Working Paper no. 339

The integrated impact of credit and interest rate risk on banks: an economic value and capital adequacy perspective

Mathias Drehmann, Steffen Sorensen and
Marco Stringa

January 2008

Bank of England

The integrated impact of credit and interest rate risk on banks: an economic value and capital adequacy perspective

*Mathias Drehmann**
*Steffen Sorensen***
*Marco Stringa****

Working Paper no. 339

* Mathias Drehmann, Financial Stability, Bank of England, Threadneedle Street, London, EC2R 8AH.
Email: mathias.drehmann@bankofengland.co.uk

** Steffen Sorensen, Monetary Analysis, Bank of England, Threadneedle Street, London, EC2R 8AH.
Email: steffen.sorensen@bankofengland.co.uk

***Marco Stringa, Monetary Analysis, Bank of England, Threadneedle Street, London, EC2R 8AH.
Email: marco.stringa@bankofengland.co.uk

The views and analysis expressed in this paper are those of the authors and do not necessarily reflect those of the Bank of England. All errors remain our responsibility. We would like to thank Matt Corder and Chris Kubelec for providing us with the impact of the stress scenario on default probabilities and the risk-free yield curve, and Greg Dudley-Smith and Ruth Yu for excellent research assistance. We are grateful to Viral Acharya, Thomas Breuer, Klaus Duellmann, Prasanna Gai, Andy Haldane, Glenn Hoggarth, David Lando, Jose A. Lopez, Stam Maes, Darren Pain, Til Schuermann, Phil Strahan and Martin Summer for their useful comments. We would also like to thank the seminar participants at the Bank of England, the Bank of Austria's (OeNB), the 2006 Money Macro and Finance conference, the 2006 Risk Management and Regulation in Banking workshop hosted by the Basel Committee on Banking Supervision and the 2007 Interaction of Market and Credit Risk conference hosted by the Deutsche Bundesbank. This paper was finalised on 05 July 2007.

The Bank of England's working paper series is externally refereed.

Information on the Bank's working paper series can be found at www.bankofengland.co.uk/publications/workingpapers/index.htm.

Publications Group, Bank of England, Threadneedle Street, London, EC2R 8AH; telephone +44 (0)20 7601 4030, fax +44 (0)20 7601 3298, email: mapublications@bankofengland.co.uk.

ISSN 1749-9135 (on-line)

Contents

Abstract

Credit and interest rate risk in the banking book are the two most important risks faced by commercial banks. In this paper we derive a consistent and general framework to measure the integrated impact of both risks on banks' portfolios. The framework accounts for all sources of credit risk and interest rate risk. By modelling the whole portfolio of a bank and by taking account of the repricing characteristics of all exposures, we can assess the impact of credit and interest rate risk not only on the bank's economic value but also on its future earnings and capital adequacy. We apply our framework to a hypothetical bank in normal and stressed conditions. The simulation highlights that it is fundamental to measure the impact of interest rate and credit risk jointly. We also show that it is crucial to model the whole portfolio, including the repricing and maturity characteristics of assets, liabilities and off balance sheet items.

Key words: Integration of credit risk and interest rate risk, asset and liability management of banks, economic value, stress testing.

JEL classification: G21; E47; C13.

Summary

Credit and interest rate risk are two of the most important sources of risk for commercial banks. Credit and interest rate risk reflect the possibility, respectively, of a borrower failing to repay her debt and of a fall in a bank's profitability due to a change in interest rates. While banks and regulators are aware of the importance of both risks, they tend to manage these risks separately. However, credit risk and interest rate risk are intrinsically related to each other and not separable. And ignoring this interdependence may potentially have relevant implications for banks' stability, especially during severe downturns.

In this paper we propose a general framework to measure the combined impact of interest rate and credit shocks on banks' economic value and profitability. In line with the literature, this framework incorporates the integrated impact of credit and interest rate risk on banks' assets. But liabilities and off balance sheet items also need to be taken into account to obtain a complete picture of the risks faced by a bank. For example, a bank subjected to a downgrade may face higher funding costs, which may adversely affect the banks' profitability. Hence, we model the whole portfolio.

The proposed framework also accounts for the asset-liability repricing mismatch. This mismatch is the result of one of the defining functions of the banking system: borrowing money at short maturities to lend to households and companies at longer maturities. This mismatch is the key source of interest rate risk for commercial banks as changes in the default-free interest rates tend to feed through more quickly on interest paid on liabilities than interest earned on assets. As a result, net interest income may decrease following an interest rates rise unless the bank has fully hedged this risk through, for example, off balance sheet items. Hence the need to include these instruments.

But net interest income is also affected by credit risk. This is because credit spreads, ie the compensation for credit risk, can be adjusted to reflect changes in the banks' own or borrowers' credit risk. And the timing of such an adjustment depends also on the above repricing mismatch. We capture both effects when modelling the bank's net interest income.

Our framework also captures other forms of interaction between credit and interest rate risk. For example, we do not only capture the direct impact of changes in macroeconomic variables, such as unemployment, on the possibility of borrowers defaulting, but also their indirect impact via potential changes in default-free interest rates.

We use two conditions to measure a bank's exposure to credit and interest rate risk. We first look at banks' economic value – the economic value condition. This provides a long-term view of banks' health based on the risk-adjusted present value of future net cash flows. This necessitates a framework which takes account of the above-mentioned repricing mismatch and the complex interdependence of interest rates and credit risk. And contrary to Basel II and standard credit portfolio models, the proposed economic value condition does not only capture default risk but all sources of credit risk, including changes in the value of net assets due to movements in credit spreads.

The economic value condition is not a sufficient metric to assess banks' exposure to credit and interest rate risk. For example, a particular path of profits may lead a bank to be undercapitalised in the short run because of severe losses which are outweighed by future profits. From an economic value perspective this bank would be solvent but because of market or regulatory constraints the bank may find it difficult to continue to operate. Therefore our second condition – the capital adequacy

condition – aims to estimate whether a bank would be sufficiently well capitalised in the short to medium term by projecting the bank's net profits and capital requirements.

We apply the framework to assess the exposure to credit and interest rate risk of a hypothetical but realistic bank in a severe macro-stress scenario. This scenario implies, among other changes, a sharp rise in the risk-free yield curve. The stability of the bank is not threatened in the stress scenario as both the economic value and capital adequacy conditions hold. But the simulation confirms that interest rate and credit risk have to be assessed simultaneously as well as jointly for the whole portfolio.

During the first year in the stress scenario, the bank experiences not only an increase in bad loans, but also a fall in net interest income. The latter is due to the compression of margins between short-term borrowing and long-term lending. The negative impact of rising bad loans is partially offset once the bank starts to reprice assets, reflecting both the change in the risk-free yield curve and the deterioration in credit quality. Were – as would be the case for most stress tests routinely run – net interest income not to be taken into account in our stress scenario, the hypothetical bank would underestimate the fall in net profits in the first year, but overestimate it in the third year.

1 Introduction

One of the defining characteristics of banks is that they borrow short and lend long. Following Diamond and Dybvig's seminal work (Diamond and Dybvig (1983)) most of the banking literature has tended to focus on the liquidity implications of such a maturity transformation function. The maturity mismatch – or more precisely the repricing mismatch – is also the key source of interest rate risk in the banking book. According to banks (see IFRI-CRO (2007)), interest rate risk is the most significant source of market risk for commercial banks. And, hence, after credit risk it is the second most important source of risk for the capital adequacy of these institutions. Banks and regulators are aware of the importance of both risks. But they tend to manage these risks separately even though, as Jarrow and Turnbull (2000) point out, '*economic theory tells us that market and credit risk are intrinsically related to each other and not separable*'.

In this paper we propose a general framework to measure the riskiness of banks which are subject to correlated interest rate and credit shocks.(1) In line with the literature following Jarrow and Turnbull (2000), this framework incorporates the integrated impact of interest rate and credit risk on banks' assets. But we go further by modelling the whole portfolio of banks, including assets, liabilities and off balance sheet items as well as taking the repricing structure of the portfolio into account.(2) Such extensions are of key importance and allow us to propose two conditions to judge the riskiness of banks: an economic value and a capital adequacy condition.

The economic value condition provides a long-term view of banks' health based on economic fundamentals and is simply based on risk-adjusted discounting of future cash flows. However, it necessitates a framework which takes account of the repricing structure of the portfolio and captures the complex interdependence of interest rates and credit risk. The repricing mismatch is the key source of interest rate risk for commercial banks, given that it determines when assets and liabilities can be repriced to reflect changes in the risk-free yield curve.(3) And it also determines when credit spreads can be adjusted to reflect changes in the banks' own or borrowers' credit risk. We capture both effects when modelling the bank's net interest income.

Furthermore, contrary to Basel II and standard credit portfolio models, the proposed economic value perspective does not only capture default risk but all sources of credit risk including, for example, changes in the value of net assets due to movements in credit spreads.

Looking at the economic value of the whole bank has some inherent problems. From a regulatory perspective it is not the economic value of liabilities but the banks' ability to repay liabilities at par when due which matters most. Therefore, our first condition to judge the riskiness of a bank is to calculate whether the economic value of assets falls below the face value of liabilities.

An economic value condition is not a sufficient metric to assess banks' stability. For example, it may be the case that a particular path of profits leads a bank to be undercapitalised in the short run because

(1) By correlated credit and interest rate risk we do not necessarily imply a linear relationship but that we model the two risks' dependence.
(2) The repricing characteristic of an asset or liability need not to be the same as its maturity. For example, a flexible loan can have a maturity of 20 years even though it can be repriced every three months. In this paper we first assume that the maturities of assets and liabilities coincide with their time to repricing. Subsequently, we remove this assumption and let the time-to-maturity be longer than the time-to-repricing.
(3)As it is common practice by risk-free yield curve we mean the government yield curve, which contains term and inflation premia.

of severe losses which are outweighed by future profits. From an economic value perspective this bank would be solvent but because of market or regulatory constraints the bank may, for example, find it difficult to continue to operate as it may be subject to liquidity runs. Therefore, in our second condition we assess whether a bank would be sufficiently well capitalised in the short to medium term. This requires projecting the banks' write-offs, net interest income and capital requirements in a consistent fashion. In turn this requires a framework, like the one proposed in this paper, which captures a) the impact of credit risk on the whole portfolio, b) interest rate risk stemming from the repricing mismatch between assets, liabilities and off balance sheet net positions as well as basis and yield curve risk,[(4)] and c) the interdependence between credit and interest rate risk.

We apply the framework to assess the exposure to credit and interest rate risk of a hypothetical but realistic bank in a severe macro-stress scenario. This scenario implies among other changes a sharp rise in the risk-free yield curve.

The stability of the bank is not threatened in the stress scenario as both the economic value and capital adequacy conditions hold. But the simulation confirms that interest rate and credit risk have to be assessed simultaneously as well as jointly for the whole portfolio. By directly modelling net interest income we are able to illustrate that the additional margin compression due to the repricing mismatch decreases profits even further in the first few quarters. The negative impact of the shock is gradually offset once the bank can start to reprice assets to reflect the change in the risk-free yield curve and the deterioration in credit quality. The offsetting effect of higher net interest income implies that after two years profits start to recover, even though write-offs peak in the third year.

We show that the impact of the margin compression and repricing is quantitatively significant. Were – as would be the case for most stress tests routinely run[(5)] – net interest income not to be taken into account in our stress scenario, the bank would underestimate the fall in net profits by over 50% in the first year. But it would overestimate the fall by nearly 100% in the third year. However, we show the magnitude of this effect and the speed at which profits return back to equilibrium crucially depend on the specific repricing characteristics of the bank's balance sheet.

The importance of interest rate risk for banks has been discussed in the literature for many years. Early on, the debate was heated for current standards. Paul A Samuelson argues that barbers know at least as much about banking as bankers (Samuelson (1945a)) and that '*the banking system as a whole is not really hurt by an increase in […]interest rates. It is left tremendously better off by such a change*' (Samuelson (1945b)). However, an economist from a bank in Mississippi rightly points out that Samuelson's conclusion is based on unrealistic assumptions on the repricing mismatch between assets and liabilities of banks and that '*even the lowliest bank clerk could have told him* (Samuelson)… *that*' (Coleman (1945)).

More recently, several papers have tried to determine the importance of interest rate risk for banks empirically. Following Flannery and James (1984) several papers find a strong negative impact of interest rates on bank stock returns (for a recent study see Fraser *et al* (2002)). However, Chen and Chan (1989) argue that this is highly dependent on the actual sample period.

[(4)] Interest rate risk also arises from differences in embedded options of assets and liabilities. Even though the framework could be extended to capture optionalities we do not consider them in this paper.
[(5)] For an overview of different stress-testing approaches see Sorge and Virolainen (2006).

A study by English (2002) concludes that it seems unlikely that interest rate changes are an important factor for the stability of a banking system, even though English acknowledges that interest rate risk may be an important source of volatility of profits. English supports his conclusions by an econometric analysis of annual aggregate net interest income in different countries. He only finds weak support that net interest income is affected by changes in the slope, level and curvature of the yield curve. In a recent study on interest rate risk in the Belgian banking sector, Maes (2004) argues that interest rate risk is important for banking stability. But again, he only finds weak empirical evidence when looking at net interest income.

Our previous discussion provides some intuition why annual net interest income may be too aggregated to disentangle the complex effects of interest rates on banks' riskiness: initially a rise in the interest rates will compress margins between short-term borrowing and long-term lending, depressing net interest income. But after a few quarters higher rates are passed on to borrowers which in turn raises net interest income. Combined with other fluctuations in the data it is therefore not surprising that an econometric analysis of annual net interest income finds it hard to support the importance of interest rate risk for banks.

