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

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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 balance sheet of a bank and taking account of the repricing characteristics of all exposures, we can not only assess the impact of credit and interest rate risk 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 correlated interest rate and credit risk jointly. We also show that it is crucial to model the whole portfolio of banks, including the repricing 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

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1 Introduction

It is a well established stylised fact that banks 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 banks' maturity transformation function. However, the maturity mismatch – or more precisely the repricing mismatch – is the key source of interest rate risk in the banking book. Empirically, 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 the 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 re-pricing structure of the portfolio into account[2]. This has important implications and allows 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 maturity structure of the portfolio and captures the complex interdependence of future interest rates and credit risk. And 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 changes in the value of net assets due to movements in credit spreads as well as defaults.

Looking at the economic value of the whole bank has some inherent problems. Most importantly, 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 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, for example, find it difficult to continue to operate as it may be subject to liquidity runs. Therefore, our second condition to judge the riskiness of a bank is to assess whether a bank would be

[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 re-pricing 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 re-priced every three months. In this paper we first assume that the

sufficiently well capitalised in all future states of the world taking account of current capital, as well as future write-offs and income. In essence, we use nothing more than cash-flow accounting. But to do so, we require a model which can project write-offs and net interest income in a consistent fashion. In turn this requires a framework, like the one proposed in this paper, which a captures a) interest rate risk stemming from the maturity mismatch between assets, liabilities and off-balance sheet net positions as well as basis and yield curve risk[3], and b) the correlation of credit and interest rate risk.

We apply the framework to assess the riskiness of a hypothetical but realistic bank in a severe stress scenario, which implies amongst other changes a rise in interest rates. 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 highlights that interest rate and credit risk have to be assessed simultaneously as well as jointly for assets and liabilities. As would be expected, write-offs increase significantly after the stress. But by directly modelling net interest income we are able to illustrate that the additional margin compression between short term borrowing and long term lending decreases profits even further in the first few quarters. Losses are gradually offset once the bank starts to reprice assets and margins reflect the change in the risk-free yield curve and the deterioration in credit quality again. The offsetting effect of higher net interest income implies that after three years, profits are roughly at the same level as in the baseline scenario, even though write-offs continue to increase significantly and peak only in the third year. We show, however, that the speed at which profits return back to equilibrium crucially depends 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 rather heated. Paul A. Samuelson argues that barbers know at least as much about banking than bankers (Samuelson, 1954a) and that '*the banking system as a whole is not really hurt by an increase in the whole complex of interest rates. It is left tremendously better off by such a change*' (Samuelson, 1945b). However, an economist for a bank in Mississippi rightly points out that Samuelson's conclusion is based on unrealistic assumptions on the re-pricing miss-match 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.

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

maturities of assets and liabilities coincide with their time to repricing. Subsequently we release this assumption and let the time-to-maturity be longer than the time-to repricing.

[3] 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.

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 already after a few quarters higher rates are passed on to borrowers which in turn raise 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 US in the late 1980s banks are aware of the potential significance of interest rate risk.[4] 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 of International Settlement, 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.[5] Using this approach as well as a model by the Office of Thrift Supervision, Wright and Houpt (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 interest rates 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 impacts 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.

All these 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 re-pricing 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 asset 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

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[4] See Curry and Shibut (2000) for an overview of the S&L crisis.
[5] 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 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-

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.[6] 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.[7] Kus1y and Ziemba (1986) are some of the 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 cost 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 that 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 in essence treated as if they are tradables and no default occurs.

The literature on portfolio optimisation taking defaults into account 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.[8] 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 some of 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 a portfolio of tradable assets, we consider non-tradable exospores 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 discount rates, write-offs and net interest income, and hence on the economic value as well as capital adequacy of a bank over time. Our simulations show that it is fundamental to measure the combined impact of interest 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 UK bank. In Section 4 we present the results of the stress test

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free term structure, banks may not be able to lower deposit rates in line with the risk-free rate because bounded by zero. By modelling the whole portfolio we can capture this compression in banks' net margins.

