account – The value of exports minus the value of imports, augmented by the interest payments received on foreign assets less interest due abroad on domestic assets owned by foreigners.

Emerging market bond – Bond issued by the government of an emerging market economy.

Equity risk premium (ERP) – The part of the return on equity that compensates for the uncertainty surrounding future equity returns.

External finance – Finance obtained by a corporation from an outside source (eg by borrowing from a bank or issuing a bond).

Funding costs – The interest a bank has to pay on its liabilities.

Funding liquidity risk – The risk that a bank is unable to meet obligations when due, ie that cash outflows are greater than cash inflows including income from asset sales and new borrowing/rollover of previous borrowing.

Funding risk – Most borrowing by banks is of short maturity (eg overnight interbank borrowing), whereas they lend with much longer maturities (eg a 25-year mortgage loan). Hence, **funding costs** (interest paid to depositors) change more rapidly with economic conditions than earned interest from assets. In addition, **funding liquidity risk** is also part of funding risk.

High-yield corporate bond – A bond in the lower rating categories (below BBB). Also known as **non-investment-grade corporate bond**.

Income gearing – The proportion of income devoted to paying debt holders (ie monthly interest and debt repayments divided by monthly income).

Income generation risk – The risk that **net interest income**, fees and commissions, trading profits and other income decrease due to a downturn in economic conditions and/or a decrease in business volume.

Investment-grade corporate bond – A bond in the higher rating categories (BBB or above). The higher the rating, the less likely credit rating agencies deem the risk of default. The name derives from the fact that bonds rated 'investment grade' are eligible for investment by commercial banks under US regulations.

LCFI – Large complex financial institution.

Liquidation – Liquidation is the process by which the business activities of a company are brought to an end.

Liquidity risk – See **funding liquidity risk** and **market liquidity risk**.

Market liquidity risk – The risk that a position cannot be easily unwound or offset at the (fundamental) price quoted in the market.

Market risk – The risk that a bank will lose money as a result of a change in the market value of assets/liabilities.

Net interest income – Interest income from assets minus interest paid on liabilities.

Operational risk – The risk of losses resulting from inadequate or failed internal processes, people and systems or from external events.

PNFC – Private non-financial corporation.

Risks – Events in which **shocks** expose a **vulnerability** with potential impact.

Risk-free rate – The interest rate that is paid on a riskless asset, typically delivered from government securities.

Risk premium – The extra return an asset must provide over the **risk-free rate** to compensate for risk that cannot be diversified away. See also **equity risk premium**.

Secured lending – Debt backed by a pledge of collateral (eg a mortgage, where the house constitutes the collateral for the loan).

Shock – An unexpected event.

Stress scenario – A simulation of a specific **shock** — or combination of shocks — that expose a **vulnerability**.

Tier 1 capital – This is high-quality, liquid capital. Mainly comprised of paid-up shares and post-tax retained earnings. This type of capital can allow a bank to absorb losses without having to cease trading.

Tier 2 capital – Lower-quality capital items which are either subject to some uncertainty about their value or are dated instruments which have to be repaid at some point in the future. Designed to protect senior creditors (mainly depositors) in the event that a bank fails.

Trading book – Contains assets which are/can be traded frequently.

Unsecured lending – Debt not backed by collateral but only by the integrity of the borrower (eg a credit card).

Vulnerability – A market failure deriving, for example, from a stock imbalance, mispricing or risk management shortcoming, which, in combination with a shock (or shocks), could potentially cause losses on a systemic scale for the major UK banks.

Write-offs – In accounting, writing off is the expensing of a balance sheet asset that has no future benefits. An example would be the writing off of a loan on which a borrower has defaulted. The unpaid loan will be recorded as an expense on the current period's income statement rather than keeping it on the balance sheet as an asset.

Yield – The value of dividends per share over the course of a year divided by the stock's price, or the effective rate of interest paid on a bond.