Certainly since the Standard and Loans (S&L) crisis in the United States in the late 1980s banks are aware of the potential significance of interest rate risk.[6] Therefore they measure their exposure regularly. And it is also one of the regulatory requirements to undertake sensitivity tests of parallel shifts or twists in the risk-free yield curve (see for example Bank for International Settlements (2004)). One of the simplest sensitivity tests is gap analysis, where banks or regulators assess interest rate risk by purely looking at the net repricing mismatch between assets, liabilities and off balance sheet items.[7] Using this approach as well as a model by the Office of Thrift Supervision, Wright and Voupt (1996) conclude that interest rate risk is not a major source of risk for most banks – at least in the risk environment of the mid-1990s. By now the literature has identified several problems with standard and more sophisticated gap analysis (eg see Staikouras (2006)). Most importantly these tests implicitly assume that shocks to the risk-free yield curve have no impact on the credit quality of assets. But clearly this assumption does not hold as interest rate risk and credit risk are correlated and, therefore, need to be assessed jointly.

Jarrow and Turnbull (2000) are among the first to show theoretically how to integrate interest rate (among other market risks) and credit risk. They propose a simple two factor model where the default intensity of borrowers is driven by interest rates and the stock index, which in turn are correlated. Their theoretical framework is backed by strong empirical evidence that interest rate changes have an impact on the credit quality of assets. For example, Jarrow and van Deventer (1998) show that in terms of hedging a bond portfolio, both credit and interest rate risk have to be taken into account. Grundke (2005) finds that significant errors are made when the correlated nature of rating transitions, credit spreads, interest rates and recoveries is ignored.

---

[6] See Curry and Shibut (2000) for an overview of the S&L crisis.
[7] Generally, gap analysis allocates assets, liabilities and off balance sheet items to time buckets according to their repricing characteristics and calculates their net difference for each bucket. Because of this netting procedure, gap analysis may fail to consider non-linearities and, consequently, underestimate the impact of interest rate risk. For example, some short-term customer deposit rates track the risk-free rate plus a negative spread. Hence, for large falls in the risk-free term structure, banks may not be able to lower deposit rates in line with the risk-free rate because they are bounded by zero. By modelling the whole portfolio we can capture this compression in banks' net margins.

All the above papers look at the integrated impact of credit and interest rate risk on assets only, by for example modelling a bond portfolio. They do not assess the impact of interest and credit risk on liabilities or off balance sheet items nor do they take repricing characteristics into account. Barnhill and Maxwell (2002) and Barnhill *et al* (2001) attempt to measure credit and market risk for the whole portfolio of banks. They develop a simulation framework to revalue assets and liabilities depending on the state of several systematic risk factors, such as the term structure of risk-free and risky interest rates, stock indices and property prices. To assess the stability of a bank, they focus on the distribution of the economic value, ie the market value of assets minus liabilities. They find that credit risk is the most significant risk factor. But their conclusion is likely to be misleading as they ignore one of the most important sources of interest rate risk – repricing mismatches between assets and liabilities.[(8)] Furthermore, in contrast to our paper Barnhill and his co-authors do not take off balance sheet items into account and do not consider the impact of credit and interest rate risk on future earnings and capital adequacy.

Our approach is possibly closest to the operations research literature discussing stochastic programming models for dynamic asset and liability management. Following the seminal work by Bradley and Crane (1972), most of this literature looks at dynamic optimal portfolio allocation when assets are tradable.[(9)] Kusy and Ziemba (1986) is one of a few papers which aim to determine the optimal dynamic asset and liability allocation for a bank. They maximise future discounted returns and capital gains of assets, net of borrowing costs and subject to regulatory, liquidity and other constraints. Importantly, their set-up ensures that the repricing characteristics of the whole book are taken into account. Furthermore, maturing assets are re-invested such that the balance sheet balances in each period and budget constraints are satisfied. Computational limitations imply that the authors can only look at a three-period binary tree model where assets and liabilities are tradable and defaults do not occur.

The literature on portfolio optimisation allowing for defaults is so far limited. For example, Jobst and Zenios (2001) and Jobst *et al* (2006) look at dynamic optimal portfolio allocation for a corporate bond portfolio.[(10)] They simulate correlated interest rates and credit spreads as well as defaults and track future portfolio valuations, re-investing all coupon payments. Using this information they compute the optimal portfolio allocation if there is only one investment decision *ex ante* or if the portfolio can be rebalanced at each point in time. These papers are also among the few which do take both an economic value and an earnings perspective.

Dynamic optimal portfolio allocation is beyond the scope of this paper. But rather than looking at a portfolio of tradable assets, we consider non-tradable exposures in the banking book of a hypothetical bank and model corporate and household credit risk directly. Further, and more importantly, we model the complex cash flows from liabilities with different repricing characteristics rather than assuming a simple cash account as Jobst and his co-authors do. Our approach also takes account of interest rate sensitive off balance sheet items. In contrast to the general literature, we are therefore able to assess the impact of a severe stress scenario on risk-adjusted discount rates, write-offs and net interest income, and hence on the economic value as well as capital adequacy of a bank over time.

---

(8) The papers also look at a maturity mismatch of +/- one year and conclude that this is important. But +/- one year is clearly too simplistic to capture the full impact of the maturity mismatch on the riskiness of banks.
(9) For an overview see Mulvey and Ziemba (1998) or Zenios and Ziemba (2007).
(10) See Jobst *et al* (2006) for further references discussing models for dynamic portfolio optimisation with default.

Our simulations show that it is fundamental to measure the combined impact of interest rate and credit risk jointly, and that it is crucial to capture the whole portfolio, including its repricing characteristics.

The remainder of the paper is structured as follows. In Section 2 we propose a general framework to derive the economic value and capital adequacy conditions for a bank which is subject to credit and interest rate risk in the banking book. In Section 3 we discuss our empirical strategy to capture credit and interest rate risk for a hypothetical bank. In Section 4 we present the results of the stress test and in Section 5 we investigate the importance of interest rate, credit risk and their interaction. Our results are evaluated against a number of sensitivity tests in Section 6. Finally, we summarise the main conclusions of the paper in Section 7.

2 The framework

In this section we first discuss the integration of interest rate and credit risk for a generic asset. We then apply the insight from the generic asset to derive the economic value and capital adequacy conditions for a bank with a portfolio of assets and liabilities with different risk and repricing characteristics. To provide some intuition, we first derive the capital adequacy condition for a simplified bank before we consider the more general case.

2.1 A generic asset

The economic value EVA^i of a generic asset i with maturity T is simply the risk-adjusted discounted value of future coupon payments C and the principal A. Hence

$$EVA_t^i = \sum_{k=1}^{T} D_{t+k}^i C_0^i A^i + D_{t+T}^i A^i \qquad \textbf{(1)}$$

For simplicity we assume that all assets are equivalent to bullet bonds – ie repay the principal only at maturity and pay a constant coupon C_0^i priced at time t=0. For example, such an asset could be a fixed-interest rate bond with no embedded options or a simple bank loan.

The discount function is given by:

$$D_{t+k}^i = \prod_{l=1}^{k} d_{t+l-1;t+l}^i \qquad \textbf{(2)}$$

with d the period by period risk-adjusted discount factor which is equal to the inverse of 1+R, the risk-adjusted interest rate. In continuous time, R equals the risk-free rate plus a credit risk premium. However, as our application is set up in discrete time, we follow Duffie and Singleton (page 134, 2003):[11]

[11] The formula assumes that the same LGD applies to both coupons and principal and that the liquidity premium is zero.

$$R^{i}_{t+l-1,t-l} = E_t\left(\frac{r_{t+l-1,t+l} + PD^{i}_{t+l-1,t+l} \times LGD^{i}_{t+l-1,t+l}}{1 - PD^{i}_{t+l-1,t+l} \times LGD^{i}_{t+l-1,t+l}} \mid \Omega_t\right) \qquad \textbf{(3)}$$

where $r_{t+l-1,t+l}$ is the forward risk-free interest rate between *t+l*-1 and *t+l* known at time *t.* LGD^i is the expected loss given default for borrower *i* which, for simplicity, we assume here to be constant.[12] $PD^{i}_{t+l-1;t+l}$ is the risk-neutral probability of default of borrower *i* between *t+l*-1 and *t+l* conditional on surviving until *t+l*-1. Expectations are taken subject to the information set Ω_t at time *t,* which, importantly, contains information on the development of systematic risk drivers of *PDs* and interest rates.

We do not observe empirical coupon rates and need to reprice assets and liabilities according to their contractual repricing characteristics. To do so we assume that at the time of issuance the economic value equals the face value of the asset. This implies that $EVA^{i}_{t=0} \mid \Omega_0 = A^i$ in equation **(1)**. Solving for $C^{i}_{t=0}$ we obtain:

$$C^{i}_{0} = \frac{1 - D^{i}_{T}}{\sum_{k=1}^{T} D^{i}_{k}} \qquad \textbf{(4)}$$

Equations **(3)** and **(4)** are crucial for understanding the channels through which credit and interest rate risk affect a generic asset. First, both the expected credit risk premium and the expected risk-free yield curve depend on a common set of macroeconomic risk factors. Hence, unexpected changes in these risk factors impact both credit and interest rate risk. Second, unexpected movements in the risk-free yield curve do change borrowers' credit risk.[13] Therefore, when economic conditions change, the yield curve and *PDs* of the asset will adjust instantaneously and hence the discount factors, D_{t+k}, will also adjust immediately. But as coupon rates remain fixed up to repricing, the economic value of the asset will diverge from its face value. Once the asset can be repriced, coupon payments will reflect the new economic conditions and the economic value will equal the face value again. Applying this insight to a bank portfolio implies that while the economic value always reflects all future and current economic conditions instantaneously, income will only adjust sluggishly depending on the assets-liabilities mismatch.[14]

2.2 A generic bank

In this section we derive the economic value and capital adequacy conditions for a generic bank. Any bank can be seen as a large portfolio of assets and liabilities. In particular, we will look at *N* asset

---

(12) Section 3.3 discusses our empirical modelling of LGDs in more detail. The implications of cyclical LGDs are investigated in Section 6.2.

(13) There is also a feedback from credit risk to interest rates. Such an effect is partially embedded in the macro-model, which we use to simulate the systematic risk factors in the following sections. But this channel is hard to quantify formally and we, therefore, do not explicitly consider it in this paper.

(14) Our discussion so far also implicitly assumed that when a coupon is repriced the risk-free part and the credit spread change simultaneously. However, the terms of contract of some variable interest rate securities may not allow the credit spread to vary before maturity. Clearly, this is not a problem to analyse within our framework. And, hence, we will explore both repricing assumptions in our simulations (see Section 6.1).

classes A_i and M liability classes L_j where all exposures in an asset (liability) class i (j) have the same risk characteristics.[15] Within each class, individual exposures may have different repricing buckets. Initially, we assume for simplicity that the maturity of an asset (liability) coincides with its repricing characteristics. This assumption will be removed in Section 6.1.

2.2.1 Condition 1: The economic value perspective

A bank's economic value *(EVB)* is the economic value of its assets *(EVA)* minus the economic value of its liabilities *(EVL):*

$$EVB_t = EVA_t - EVL_t \qquad with \qquad EVA_t = \sum_{i=1}^{N} EVA_t^i \quad and \quad EVL_t = \sum_{j=1}^{M} EVL_t^j \tag{5}$$

As discussed in the introduction, looking at the economic value of liabilities may not be desirable from a regulatory perspective since it is not the economic value of liabilities but the banks' ability to repay liabilities at par when due which matters most. Hence, our first condition to assess the stability of a bank is to see whether the economic value of assets conditional on credit and interest rate risk is greater than the face value of all its liabilities $FVL_t = \sum_{j=1}^{M} L_t^i$.

Condition 1 – Economic value:

$$EVA_t > FVL_t \tag{6}$$

From a regulatory perspective this condition has two benefits. First, it provides a long-term view of the bank's ability to repay all its liabilities when due. Second, in stressed conditions with hikes in interest rates, it is likely to represent an upper bound in comparison to an economic value analysis as the face value of liabilities will be greater than their economic value.

2.2.2 Condition 2: The capital adequacy perspective

Whereas the economic value perspective provides a long-term view, the capital adequacy perspective focuses on whether a bank would be sufficiently well capitalised in all future states of the world. This provides an important dimension to risk assessment as an undercapitalised bank may be subject to regulatory interventions or prone to liquidity runs. It is therefore crucial to assess whether a bank's expected capital adequacy given its net profits profile remains above the regulatory minimum k for all periods in the medium term W. Hence, our second condition is:

Condition 2 – Capital adequacy:

$$\frac{SF_t}{RWA_t} > k \qquad \forall t < W \tag{7}$$

---

[15] More generally, a bank's portfolio also includes off balance sheet items. In the framework, we do not distinguish whether assets and liabilities are on or off balance sheet items. But we will model them separately in our application in the next sections (for a discussion see Section 3.6).

where RWA denotes expected risk-weighted assets and SF expected shareholder funds, which are assumed to be the only capital of the bank.