[6] 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 miss-match on the riskiness of banks.

[7] For an overview see Mulvey and Ziemba (1998) or Zenios and Ziemba (2007).

[8] See Jobst *et al* (2006) for further references discussing models for dynamic portfolio optimisation with default.

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

$$EVA_t^i = \sum_{k=1}^{T} D_{t+k}^i C_0^i A^i + D_{t+T}^i A^i \tag{1}$$

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:

$$D_{t+k}^i = \prod_{l=1}^{k} d_{t+l-1;t+l}^i \tag{2}$$

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 premia. However, as our application is set up in discrete time, we follow Duffie and Singleton (2003):[9]

$$R_{t+l-1,t-l}^i = E_t\left(\frac{r_{t+l-1,t+l} + PD_{t+l-1,t+l}^i \times LGD_{t+l-1,t+l}^i}{1 - PD_{t+l-1,t+l}^i \times LGD_{t+l-1,t+l}^i} \mid \Omega_t\right) \tag{3}$$

with $r_{t+l-1,t+l}$ the forward risk free interest rate between $t+l-1$ and $t+l$ known at time *t*, LGD^i the expected loss given default for borrower *i* which, for simplicity, we assume to be constant. $PD_{t+l-1;t+l}^i$ is the 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.

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

We do not observe empirical coupon rates and need to re-price assets once they mature. 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:

$$C^i_0 = \frac{1 - D^i_T}{\sum_{k=1}^{T} D^i_k} \tag{4}$$

Equations (3) and (4) are crucial for understanding the channels through which credit and interest rate risk are correlated. First, both the expected risk premium and the expected risk free yield curve are dependent on a common set of macroeconomic risk factors. Hence, unexpected changes in these risk factors do impact both credit and interest rate risk. Second, unexpected movements in the risk-free yield curve do change borrowers' credit risk.[10]

When economic conditions change over time, 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 whilst the economic value always reflects all future and current economic conditions instantaneously, income will only adjust sluggishly as assets (and liabilities) are repriced gradually.

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 classes A_i and *M* liability classes L_j where all exposures in an asset (liability) class *i (j)* have the same risk characteristics.[11] Within each class, individual exposures may have different repricing buckets but we assume for simplicity that the maturity of an asset (liability) coincides with its repricing characteristics.

2.2.1 Condition 1: The economic value perspective

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

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

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[10] 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.

[11] 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.

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 based on economic fundamentals, 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 important to assess whether a bank's expected capital adequacy given losses and net profits remains above the regulatory minimum *k* for all periods in the medium term *W*. Hence, our second condition is:

Condition 2 – Capital adequacy:

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

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 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

Deriving the economic value condition requires no strong assumptions as it is based on risk adjusted discounting. Given we do not observe original coupon rates, we only need to assume that that the economic value of assets equals their face value to derive initial coupon payments. We will keep this assumption. But in order to forecast shareholder funds we need to add four more:

First, we assume that portfolios within an asset class are infinitely fine grained, ie individual exposures within an asset class are small. This assumption is for example in line with the basic Basel II formula and 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, we assume that 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 only the case if either the earnings or the economic value condition is not met.

Third, we assume that banks are passive investors: once assets mature, the bank continues to invest into new projects with the same repricing and risk characteristics as the matured assets. 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 deposits.

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. But the reader should keep in mind that all calculations are based on expectations conditional on the information set available at the time of pricing. We will also use subscript t to indicate the flow between $t-1$ and t. To clarify: for stock variables, for example the economic value of a loan, the subscript t indicates the value of the variable at time t. While for flow variables, for example a bank's interest receivables, the subscript t indicates 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.[12] 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 net interest income plus other 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 has to pay 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 1 provides an overview of the initial balance sheet. We assume that liabilities have zero maturity and the coupon rate on liabilities C^L is equal to the risk free interest rate *r*. A^i (A^j) has a 1 (2) year maturity with PD^i and LGD^i (PD^j and LGD^j). For simplicity, the bank has no other income nor does it pay any costs, dividends or taxes ie $OI=Cost=0$ and $\theta=1$.