Risk-weighted assets are calculated under two different approaches. We first take risk weights to be constant over time. This could be seen as an approximation of the Basel I framework currently in use. Under this approach, risk-weighted assets are simply the weighted sum of exposures to asset i at time t with risk weights $\overline{w}^{\,i}$ differing across asset classes. Hence Condition 2 under this approach is:

Condition 2a – Capital adequacy with constant risk weights:

$$\frac{SF_t}{RWA_t^{CRW}} > k \quad \forall t < W \quad with \quad RWA_t^{CRW} = \sum_i \overline{w}^{\,i} A_t^i \tag{8}$$

As we are especially interested in severe manifestations of credit risk, the constant risk weight approach described above may not be suitable as it may underestimate the risks to the capital adequacy of the bank. We therefore also use the Basel II internal rating based approach to derive time-varying risk weights w_t^i for different asset classes (see Bank for International Settlements (2004)). Hence Condition 2 under this approach becomes:

Condition 2b – Capital adequacy with time-varying risk weights:

$$\frac{SF_t}{RWA_t^{IRB}} > k \quad \forall t < W \quad with \quad RWA_t^{IRB} = \sum_i w_t^i A_t^i \tag{9}$$

2.2.3 Forecasting shareholder funds

Were it possible to observe the profile of all coupon rates, the economic value condition would only require determining the appropriate risk-adjusted discount rate. However, as this is not the case, we need to assume that the economic value of assets equals their face value in order to derive initial coupon payments. Such an assumption is applied every time an asset or a liability is repriced. In addition we add four more assumptions in order to forecast shareholder funds.

First, we assume that exposures within an asset class are infinitely fine grained, ie individual exposures within an asset class are small. This not uncommon assumption, which is in line with the basic Basel II formula, implies that, conditional on a specific path of systematic risk factors, unexpected losses are zero.

Second, we assume that depositors are passive: once deposits mature, depositors are willing to roll over their deposits with the same repricing characteristics unless the bank defaults on its obligations. Given there are no strategic defaults by banks, this is the case only if either the earnings or the economic value condition is not met.

Third, we assume that the bank does not actively manage its portfolio composition: once assets mature, the bank continues to invest in new projects with the same repricing and risk characteristics as the matured assets. However, the bank changes coupon rates to reflect changes in economic and borrowers' conditions once assets reprice. This implies that the bank's portfolio composition only changes in line with defaulted assets.

Fourth, we assume that the bank uses its free cash flows to pay back the most costly liabilities that matured rather than invest into new assets or expand the balance sheet. If shareholder funds decrease by more than write-offs, we assume that the bank is able to attract new interbank deposits.(16)

Our behavioural assumptions are to a certain degree arbitrary. But we restrict ourselves to the simplest behavioural rule rather than re-optimising the bank's portfolio in a mean-variance sense in each period as this would be beyond the scope of this paper.

Before deriving shareholder funds explicitly we also need to clarify the notation. To enhance readability for a multi-asset and multi-liability bank we will drop the expectation operator and will do so for the remainder of the paper. All calculations are, however, based on expectations conditional on the information set available at the time of pricing. Furthermore, for stock variables, for example the economic value of a loan, we use the subscript *t* to indicate the value of the variable at time *t*. For flow variables, for example a bank's interest receivables, we use the subscript *t* to indicate the accrued value of the variable between *t*-1 and *t*.

Deriving expected shareholder funds *SF* at each future period requires tracking expected net profits which either grow by retained earnings (ie profits after taxes and dividend payouts) or decrease by losses, in which case no taxes and dividends are paid.(17) Hence, shareholder funds can be computed as

$$SF_t = \theta \max(0; NP_t) + \min(0; NP_t) + SF_{t-1} \tag{10}$$

with $\theta<1$ given that the bank pays taxes as well as dividends.

Expected net profits (NP_t) between period *t*-1 and *t* are the sum of expected net interest income plus other expected income (OI_t) minus expected write-offs (WR_t) and expected costs (C). Expected net interest income in turn is the sum of the expected total cash flows the bank receives from its assets (CFA_t), minus expected total cash flows it pays on its liabilities (CFL_t).

$$NP_t = (CFA_t - CFL_t) - WR_t + OI_t - Cost_t \tag{11}$$

For simplicity, we assume that other income and costs are driven by a constant exogenous process and we will therefore not focus on it in the remainder of the framework discussion.

2.2.3.1 Forecasting shareholder funds for a simplified bank

To provide some intuition, it is useful to consider a simplified bank with two asset classes A^i, A^j, one liability class *L* and shareholder funds *SF*. The first column in Table A provides an overview of the

---

(16) We test the sensitivity of our results against this assumption in Section 6.3. We first modify the bank's portfolio by introducing debt instruments with time-varying spreads. Then we also assume that if the bank's rating falls below a given threshold (arbitrarily set to BBB-), the bank no longer has access to the interbank market. Therefore, it will have to borrow more in the more costly debt market if shareholder funds decrease by more than write-offs.

(17) This equation implicitly assumes that the bank pays dividends proportionally to its income as long as it is able to do so. Furthermore, it is assumed that losses cannot be carried forward to offset future taxes. We tested for different tax and dividend regimes and the main conclusions were not affected.

initial balance sheet. Asset A^i (A^j) has PD^i and LGD^i (PD^j and LGD^j) and gets repriced after one (two) year(s). For simplicity we assume that liabilities reprice every year and they pay a coupon rate (C^L) equal to the risk-free interest rate r and that the bank has no other income costs, dividends nor taxes, ie $OI=Cost=0$ and $\theta=1$. We also assumed that the risk-free yield curve is flat.

Following equation **(4)**, the initial risk-free yield curve and expected *PDs* in year one and two determine coupon rates C_0^i and C_0^j for each asset exposure. The contribution of a single asset with unit size in asset class i to net interest income in period one is simple to calculate. In the event of no default the contribution is C_0^i. In the event of default the contribution is $(1-LGD^i)C_0^i$ as we assume that the coupon in that period can be partially recovered to ensure consistency with equation **(5)**. Furthermore, in the period of default the bank will write off its losses: LGD^i.

Therefore, given a well-diversified portfolio within the two asset classes, write-offs are:

$$\begin{aligned} WR_1 &= WR_1^i + WR_1^j \\ &= PD_1^i LGD^i A_0^i + PD_1^j LGD^j A_0^j \end{aligned} \qquad \textbf{(12)}$$

and given the bank is a passive investor total assets at the end of year one are:

$$A_1 = (1 - PD_1^i \cdot LGD^i) A_0^i + (1 - PD_1^j \cdot LGD^j) A_0^j \qquad \textbf{(13)}$$

It follows that expected cash flows from assets in period one are:

$$\begin{aligned} CFA_1 &= [(1 - PD_1^i) + PD_1^i(1 - LGD^i)]C_0^i A_0^i \\ &\quad + [(1 - PD_1^j) + PD_1^j(1 - LGD^j)]C_0^i A_0^j \\ &= C_0^i A_1^i + C_0^j A_1^j \end{aligned} \qquad \textbf{(14)}$$

where the first term is cash-flow contributions from asset i and the second from asset j.

There is only one liability class with coupon rate C^L and cash-flow payments $CFL_1=C^L L_o$. Net profits are therefore $NP_1=CFA_1 - CFL_1 - WR_1$ and shareholder funds grow exactly by net profits given that $\theta=1$.

As we assume that the bank uses its free cash flows to pay back those liabilities that matured, total liabilities change in line with write-offs and shareholder funds:

$$L_1 = L_0 - \Delta SF_1 - WR_1 \qquad \textbf{(15)}$$

The development of the key variables in the first period is summarised in column 2 of Table A.

Table A: Development of stock and flow variables for the simple bank

	t_0	t_1	t_2	t_3	t_4
Stock Variables					
Assets	A_0^i A_0^j	$A_1^i = (1 - PD_1^i LGD^i)A_0^i$ $A_1^j = (1 - PD_1^j LGD^j)A_0^j$	$A_2^i = (1 - \overline{PD}_2^i LGD^i)A_1^i$ $A_2^j = (1 - \overline{PD}_2^j LGD^j)A_1^j$	…	…
Liabilities	L_0	$L_1 = L_0 - \Delta SF_1 - WR_1$	…	…	…
Shareholder Funds	SF_0	$SF_1 = NP_1 + SF_0$	…	…	…
Flow Variables and Coupon Rates					
Coupon Rates		C_0^i C_0^j C_0^L	$\overline{C}_1^i$ C_0^j $\overline{C}_1^L$	$\overline{C}_2^i$ $\overline{C}_2^j$ $\overline{C}_0^L$	… $\overline{C}_2^j$ …
Cash Flows		$CFA_1 = C_0^i A_1^i + C_0^j A_1^j$ $CFL_1 = C_0^L L_0$	$CFA_2 = \overline{C}_1^i A_2^i + C_0^j A_2^j$ $CFL_2 = C_1^L L_1$	…	…
Write-Offs		$WR_1 = PD_1^i LGD^i A_0^i$ $+ PD_1^j LGD^j A_0^j$	$WR_2 = \overline{PD}_2^i LGD^i A_1^i$ $+ \overline{PD}_2^j LGD^j A_1^j$	…	…
Net Profits		$NP_1 = CFA_1 - CFL_1 - \mathrm{WR}_1$	…	…	…

Cash flows for period two can be forecasted by following the same line of argumentation as above. But assume that, just before the end of year one, economic conditions change so that $\overline{PD}_2 > PD_1$ for both asset classes, even though risk-free yield curve remains unchanged. The bank will be able to reprice *i* assets to reflect the higher credit risk given that they are in the year-one repricing bucket: so $\overline{C}_1^i > C_0^i$. However, it cannot do so for asset class *j* as coupon rates are locked in for another year. Cash flows for assets in year two are therefore $CFA_2 = \overline{C}_0^i A_1^i + C_0^j A_1^j$. Even though CFA_2>CFA_1 the bank will be expected to make a loss in this period as cash flows earned on asset *j* will not offset expected write-offs $WR_2^j = \overline{PD}_2^j LGD^j A_1^j$ in this asset class.

2.2.3.2 Forecasting shareholder funds, cash flows and exposures for a general bank

In the more general case we consider a bank with *N* asset classes A^i which have different *PDs* and *LGDs*. Within each asset class, exposures can be in different repricing buckets *b*. Following the behavioural assumption outlined above, the bank invests in new projects with the same repricing and risk characteristics of the matured assets. Hence, the expected evolution of each asset class adjusting for default is:

$$A_t^i = A_{t-1}^i (1 - PD_t^i \cdot LGD^i) \qquad and \qquad A_0^i = A^i \tag{16}$$

and the total expected cash flow from assets (*CFA*) between *t*-1 and *t* is:

$$CFA_t = \sum_{i=1}^{N} \left(\sum_{b=t}^{T} C_0^{i,b} A_t^{i,b} + \sum_{b=1}^{t-1} \sum_{l=1}^{t-1} I_l \, \overline{C}_l^{i,b} A_t^{i,b} \right) \qquad \textbf{(17)}$$

with

I_l=1 in period l when assets in bucket b have been repriced the last time prior to t
I_l=0 otherwise

Given the example of the simplified bank, the interpretation of equation **(17)** is relatively straightforward. The first term in the brackets sums the expected coupon payments C^i of asset classes which have not been repriced at time *t,* and the second term sums expected coupon payments $\overline{C}^i$ of asset classes which were last repriced in period *l* prior to time *t*. Finally, equation **(17)** sums over the *N* different asset classes.

Given the evolution of expected assets, expected future write-offs are given by:

$$WR_t = \sum_{i=1}^{N} LGD^i PD_t^i A_{t-1}^i \qquad \textbf{(18)}$$

Equation **(17)** and **(18)** highlight how profits are driven by changes in write-offs, exposures and cash-flow contributions to net interest income. For example, if economic conditions deteriorate expected write-offs will increase. Such an increase will also decrease A_t^i and in turn *CFA* collected between time *t*-1 and *t*, ultimately reducing NP_t. On the other hand, the bank also receives higher coupon payments $\overline{C}^i$ from non-defaulted assets which have been repriced to reflect the increase in credit risk and risk-free interest rates.

Similarly, given that we assume that borrowers are willing to roll over the bank's liabilities, the total expected cash flow paid on liabilities (*CFL*) between *t*-1 and *t* is:

$$CFL_t = \sum_{j=1}^{M} \left(\sum_{b=t}^{T} C_0^{j,b} L_{t-1}^{j,b} + \sum_{b=1}^{t-1} \sum_{l=1}^{t-1} I_l C_l^{j,b} L_{t-1}^{j,b} \right) \qquad \textbf{(19)}$$

with:

I_l=1 in period l when liabilities in bucket b have been repriced the last time prior to t
I_l=0 otherwise

In line with equation **(17)**, equation **(19)** sums over all liability classes with the first term in brackets summing the coupon payments C^j of liability classes which have not been repriced at time *t,* and the second term summing coupon payments $\overline{C}^j$ of liability classes which were last repriced in period *l* prior to time *t*.

In theory formulae **(1)**-**(4)** should apply to the pricing of all liabilities using the bank's own *PD* and *LGD*. While this seems to be the case for banks' debt instruments, it is well known that shorter-term customer deposit rates are generally below the risk-free interest rate even when accounting for non-interest costs net of fees. This may be the result of deposit insurance schemes or barriers to entry limiting competition (see eg Corvoisier and Gropp (2002)). Therefore, we have to take into account this stylised fact when we implement the model. Our empirical approach will be discussed in more detail in Section 3.5. The same section will also discuss an indirect method to price banks' debt instruments that overcomes the circularity problem due to the fact that interest rates the bank pays on its debt depend on the *PD* of the bank, which in turn depends, *inter alia*, on the bank's debt interest rates.

Equations **(16)** to **(19)** allow us to forecast net profits and hence the evolution of shareholder funds. Combining equation **(10)** and equation **(11)** and setting other income and cost to zero, the change in shareholder funds is given by:

$$\begin{aligned} \Delta SF_t &= \theta \cdot max\left[0;(CFA_t - CFL_t - WR_t)\right] \\ &+ min\left[0;(CFA_t - CFL_t - WR_t)\right] \end{aligned} \quad \textbf{(20)}$$

Whereas shareholder funds change in line with write-offs and income, assets will only vary in line with write-offs (as shown in equation **(16)**). Given assumption 4 this implies that:

$$\Delta FVL_t = \Delta L_t = \Delta \overline{A}_t - \Delta SF_t = -WR_t - \Delta SF_t \quad \textbf{(21)}$$

3 Stress testing credit and interest rate risk for a stylised bank

The theoretical framework outlined above is flexible enough to accommodate standard credit and interest rate risk models as long as different building blocks are mutually consistent. It is essential that underlying correlations are captured – between *PDs* of different asset classes and between *PDs* and the risk-free yield curve. Before turning to the results in Section 4, this section describes our empirical strategy and the composition of the balance sheet of the hypothetical bank used in the analysis.

3.1 The hypothetical bank

As an example for this paper we construct a hypothetical bank with a stylised balance sheet with five asset classes, three liability classes, shareholder funds and interest rate swaps as off balance sheet items (see Table A1 in the appendix). We allocate assets, liabilities and off balance sheet items into five repricing buckets and we refer to the repricing mismatch between them as interest rate sensitivity gaps. In our example, we restrict ourselves to domestic exposures only. This reduces the number of systematic risk drivers dramatically without changing the key insights of this paper.

Although our balance sheet is a hypothetical construct we ensure that shareholder funds, profitability (in terms of return on equity and on assets), the cost-income ratio and the interest rate sensitivity gap roughly match a realistic commercial bank.

3.2 *The risk-free term structure of interest rates*

We use a term-structure model by Diebold *et al* (2006) with three latent factors and three observable macroeconomic variables and apply it to UK interest rates with maturities from three months to ten years extracted from the Bank of England yield curve data set.(18) The yield curve data are estimated by fitting a spline through general collateral repo rates and conventional government bonds. In vector form, the state-space system of the vector of latent and observable variables, f_t, is given by the vector autoregression of order one:

$$f_t - \mu = \Phi(f_{t-1} - \mu) + \eta_t \tag{22}$$

The three latent factors $f_{1:3}$ have the usual interpretation as the level, slope and curvature of the yield curve. The vector of yields, y_t, with different maturities is related to the latent and observable macro factors by:

$$y_t = \Gamma f_{1:3,t} + \varepsilon_t \tag{23}$$

where Γ contains one free parameter and the yields are assumed only to be affected by the three latent factors. Appropriate zero restrictions are thus imposed on Γ. The transition and measurement disturbances are assumed orthogonal to one another with:

$$\begin{pmatrix} \eta_t \\ \varepsilon_t \end{pmatrix} \sim N\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} \Delta & 0 \\ 0 & \Pi \end{bmatrix} \right) \tag{24}$$

whereas Δ is not constrained, Π is diagonal and hence the innovations across yields are assumed to be independent. The three observable macroeconomic variables are the output gap, inflation and the Bank Rate.

The estimated term-structure model enables us to forecast the risk-free yield curves across maturities up to ten years conditional on a given macro scenario. Libor is then forecasted by assuming a constant spread over the risk-free term structure of 30 basis points. In Section 6.3 we will relax this assumption by linking the bank's access to the interbank market to its rating.

3.3 *Modelling PDs and LGDs for different asset classes*

It has also long been understood that macroeconomic factors are important drivers of credit risk (for an overview see Duffie and Singleton (2003)). In contrast to most credit risk models, our adopted approach has the benefit that it explicitly models the interaction between the systematic risk drivers of credit and interest rate risk as macroeconomic factors. This allows us to undertake a scenario analysis and simulate the economic value as well as capital adequacy for normal and highly adverse economic conditions.

---

(18) We are very grateful to Chris Kubelec who has estimated this model using monthly data between 1986 and 2005. See Anderson and Sleath (1999) for the data extraction method.

To capture the interaction between macroeconomic shocks and credit risk we build on a *PD* model described in Bunn *et al* (2005).[19] It is based on models linking aggregate default probabilities to macroeconomic variables.

The corporate probability of default is modelled as a function of own lagged values, GDP growth, corporate income gearing, the change in commercial property capital values, change in real interest rates and the ratio of net debt of PNFCs to nominal GDP. Similarly the probability of default on mortgage loans is modelled as a function of mortgage income gearing, unemployment, undrawn housing equity and loan to value ratio (LTV) of first-time buyers. Finally the probability of default on credit card loans is modelled as a function of household income gearing and the number of active credit balances.

For all types of household and corporate lending, income gearing – a measure of the ease with which households and firms can cover debt-servicing obligations – is found to be an important driver of the probability of default. Income gearing in turn is highly sensitive to changes in interest rates. This implies that (unexpected) interest rates will not only affect the net profits through the interest rate sensitivity gap but also through borrowers' default risk. GDP and unemployment are additional significant explanatory variables. The probability of default on corporate and mortgage loans is also found to be affected by the prices of commercial and residential property respectively.

In our main simulation we assume that the *LGD* is fixed and not changing in the stress scenario. Slightly worse than average industry numbers suggest, we assume that the *LGD* on interbank loans is 40%, the *LGD* on mortgage loans to be 30%, the *LGD* on credit cards to be 80% and the *LGD* on corporate loans to be 60%. In Section 6.2 we consider the impact of increasing *LGDs* in stressed conditions.

3.4 Pricing

In Section 2.1 we proposed a risk-neutral pricing framework to derive coupon rates which we do not observe. It is well known that there is no simple mapping from actual *PDs*, which we simulate, into risk-neutral *PDs*, which we require for pricing (see eg Duffie and Singleton (2003)). Following Driessen (2005), the literature has started to look at this problem empirically. Rather than an additive component, Driessen defines the jump-to-default risk premia as the ratio of risk-neutral over actual *PDs*.[20]

Driessen (2005) finds an average jump-to default risk premia of 2.31 by extracting risk-neutral *PDs* from bonds and comparing them to long-run averages from ratings data taking account of liquidity and tax effects. Even though economically relevant, his statistical evidence is inconclusive. Two other papers use credit default swaps data to derive risk-neutral and Moody's KMV to derive actual *PDs*: Berndt *et al* (2005) find jump-to-default risk premia between 1.5 and 4, and Saita (2006) estimates a range of 1-3.5. In line with these papers Amato and Luisi (2006) show that higher-rated

---

(19) All coefficients are reported in Bunn *et al* (2005). The models for corporate and household sector *PDs* were originally developed by Benito *et al* (2001) but extended work has been undertaken by Whitley and Windram (2003), Bunn and Young (2004) and Whitley *et al* (2004).

(20) For example, Saita (2006) estimates the actual one-year *PD* for Xerox in December 2000 was 4.8% while he extracts 13% as the one-year risk-neutral *PD*. This implies a jump-to-default risk premium of 2.7.

bonds carry higher risk premia. They also show that jump-to default risk premia are countercyclical and vary widely.

It is hard to derive firm conclusions from the literature. And given that the core of our framework is to assess the riskiness of banks which are subject to correlated credit and interest rate risk an explicit model of the risk premia is beyond the scope of this paper. In all our simulations we therefore assume that the jump-to-default risk premia is stable over time and equal to unity, ie risk-neutral *PDs* equal actual *PDs*. This is at the lower end of the reported range in the empirical literature. But it may be a reasonable starting point given that *a)* jump-to-default risk premia fall with lower ratings and that banks' exposures are on average more risky than the bonds considered in the above studies, and *b)* this assumption is likely to introduce a downward bias in the bank's net interest income as we use lower coupon rates.[21] Hence, our economic value and capital adequacy conditions are more likely to be violated in line with a conservative approach to risk management.

3.5 Modelling liabilities

As discussed in the framework it is well known that shorter-term customer deposit rates are generally below the risk-free interest rate. While an economic rationalisation of negative spreads can be found for short maturities it is not convincing for medium to long maturities. We assume that as the time to repricing increases the interest paid by the bank on deposits gradually converges to the risk-free interest rate. We model the deposit rate on household deposits with one quarter to repricing to be 2% below the Bank Rate and the corporate deposit rate to be 1% below the Libor rate. The negative spreads are then assumed to decline linearly to be zero in the fourth quarter.

For most of our simulation we assume that all liabilities of the hypothetical bank are in the form of deposits and interbank lending. In Section 6.3 we modify the hypothetical bank's portfolio by introducing debt instruments. Debt instruments should be priced according to formulae **(1)**-**(4)** by taking the bank's own credit risk into account. However, there is a circularity problem as a bank's own credit risk depends, *inter alia*, on the spread that the bank pays on its debt instruments which in turn depends on the bank's own credit risk.

We therefore use an indirect method: starting with an initial rating (A+) we forecast the evolution of this rating by applying a rating model similar to Blume *et al* (1998). This model is an ordered probit model that predicts ratings based on factors which can be forecasted by our framework such as capital adequacy, profits before tax and write-offs, write-offs relative to net interest income, cost-income ratio, interest rates, bank's size, GDP, and country.[22] We then map ratings to spreads where spreads are obtained from the average credit spread term structure of sterling corporate bonds over the 2003-06 period per rating category (see Chart A2, Panel A in the appendix). We use corporate spreads as we do not observe sufficient bank-specific spreads for all ratings in the United Kingdom.

---

[21] This is because a larger amount of liabilities than assets does not carry (positive) credit spreads, see section 3.5. Furthermore, to analyse the sensitivity of our results, we assessed the impact of jump-to-default premia greater than one. In all cases, net interest income shifts upward in a parallel manner without affecting any of the key results of the paper. We therefore did not include these results but they are available on request.

[22] Estimation results are available on request.

3.6 Modelling interest sensitive off balance sheet items

We also consider how the bank uses off balance sheet items to manage its exposure to interest rate risk.[23] For example, our hypothetical bank (see Table A1, Appendix A3) uses interest rate derivatives to decrease its exposure to increases in short-term interest rates. Hence, the bank has a lower interest rate sensitivity gap in the zero to three month bucket than implied by its on balance sheet exposures.

In order to capture how the bank's hedging strategy modifies the interest rate sensitivity gap we simply assume that a positive (negative) net off balance sheet position in a given repricing bucket increases (decreases) the bank's assets in that bucket and that the bank receives (pays) a risk-free coupon rate. This is equivalent to assuming that counterparty risk is costlessly eliminated by a clearing house. Hence, we assume no counterparty risk for interest rate derivatives and model them as risk-free instruments.

3.7 Calibrating condition 2

Throughout the simulation we assume that capital can be proxied by shareholder funds for which the current minimum capital requirement relative to risk-weighted assets is 4%. Therefore, we set 4% as our threshold k. For condition 2a we set the following constant risk weights: 0.5 for interbank lending, 0.35 for mortgage lending, 0.75 for unsecured lending and 1 for corporate loans.

3.8 Forecasting systematic risk factors

To be able to forecast *PDs* and yield curves we need a model that forecasts and captures the correlation of systematic risk factors across time. Rather than using a macro VAR model which has been used in the literature (see Pesaran *et al* (2006)) we use the Bank of England's macro model. This allows us to use the Bank of England *Inflation Report* forecasts as the baseline scenario.

As discussed above it is necessary to consider the stability of the bank in the short and medium as well as the long term. We choose the medium term to be three years. For a given macro scenario we forecast the dynamics of the macro economy and map these into *PD* forecasts over the next three years using the models discussed in Section 3.3.[24]

3.9 The scenarios

We follow Bunn *et al* (2005) and look at the combination of three shocks originally used for the IMF 'Financial Stability Assessment Programme' (FSAP) in 2002: a 12% decline in UK residential and commercial property prices, a 1.5% unanticipated increase in UK average earnings growth and a 15% unanticipated depreciation in the trade-weighted sterling exchange rate. Individual scenarios are described in Appendix A1. All our scenarios are run from 2005 Q1 and forecasted over a three-year

---

(23) For simplicity we assume that our hypothetical bank does not engage in any other off balance sheet activities such as buying and selling credit derivatives.

(24) After the third year we assume that the probability of default of each asset class reverts back to its long-run level over the following ten years. The quarterly probability of default on corporate loans thus reverts to 0.35%, on mortgage loans to 0.70% and on credit cards to 0.61%. These assumptions are not going to be strongly decisive for the results presented in the next section. Results of this sensitivity test can be provided by the authors on request.

horizon. As base case scenario we use the Bank of England February 2005 *Inflation Report* projections where interest rates are assumed to follow the market forward curve (see Bank of England (2005)). When running the combination of shocks through the macro model, we do not apply any judgements and we simply apply the shocks mechanically. As will become apparent, and at the heart of this paper, the key macroeconomic variable is the interest rate. Hence, modelling the monetary policy reaction to the initial shock is crucial. In line with general macro stress-testing practices we assume a mechanical Taylor rule.[25]

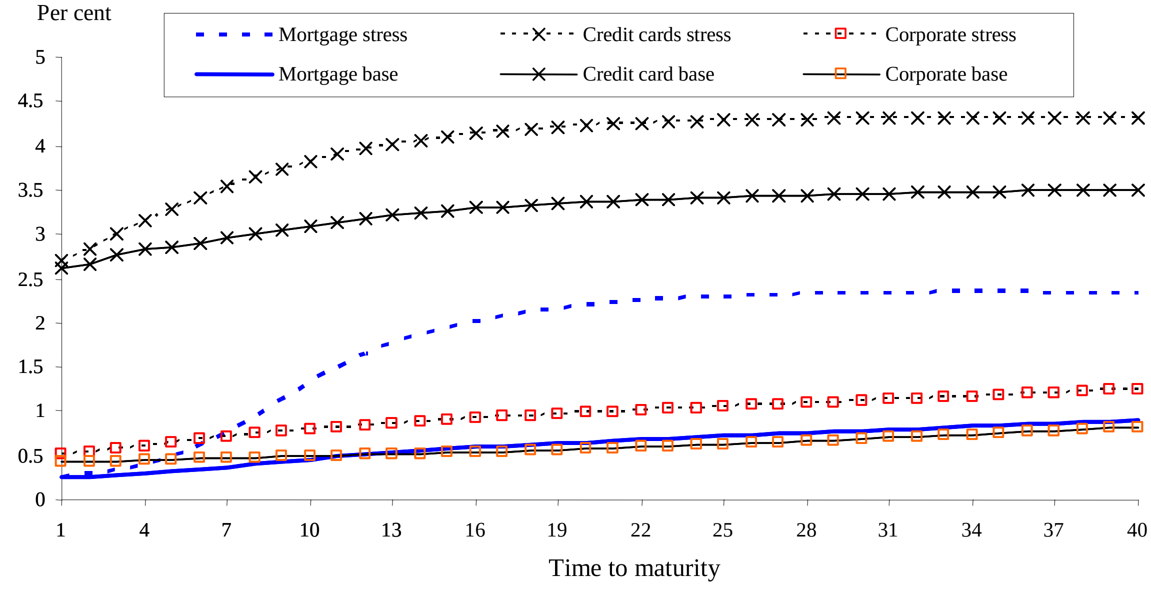
4 Results

In this section we measure the impact in the baseline and stress scenario of credit risk, interest rate risk and their interaction on the economic value and the capital adequacy of our representative bank over a three-year horizon.

4.1 Risk-free and credit spread yield curves

In Chart A1 in the appendix we compare the evolution of the risk-free yield curves over the next three years in the baseline and stress scenario. Whereas in both cases the risk-free yield curve is downward sloping, as has often been the case in the United Kingdom, the increase in the level following the stress is evident across all maturities. Furthermore, the yield curve flattens in the stress scenario with the short end of the curve around 5.5% in the first quarter increasing steadily over the three years reaching almost 10% three years after the shock.

Chart 1: Annualised credit spread curves before and after the stress



[25] Under a Taylor rule, interest rates are modelled as a linear combination of deviations of inflation from a target rate and output from potential output. This treatment is, of course, not representative of the way in which the Monetary Policy Committee sets interest rates. As has been described by the Bank of England elsewhere, Committee members use a range of models and judgements in forming their assessments.

Chart 1 shows the credit spread curves for mortgages, corporate debt and credit cards. The solid lines represent the spreads after one quarter in the base case and the dashed lines the spreads one quarter after the shock (indicated by 1 in Chart A1). As default rates and LGDs on credit cards are highest, spreads on credit card lending are much higher than for lending to (secured) households or corporates. In the base case spreads on mortgages are in line with average mortgage rates currently observed in the market place. Spreads on corporates compare to a BBB spread which is slightly above the average quality (BB) of the corporate portfolio of a typical G10 bank (see Catarineu-Rabell *et al* (2003)).

The largest increase in spreads in the stress scenario occurs for mortgages. Although the spread on credit cards does not rise by as much, it remains higher than that for mortgages. The corporate spread is least affected by the macroeconomic shock. The main reason for the subdued rise in the corporate spread is consistent with the relatively high credit quality of the banks' corporate lending book and with characteristics of the chosen shock.

4.2 Condition 1: the economic value perspective

As discussed in the framework section the economic value perspective measures the potential long-term impact of the shock on the bank. The net economic value of our hypothetical bank in the baseline scenario is calibrated to 7.3% of the face value of assets. This equals the book value of assets net of liabilities and off balance sheet items. Immediately after the shock crystallises the economic value falls to 5.7%. Notwithstanding that this represents a 21% fall, the long-term combined impact of credit and interest rate risk is not large enough to threaten the stability of the hypothetical bank.

4.3 Condition 2: the capital adequacy perspective

Even though the economic value condition is not violated, it may still be the case that in the short or medium term the bank makes losses which could threaten its capital. For this reason it is important to investigate whether condition 2 is satisfied, that is whether the bank's expected capital adequacy remains above the regulatory minimum in all periods for the next three years.

As described in the framework section, condition 2 depends, *inter alia*, on the evolution of net profits, shareholder funds and risk-weighted assets. In turn the key two determinants of net profits are net interest income and write-offs. In line with Bunn *et al* (2005) write-offs are significantly higher in the stress scenario and peak towards the end of the final year (dotted lines in Chart 2). This increase in credit risk is also reflected in the increasing credit spreads in Chart 1. However, the trough in the bank's net profits in the stress scenario occurs after two years. This is because net interest income initially falls slightly due to a rise in borrowers defaulting as well as to the margin compression between short term borrowing and long-term lending rates (solid lines in Chart 2). But, after one and a half years, net interest income starts to increase. This follows the gradual repricing of assets reflecting the higher credit risk in the stress scenario.[26]

---

[26] Note that we are assuming that the bank can fully translate the increase in *PDs* into the premia it charges on borrowers, and that such a rise in premia does not affect write-offs and arrears. We analyse the sensitivity of the results to this assumption in Section 6.1.

Chart 2: Evolution of quarterly net interest income and write-offs

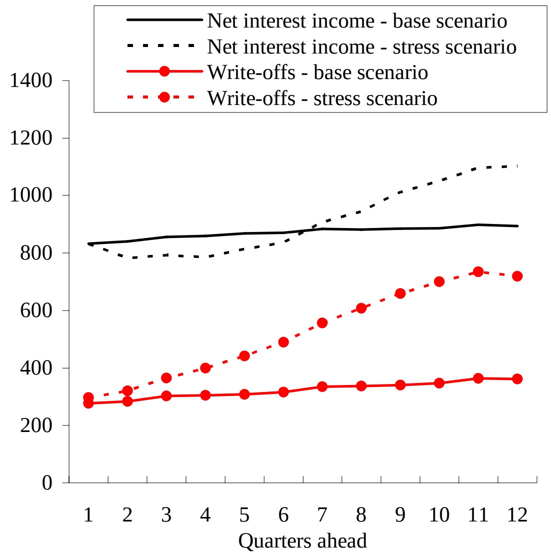
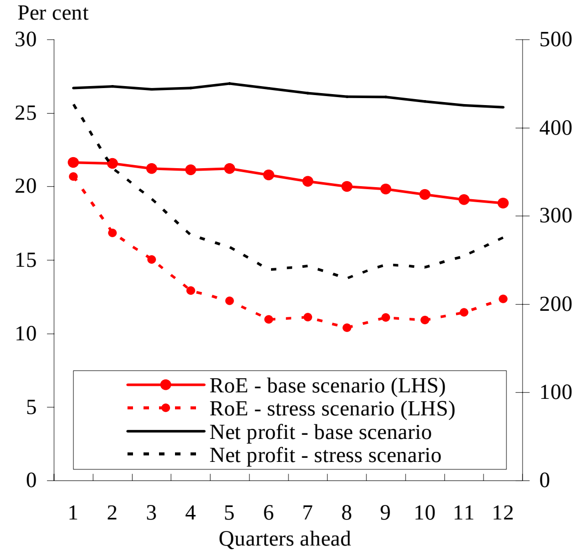


Chart 3: Evolution of annualised net profit and return on equity per quarter (RoE)



The combined impact of write-offs and net interest income imply that net profits fall by more than 50% in the eighth quarter but then start to recover (Chart 3). As will be discussed in more detail in the next section, it is clear from Chart 3 that interest rate and credit risk have to be assessed jointly. Were a bank to focus solely on credit risk by looking only at write-offs, it would underestimate risks in the short term when the margin compression following an increase in interest rates lowers net interest income and hence profits further, and overestimate it in the long run, when net interest income starts to recover even though write-offs continue to rise.

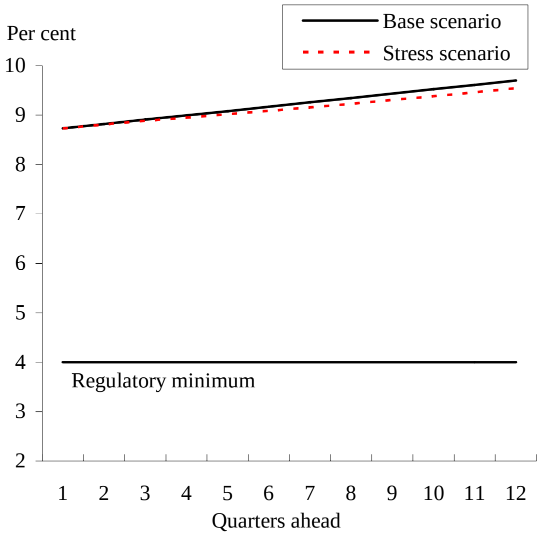
The impact of the shock can also be summarised in terms of return on equity (RoE) as illustrated in Chart 3 (dotted line).[27] Compared to an initial RoE of around 20% in the baseline scenario, the shock nearly halves the bank's RoE in the worst quarter two years after the shock. But it is also evident that the bank remains profitable in every quarter over the three-year horizon. Given our assumption that profits after tax and dividends are retained as capital, shareholder funds increase in each quarter. And given that under the standardised approach risk weights do not adjust to the decrease in credit quality, condition 2a improves in both scenarios as shown in Chart 4, Panel A.

Conversely, under the internal approach the increase in shareholder funds is more than offset by the increase in risk weights reflecting the rise in credit risk (Chart 4, Panel B). However, the overall fall does not threaten the stability of the bank as the capital ratio always remains well above the regulatory minimum. As well as condition 2a, condition 2b is therefore satisfied in all periods.

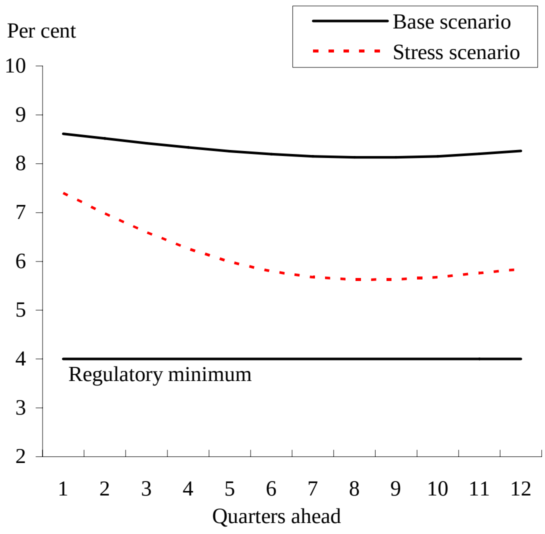
[27] RoE declines slightly over time in the baseline scenario mainly because write-offs are forecast to rise slightly from the very low initial level. Furthermore, positive retained earnings also increase the denominator of RoE.

Chart 4: Shareholder funds as a proportion of risk-weighted assets – condition 2

Panel A: Condition 2a – constant risk weight



Panel B: Condition 2b – time-varying risk weights



Overall, we can conclude that independently of whether we look at the short or long-run indicators developed in this paper, the shock would weaken our hypothetical bank but it would not threaten its stability.

5 Integration of interest and credit risk

Given that interest rate and credit risk are intrinsically related, this section investigates which risk is the main driver of the fall in profits in the stress scenario. To do so, we disentangle the impact of the shock into three components:

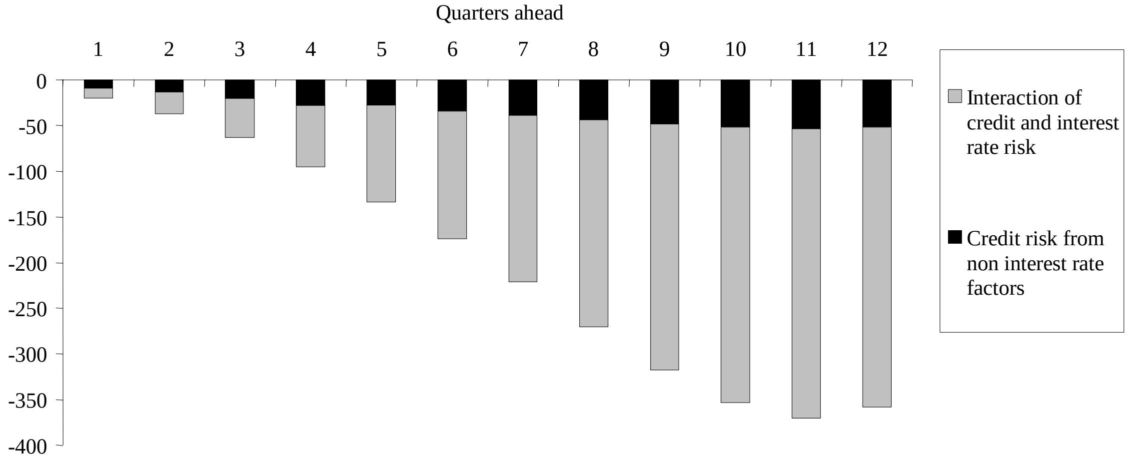
A. The impact of credit risk from non interest rate factors.

B. The impact of interest rate risk but excluding the effect of changes in interest rates on credit risk.

C. The impact of the interaction of credit risk and interest rate risk.

To assess (A) we calculate *PDs* conditional on all systematic risk factors changing to their stressed levels and interest rates remaining at their base case scenario level. Hence, (A) highlights the importance of all non direct interest rate factors. (B) is similar to interest sensitivity analyses run by banks. As discussed previously, these tests look at shifts (often only parallel ones) in the yield curve but ignore any implications this may have on credit risk. (C) is calculated as the difference between the impact of the overall shock, as described in the previous section, and the combined impact of (A) and (B). The results are illustrated in Charts 5-7.

Chart 5: Impact on write-offs[(a)]



(a) The scale is inverted to visually enable the adding of write-offs and net interest income

Chart 6: Impact on net interest income

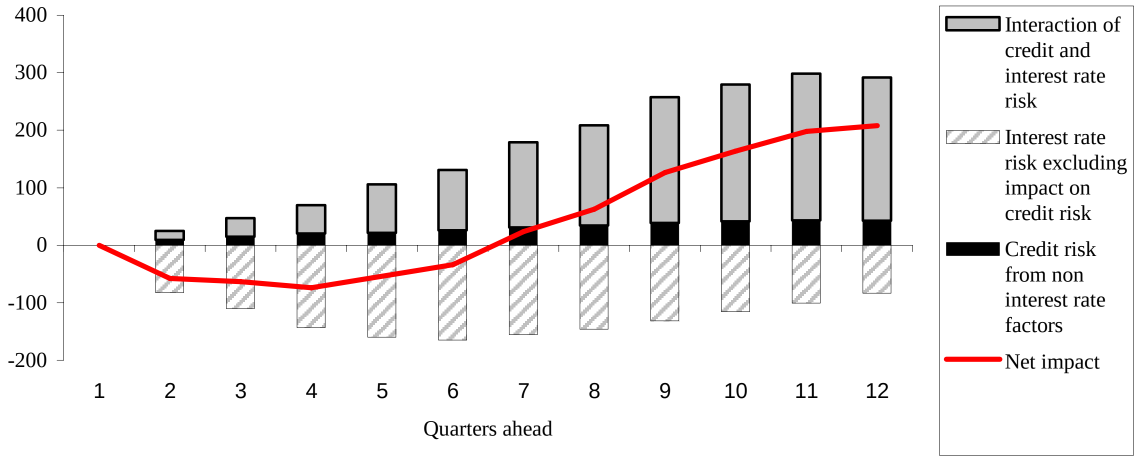
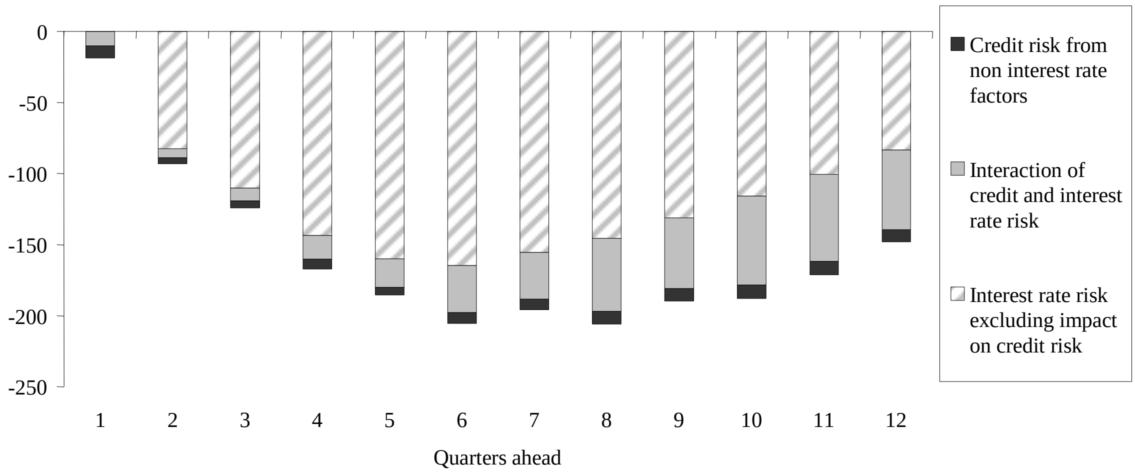


Chart 7: Impact on net profits



In Chart 5 we show that in comparison to other macroeconomic factors, interest rates are the key drivers of the rise in credit risk in our scenario. Chart 6 disentangles the complex effects of interest rate and credit risk on net interest income. As gap analysis suggests, 'pure interest rate risk' decreases net interest income as margins are compressed (shaded area in Chart 6).[28] However, 'pure interest rate risk' does not take account of the impact of interest rates on credit quality nor the interaction between interest rates and other credit risk drivers in a stressed scenario. As already discussed, the increase in credit risk has two opposing effects on net interest income. On the one hand, higher write-offs decrease net interest income as borrowers default on coupon payments and the bank's exposures decline over time. On the other hand, there is a positive impact of credit risk on net interest income because, over time, banks adjust the credit spread on loans that are repriced.

Looking at the overall impact on profits (Chart 7) it is evident that in our scenario the rise in interest rates is the main cause of the fall in net profits as it drives both the squeeze in net margins and the rise in write-offs. But, more important, Charts 5-7 clearly show why credit and interest rate risk have to be assessed jointly and simultaneously for the whole portfolio. In our stress scenario, were the bank to focus only on the impact of credit risk on write-offs (Chart 5) without taking net interest income into account – as it is often the case for a standard stress-test analysis – it would overestimate the overall negative impact of the scenario on net profits by around 25%. Interestingly, the effects are not symmetric over time. In the first year, focusing only on write-offs would lead to underestimate the negative impact on net profits by over 50% as the decrease in net interest income (red line in Chart 6) is not taken into account, However, by the third year, the bank has repriced a large proportion of its assets leading to an increase in net interest income. Therefore, a bank focusing solely on write-offs would ignore this positive effect and over estimate the negative impact on net profits by nearly 100% in the third year. Conversely, were the bank to assess the impact of higher interest rates on its book by purely undertaking a sensitivity analysis based on its repricing mismatch (shaded area in Chart 6), it would underestimate the negative impact of the shock by around 30% over the three-year period.

6 Sensitivity analysis

The previous discussion highlights that effects of interacting credit and interest rate risk can be significant. In this section we analyse the sensitivity of the results to some of our main assumptions. In particular, we focus on three assumptions that may lead to an underestimation of the impact of the shock: perfectly flexible credit spreads of mortgages, constant *LGD*, and the absence of debt-like instruments on the liabilities side. The combined removal of these three assumptions without including possible mitigation actions by the management of the bank should provide a reliable worst case estimate of the impact of the shock.[29]

---

[28] Even though net interest income falls in the first quarter due to some loans defaulting this effect is negligible. But the small impact on net interest income in this quarter is driven by our assumption that the shortest repricing maturity is 3 months across all asset and liability classes. Shorter maturities such as overnight bank deposits would only lead to a bigger decrease in net interest income in the first quarter but would not change the remainder of the analysis.

[29] We also undertook further sensitivity tests. For example, we changed characteristics of the hypothetical bank's balance sheet to increase the customer funding gap. We also considered sticky dividends or a jump-to-default risk premia greater than one. The direction of the results was intuitive and in no case was the financial stability of the bank threatened. These results are available on request.

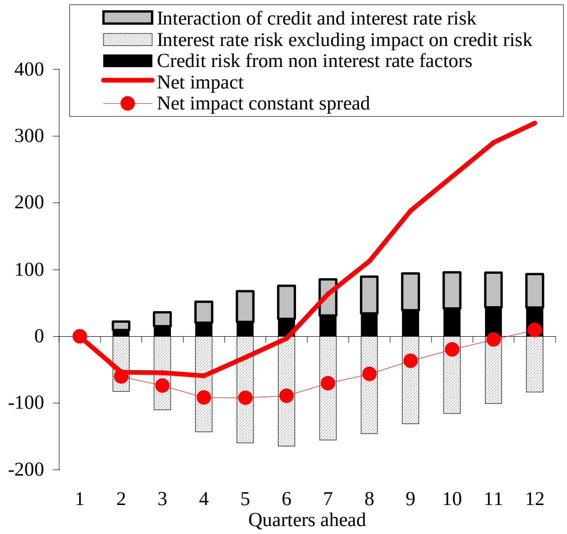
6.1 Constant spread on variable-rate mortgage loans

In the main section we assumed that the maturities of assets and liabilities coincide with their time to repricing. This implies that every contract can be rewritten every time a loan is repriced. Hence the bank can change the lending rate on variable-rate mortgages reflecting both the changes in the risk-free interest rate and in credit risk. If, more realistically, the time to maturity is longer than the time to repricing, it will depend on the legal characteristics of the contract whether banks can modify the credit spread on variable-rate mortgages whenever the loans are repriced.

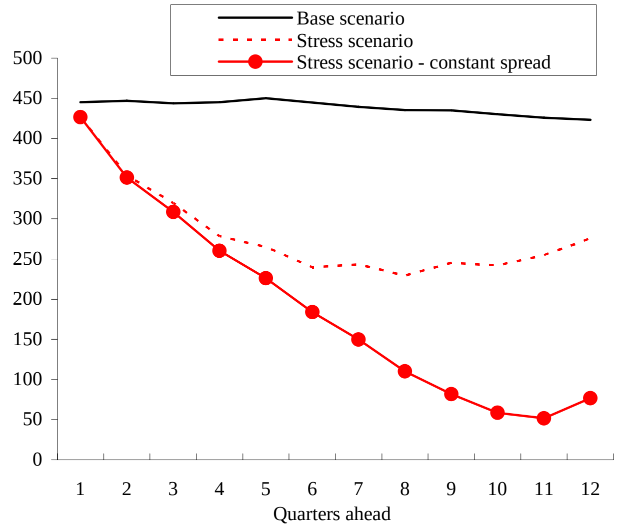
To analyse how sensitive our results are to the assumption of perfectly flexible credit spreads we consider the opposite case. We assume that the bank can adjust mortgage rates in line with risk-free interest rates but must hold a constant spread on the variable-rate mortgages for the first three years.

Chart 8: Net profits and net interest income with constant credit spread on variable mortgages

Panel A: Net interest income



Panel B: Net profits



Comparing the dotted and continuous lines in Panel A in Chart 8, it is clear that net interest income adjusts more slowly when spreads are held constant. Hence, net interest income is substantially lower because the bank cannot pass on the higher credit risk to borrowers. Therefore, the bank's net profits fall more sharply and for a longer time, reaching a minimum of around 50 in quarter eleven (Panel B in Chart 8). However, the bank continues to make positive net profits and satisfies the economic value as well as both capital adequacy conditions. In the event of time-varying risk weights, capital adequacy always remains above 5.5%. This result highlights that, even when risk characteristics in terms of *PDs* and *LGDs* dynamics remain the same, repricing characteristics of exposures can have a substantial impact on the financial strength of a bank.

6.2 Cyclical LGD

A recent book edited by Altman *et al* (2005) provides strong evidence that recovery rates are low when aggregate default rates are high. For example, Schuermann (2005) finds that recovery rates are one-third lower in recessions. Frye (2003) supports this evidence by showing that the *LGD* in high default years exceeds *LGD* in low default years by around 15 percentage points.

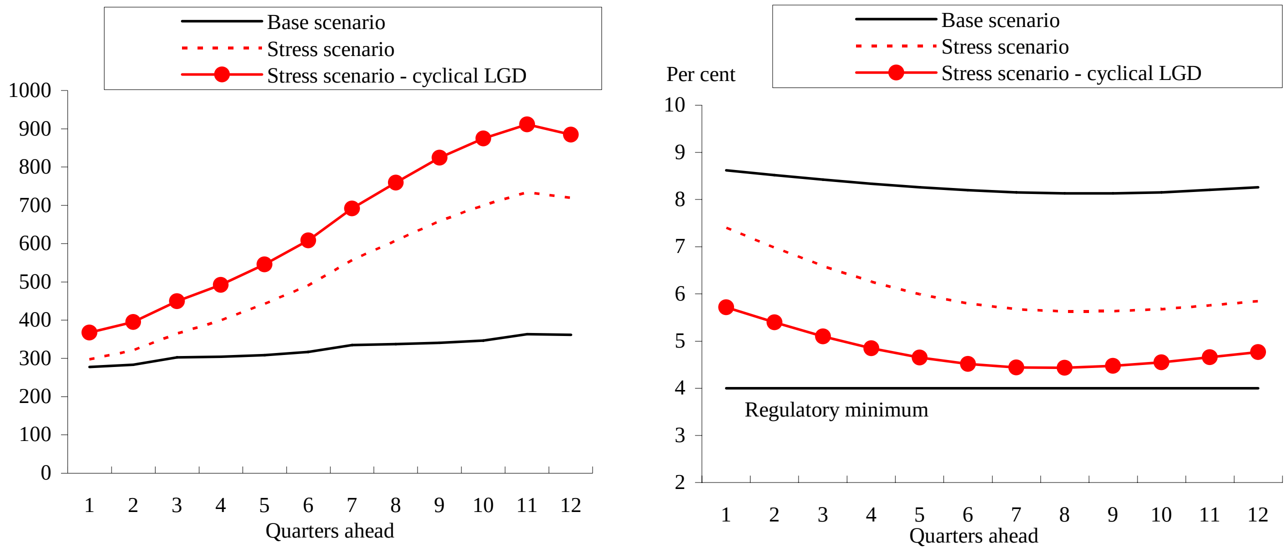
Even though we start with relatively high *LGDs* in the main section, we assume that they do not change in the stress scenario. We test the sensitivity of our results to this assumption by decreasing the recovery rates by 15 percentage points as suggested by Frye. Given it is unrealistic that *LGDs* remain at the new higher level forever, we assume that they gradually revert to their baseline levels over the following ten years.

One of the effects of higher *LGDs* is a rise in discount rates and hence a fall in the economic value in the stressed condition by 24%, but the economic value conditions remain satisfied. Higher *LGDs* also imply a significant rise in write-offs (Panel A in Chart 9).

Chart 9: Profitability with constant *LGD* versus rising *LGD*

Panel A: Write-offs and net interest income

Panel B: Capital adequacy – internal approach



Although credit spreads increase in response to higher *LGDs*, they do not fully offset the higher write-offs during the horizon we consider. The result is a further fall in net profits in comparison to non-cyclical *LGDs*. However, net profits continue to be positive and shareholder funds rise over time. Therefore, the *LGD* assumption does not have a material impact on shareholder funds as a proportion of RWA, under the constant risk weights approach. But under the internal rating based approach, RWA do increase and the capital ratio falls to a minimum of 4.43% (dotted line in Panel B in Chart 9) versus a minimum of 5.62% in the base case (broken line in Panel B in Chart 9) or 5.58% with constant spreads. The latter is an interesting comparison as profits fall to a minimum of 50 when spreads are constant whereas they remain above 200 with cyclical *LGDs*. This is a clear indication that higher *LGDs* 'hurt' the bank twice: first higher *LGDs* lead to higher losses and therefore a slower accumulation of shareholder funds. Second, and more importantly, higher *LGDs* increase risk weights significantly and hence lower capital adequacy ratios for the internal-based approach.

6.3 *Including debt instruments*

In the previous sections we assumed that all liabilities of the hypothetical bank are in form of deposits or interbank lending. However, debt instruments usually account for a sizable proportion of banks' liabilities. In this section we modify the hypothetical bank's portfolio by substituting 50% of the interbank liabilities with debt instruments. The new balance sheet is shown in Table A2 in the appendix.

As discussed in Section 3.5 debt instruments should be priced according to formulae **(1)-(4)** by taking the bank's own credit risk into account. Given the circularity between a bank's own *PD* and its cost of debt, we use the indirect method described in Section 3.5 to forecast the bank's rating which in turn determines the bank's spread on debt instruments.(30)

When we simulate the bank with debt instruments, we find that net interest income and net profits fall in both the baseline and stress scenarios relative to the base case of Section 4. This is not surprising given that spreads in the debt market are higher than in the interbank market. More interestingly, we also find that the deterioration in the bank's financial ratios is not large enough to trigger a downgrade (ie the bank's rating does not change from the initial A+ level).

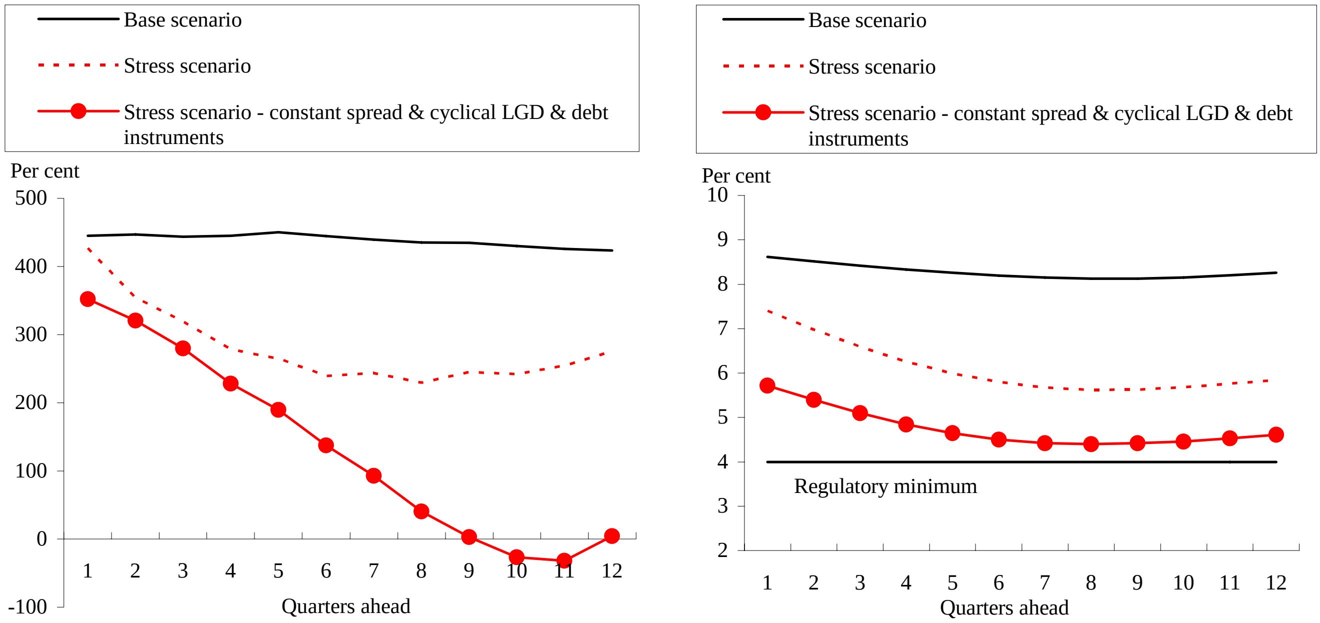
To explore a possible worst case of the impact of the shock on the bank's balance sheet, we combine the above three sensitivity tests and look at a bank with constant spreads for mortgages, cyclical *LGDs* and debt instruments outstanding. In comparison to the impact of the stress in the base case, profits are significantly lower. As a consequence the bank gets downgraded twice after the second year, which in turn implies that the bank has to pay higher spreads in the debt market. Following an increase in the cost of debt the bank does make losses throughout the third year (Chart 10, Panel A). However, even in this more extreme case the impact of the shock is still not sufficiently severe to push the bank below the 4% capital adequacy threshold (Chart 10, Panel B). It is interesting that the fall in capital adequacy is not much more marked than when only considering cyclical *LGDs*: the capital ratio falls to a minimum of 4.39% (dotted line in Panel B in Chart 10) versus a minimum of 4.43% (dotted line in Panel B in Chart 9). This stresses the importance of *PD* and *LGD* assumptions for the bank's capital adequacy in the internal approach.

(30) As mentioned in Section 2.2.3, we also assume that if the bank's rating falls below BBB-, the bank no longer has access to the interbank market. However, in our scenario the bank's rating always remains above such a threshold.

Chart 10: Profitability and capital adequacy with subordinated debt, constant spreads and cyclical *LGD*

Panel A: Net profits

Panel B: Capital adequacy – internal approach



The broken and dotted lines in Chart 10 can be seen as a lower and upper bound respectively of the likely impact of the shock. In other words, in all our sensitivity tests the bank continues to experience positive net profits over the forecasting period and it always satisfies the capital adequacy condition. Similarly, after the shock crystallises, the bank's economic value falls by more than 24% but it always remains positive. Hence, we can conclude that both in the short and long term the combined impact of credit and interest rate risk is not large enough to threaten the stability of the bank.

7 Conclusion

Credit and interest rate risk are the two most important risks faced by commercial banks. And given that they are intrinsically related, they cannot be measured separately. Surprisingly, most studies focus only on the combined impact of interest rate risk and default risk on assets. But a bank's profitability and net worth depend not only on default risk of assets but also on the overall credit quality, liabilities and off balance sheet items as well as the repricing characteristics of its book.

This paper proposes a general framework to compute a bank's economic value as well as its future profitability and capital adequacy over time by assessing the combined impact of credit and interest rate risk on risk-adjusted discount rates and cash-flow contributions to profits. The essence of our framework is relatively simple but at the same time holistic.

We apply our framework to evaluate the impact of a severe stress on the economic value and capital adequacy of a hypothetical bank. To capture the combined impact of credit and interest rates we employ a simple bottom-up approach linking macroeconomic factors to the risk-free yield curve and *PDs* of companies and households.

Although the stability of our hypothetical bank is not threatened, we find that it is fundamental to assess the impact of interest rate and credit risk jointly on assets, liabilities and off balance sheet items. We show that a simple gap analysis will underestimate the risks to banks. Even though it captures the initial repricing mismatch it will not account for the strong negative impact of interest rates on the credit quality of assets. Similarly, focusing only on assets' default risk by, for example, projecting expected write-offs is misleading. Such an analysis does not account for changes in net interest margins due to variations in assets and liabilities' credit spreads that can occur once the bank's portfolio is repriced.

The qualitative results of our paper are stable across a whole range of sensitivity tests. However, we show that the cyclicality of *LGDs* and the maturity of assets, and hence the ability of a bank to pass on higher credit and interest rate risk to customers, can matter significantly. Obviously the implementation of the framework relies on a particular risk-free term structure and credit risk models. These are key inputs to measure the riskiness of a bank. And we stress that it is important to use consistent models, which capture the dependence between yield curves and credit risk by explicitly modelling the underlying systematic risk drivers. We think that this is an area where it may be interesting to undertake more work.

First, it could be useful to look at more disaggregated and sophisticated credit risk models such as Pesaran *et al* (2006) or the panel data models of UK corporate and household *PDs* (see, for instance, May and Tudela (2005)). Second, it would be interesting to explore the sensitivity of *LGDs* to systematic risk factors in greater depth. Even though the literature is expanding in this area, data limitations on recovery rates, especially for UK bank loans, could be a potential obstacle. Finally, in this paper we measure conditional expected losses only, whereas it would be useful to generate the full loss distribution during periods of stress and for all states of the world.

Although we expect that such extensions will refine the exact importance of credit versus interest rate risk, we think that they will not alter the main message of this paper: for a complete risk assessment it is fundamental to measure the combined impact of interest and credit risk jointly. And it is also crucial to capture the whole portfolio, including the repricing characteristics of assets, liabilities and off balance sheet items.

Appendix

A1: Stress scenarios

A) Decline of 12% in residential and commercial property prices. This scenario is assumed to result from a general drop in demand for the flow of property services. Since housing accounts for one half of households' net worth, the personal sector's balance sheet deteriorates and household consumption is reduced. Output is lower than otherwise but the adverse effect is a little smaller than under the first scenario.

B) 1.5 percentage point unanticipated increase in average earnings growth (reflecting a step increase in real reservation wages). This supply shock boosts personal incomes and consumption but the transmission to higher inflationary pressure induces a rise in official interest rates under the Taylor rule. Overall there is a marginal decline in GDP compared with the base case.

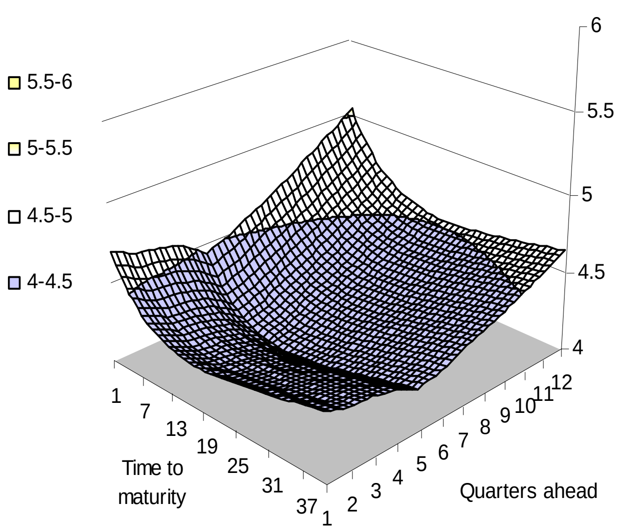
C) A 15% (initial) unanticipated depreciation in the trade-weighted sterling exchange rate. This scenario entails a fall in the demand for sterling owing to an increase in the perceived relative riskiness of sterling assets (in other words, a rise in the sterling risk premium). Sterling depreciation results in higher inflation and, in response, nominal interest rates increase under the Taylor rule. Nonetheless, since wages and prices adjust only gradually, there is a temporary depreciation in the real exchange rate which in turn boosts net export volumes.

In addition, the IMF FSAP also considered a shock to the world equity prices due to a downward revision in corporate earnings, which we do not include in our exercise as the Taylor rule implies a monetary policy reaction offsetting some of the consequences of the initial shock.

A2: Additional charts

Chart A1: Evolution of the risk-free term structure over the next twelve quarters in the base and stress scenario respectively

Panel A: Baseline



Panel B: Stress

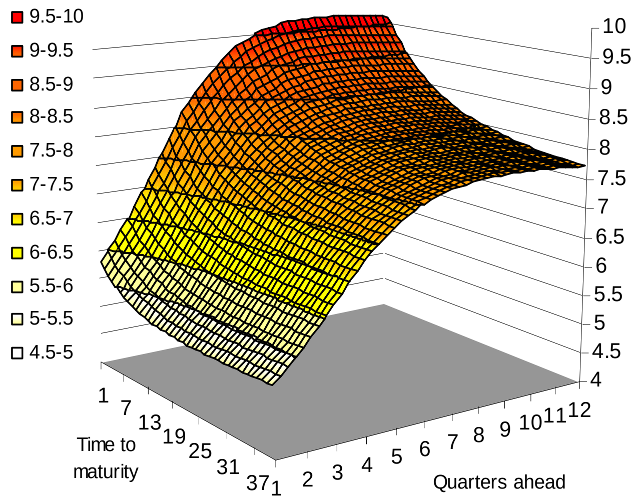
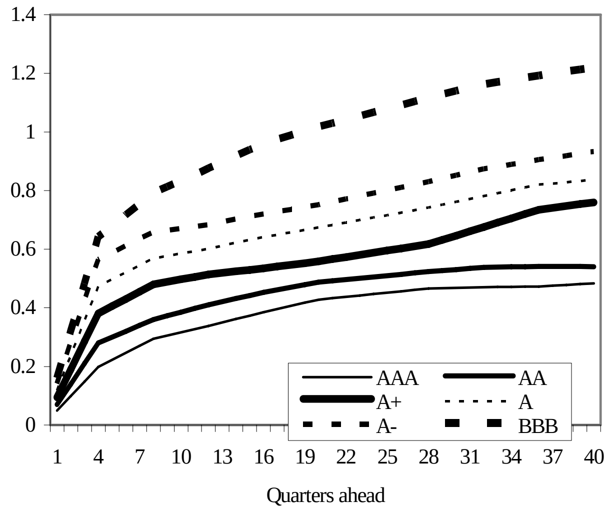
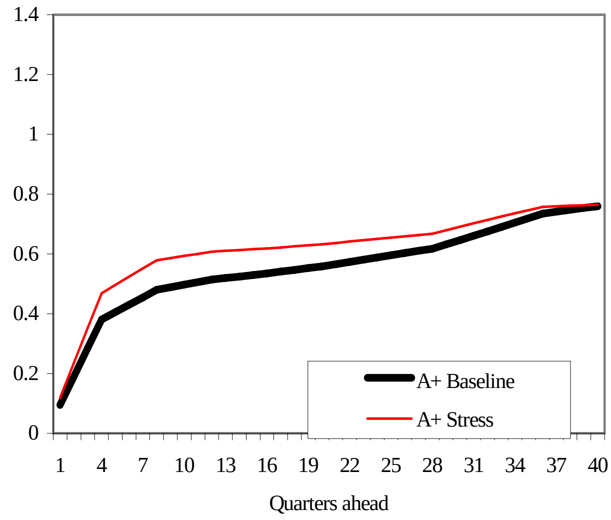


Chart A2: Corporate spreads

Panel A: Corporate spreads for different rating categories



Panel B: A+ rating in baseline and stress scenario(a)



(a) We assume that the *LGD* on subordinated debt increases proportionally to the corporate *LGD*. It then falls gradually to reach the baseline spread after ten years as usual.

A3: Additional tables

Table A1: Balance sheet of the hypothetical bank[(a)]

	Time buckets					Non-interest bearing funds	Total
	0 - 3 months	3 - 6 months	6 - 12 months	1 - 5 years	> 5 years		
Assets							
Total loans and advances to banks	5,500	1,900	500	100	100	0	8,100
Total loans and advances to customers	86,900	12,200	5,000	17,800	12,300	0	134,200
Total Households	44,700	10,600	2,400	10,600	5,600	0	73,900
Mortgage	24,600	9,800	1,200	7,200	2,400	0	45,200
Fixed-Rate Mortgages	0	0	1,200	7,200	2,400	0	10,800
Variable-Rate Mortgages	24,600	9,800	0	0	0	0	34,400
Credit Cards+Credit Cards	20,100	800	1,200	3,400	3,200	0	28,700
Total PNFCs/NPISH	42,200	1,600	2,600	7,200	6,700	0	60,300
Treasury bills and other debt securities	6,700	2,300	2,100	3,400	3,200	0	17,700
Total assets	99,100	16,400	7,600	21,300	15,600	0	160,000
Liabilities							
Total deposits by banks	32,300	1,600	600	100	300	0	34,900
Total deposits to customer accounts	98,000	3,400	4,300	4,300	300	6,000	116,300
Total Households	49,000	1,700	2,150	2,150	150	3,000	
Total PNFCs/NPISH	49,000	1,700	2,150	2,150	150	3,000	
Shareholders funds - equity						8,800	8,800
Total liabilities (excl shareholder funds)	130,300	5,000	4,900	4,400	600	6,000	151,200
Total liabilities	130,300	5,000	4,900	4,400	600	14,800	160,000
Off balance sheet items	13,600	-9,800	-1,100	-2,500	2,600		2,800
Interest rate sensitivity gap	-17,600	1,600	1,600	14,400	17,600		

(a) All assets and liabilities are assumed to be domestic exposures. For the actual analysis, the exposure of the bank to an asset/liability in a particular repricing bucket is equally split between the number of quarters within the bucket. For the last bucket we assume that the maximum time to repricing is ten years.

Table A2: Balance sheet of the hypothetical bank with debt instruments

	Time buckets					Non-interest bearing funds	Total
	0 - 3 months	3 - 6 months	6 - 12 months	1 - 5 years	> 5 years		
Assets							
Total loans and advances to banks	5,500	1,900	500	100	100	0	8,100
Total loans and advances to customers	86,900	12,200	5,000	17,800	12,300	0	134,200
Total Households	44,700	10,600	2,400	10,600	5,600	0	73,900
Mortgage	24,600	9,800	1,200	7,200	2,400	0	45,200
Fixed-Rate Mortgages	0	0	1,200	7,200	2,400	0	10,800
Variable-Rate Mortgages	24,600	9,800	0	0	0	0	34,400
Credit Cards+Credit Cards	20,100	800	1,200	3,400	3,200	0	28,700
Total PNFCs/NPISH	42,200	1,600	2,600	7,200	6,700	0	60,300
Treasury bills and other debt securities	6,700	2,300	2,100	3,400	3,200	0	17,700
Total assets	99,100	16,400	7,600	21,300	15,600	0	160,000
Liabilities							
Total deposits by banks	17,900	1,290	250	100	150	0	19,691
Total deposits to customer accounts	88,000	2,610	3,000	2,700	200	6,000	102,509
Total Households	44,000	1,305	1,500	1,350	100	3,000	
Total PNFCs/NPISH	44,000	1,305	1,500	1,350	100	3,000	
Debt-like instruments	18,850	2,850	2,850	3,190	1,260	0	29,000
Shareholders funds - equity						8,800	8,800
Total liabilities (excl shareholder funds)	124,750	6,750	6,100	5,990	1,610	6,000	151,200
Total liabilities	124,750	6,750	6,100	5,990	1,610	14,800	160,000
Off balance sheet items	8,050	-8,050	100	-910	3,610		2,800
Interest rate sensitivity gap	-17,600	1,600	1,600	14,400	17,600		

See footnote to Table A1.

References

Altman, E, Resti, A and Sironi, A (2005), *Recovery risk*, Risk Books.

Amato, J D and Luisi, M (2006), 'Macro factors in the term structure of credit spreads', *BIS Working Papers no. 203.*

Anderson, N and Sleath, J (1999), 'New estimates of the UK real and nominal yield curves', *Bank of England Quarterly Bulletin*, Vol. 39, No. 4, pages 384-96.

Bank of England (2005), *Inflation Report*, February.

Bank for International Settlements (2004), 'International convergence of capital measurement and capital standards', *Basel Committee on Banking Supervision*.

Barnhill Jr, T M and Maxwell, W F (2002), 'Modeling correlated market and credit risk in fixed income portfolios', *Journal of Banking and Finance*, Vol. 26, pages 347-74.

Barnhill Jr, T M, Papapanagiotou, P and Schumacher, L (2001), 'Measuring integrated market and credit risk in bank portfolios: an application to a set of hypothetical banks operating in South Africa', *Milken Institute*.

Benito, A, Whitley, J and Young, G (2001), 'Analysing corporate and household sector balance sheets', Bank of England, *Financial Stability Review*, December, pages 160-74.

Berndt, A, Douglas, R, Duffie, D, Ferguson, M and Schranz, D (2005), 'Measuring default risk premia from default swap rates and EDFs', *BIS Working Paper no. 173*.

Blume, M E, Lim, F and Mackinlay, A C (1998), 'The declining credit quality of U.S. corporate debt: myth or reality?', *Journal of Finance*, Vol. 53, No. 4, pages 1,389-413.

Bradley, S P and Crane, D B (1972), 'A dynamic model for bond portfolio management', *Management Science*, Vol. 19, pages 139-51.

Bunn, P, Cunningham, A and Drehmann, M (2005), 'Stress testing as a tool for assessing systemic risk', Bank of England, *Financial Stability Review*, June, pages 116-26.

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

Catarineu-Rabell, E, Jackson, P and Tsomocos, D P (2003), 'Procyclicality and the new Basel accord – banks' choice of loan rating system', *Bank of England Working Paper no. 181*.

Chen, C and Chan, A (1989), 'Interest rate sensitivity, asymmetry and stock returns of financial institutions', *Financial Review*, Vol. 24, No. 3, pages 457-73.

Coleman, G (1945), 'The effect of interest rate increases on the banking system', *American Economic Review*, Vol. 35, No. 4, pages 671-73.

Corvoisier, S and Gropp, R (2002), 'Bank concentration and retail interest rates', *Journal of Banking and Finance*, Vol. 26, pages 2,155-89.

Curry, T and Shibut, L (2000), 'The cost of the saving and loans crisis: truth and consequences', *FDIC Banking Review*, Vol. 13, pages 26-35.

Diamond, D W and Dybvig, P H (1983), 'Bank runs, deposit insurance and liquidity', *Journal of Political Economy*, Vol. 91, No. 3, pages 401–19.

Diebold, F X, Rudebusch, G D and Aruoba, B (2006), 'The macroeconomy and the yield curve: a dynamic latent factor approach', *Journal of Econometrics*, Vol. 131, pages 309-38.

Driessen, J (2005), 'Is default event risk priced in corporate bonds?', *Review of Financial Studies*, Vol. 18, No. 1, pages 165-95.

Duffie, D and Singleton, K J (2003), *Credit risk*, Princeton University Press.

English, W B (2002), 'Interest rate risk and bank net interest margins', *BIS Quarterly Review*, December, pages 67-82.

Flannery, M J and James, C M (1984), 'The effect of interest rate changes on the common stock returns of financial institutions', *Journal of Finance*, Vol. 39, No. 4, pages 1,141-53.

Fraser, D R, Madura, J and Wigand, R A (2002), 'Sources of bank interest rate risk', *The Financial Review*, Vol. 37, No. 3, pages 351-67.

Frye, J (2003), 'LGD in high default years', *mimeo*, Federal Reserve Bank of Chicago.

Grundke, P (2005), 'Risk measurement with integrated market and credit portfolio models', *Journal of Risk*, Vol. 7, No. 3.

IFRI – CRO Forum (2007), *Survey on economic capital practice and applications*, The Institute of the Chief Risk Officers (CRO) and International Financial Risk Institute.

Jarrow, R A and Turnbull, S M (2000), 'The intersection of market and credit risk', *Journal of Banking & Finance*, Vol. 24, pages 271-99.

Jarrow, R A and van Deventer, D R (1998), 'Integrating interest rate risk and credit risk in asset and liability management', in *Asset & liability management: the synthesis of new methodologies*, Risk Books.

Jobst, N J, Gautam, M and Zenios, S A (2006), 'Integrating market and credit risk: a simulation and optimisation perspective', *Journal of Banking and Finance*, Vol. 30, pages 717-42.

Jobst, N J and Zenios, S A (2001), 'Extending credit risk (pricing) models for the simulation of portfolios of interest rate and credit risk sensitive securities', *Wharton School Centre for Financial Institutions Working Papers*, No. 01-25.

Kusy, M I and Ziemba, W T (1986), 'A bank asset and liability management model', *Operations Research*, Vol. 34, No. 3, pages 356-76.

Maes, K (2004), 'Interest rate risk in the Belgian banking sector', *Financial Stability Review*, National Bank of Belgium, June, pages 157-79.

May, O and Tudela, M (2005), 'When is mortgage indebtedness a financial burden to British households? A dynamic probit approach', *Bank of England Working Paper no. 277*.

Mulvey, J M and Ziemba, W T (1998), *Worldwide asset and liability management*, Cambridge University Press, Cambridge.

Pesaran, H M, Treuler, B J, Schuermann, T and Weiner, S M (2006), 'Macroeconomic dynamics and credit risk: a global perspective', *Journal of Money, Credit and Banking*, Vol. 38, No. 5, pages 1,211-62.

Saita, L (2006), 'The puzzling price of corporate default risk', *mimeo.*

Samuelson, P A (1945a), 'Hansen on world trade', *The New Republic*, Vol. 112, pages 409-11.

Samuelson, P A (1945b), 'The effect of interest rate increases on the banking system', *American Economic Review*, Vol. 35, No. 1, pages 16-27.

Schuermann, T (2005), 'What do we know about loss given default?', in Altman, E, Resti, A and Sironi, A (eds), *Recovery risk*, Risk Books.

Sorge, M and Virolainen, K (2006), 'A comparative analysis of macro stress-testing methodologies with application to Finland', *Journal of Financial Stability*, Vol. 2, No. 1, pages 113-51.

Staikouras, S K (2006), 'Financial intermediaries and interest rate risk: II', *Financial Markets, Institutions and Instruments*, Vol. 15, No. 5, pages 225-72.

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*.

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

Wright, D M and Voupt, J V (1996), 'An analysis of commercial bank exposure to interest rate risk', *Federal Reserve Bulletin*, Vol. 77, pages 625-37.

Zenios, S A and Ziemba, W T (2007), 'Volume 1: Theory and methodology', *Handbook of asset and liability management*, Elsevier, Amsterdam.