Following equation (4), the initial risk free yield curve and expected PDs in year 1 and 2 determine coupon rates C_0^i and C_0^j for each exposure. The contribution of a single asset with unit size in asset class *i* to net interest income in the period 1 is simple to calculate: in the case of no default the contribution is C_0^i. If the borrower defaults 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.

Given a well diversified portfolio within the two asset classes, write-offs are

$$\begin{aligned} WR_1 &= WR_1^i + WR_1^j \\ &= PD_1^i LGD^i A_0^i + PD_1^j LGD^j A_0^j \end{aligned} \tag{12}$$

and given the bank is a passive investor total exposures at the end of year 1 are

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

[12] This equation implicitly assumes that the bank pays dividends proportionally to its income and that the bank is paying dividends as long as it is able to do so. Furthermore, it is assumed that losses cannot be carried forward to offset future taxes. However, it is easy to incorporate different tax and dividend regimes in our simulation as we will show in our sensitivity analysis.

Expected cash flows of assets in period one are therefore:

$$\begin{aligned} CFA_1 &= [(1-PD_1^i)+PD_1^i(1-LGD^i)]C_0^iA_0^i \\ &\quad +[(1-PD_1^j)+PD_1^j(1-LGD^j)]C_0^iA_0^j \\ &= C_0^iA_1^i + C_0^jA_1^j \end{aligned} \tag{14}$$

where the first term are cash flow contributions from asset *i* and the second from asset *j*.

There is only one liability class which pays C^L and hence the cash flow payments for liabilities are $CFL_1=C^L*L_o$. Net profits are therefore $NP_1=CFA_1-CFL_1-WR_1$ and shareholder funds grow exactly by net profits.

As we assume that the bank uses its free cash flows to pay back liabilities which matured (which in this example are all liabilities), liabilities change in line with write-offs and shareholder funds. Hence,

$$L_1 = L_0 - \Delta SF_1 - WR_1 \tag{15}$$

The development of the key variables in the first period is summarized in column 2 of Table 1.

Table 1: 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	$A_1^i = (1-PD_1^iLGD^i)A_0^i$ $A_1^j = (1-PD_1^jLGD^j)A_0^j$	$A_2^i = (1-\overline{PD}_2^iLGD^i)A_1^i$ $A_2^j = (1-\overline{PD}_2^jLGD^j)A_1^j$	…	…
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	$\overline{C}_1^i$ C_0^j	$\overline{C}_2^i$ $\overline{C}_2^j$	… $\overline{C}_2^j$
Cash Flows		$CFA_1 = C_0^iA_1^i + C_0^jA_1^j$ $CFL_1 = C_0^LL_0$	$CFA_2 = \overline{C}_1^iA_2^i + C_0^jA_2^j$ $CFL_2 = C_1^LL_1$	…	…
Write-Offs		$WR_1 = PD_1^iLGD^iA_0^i + PD_1^jLGD^jA_0^j$	$WR_2 = \overline{PD}_2^iLGD^iA_1^i + \overline{PD}_2^jLGD^jA_1^j$	…	…
Net Profits		$NP_1=CFA_1-CFL_1-WR_1$	…	…	…

With the same line of argumentation as above, cash flows for period two can be forecasted. However, assume now that after year 1, economic conditions change so that $\overline{PD}_2 > PD_1$ for both asset classes. The bank will use the new information to reprice the maturing assets in the 1 year bucket so that $\overline{C}_1^i > C_0^i$. However, it can not do this for asset *j* as coupon rates remain locked-in for another year. Cash flows for assets in year 2 are therefore $CFA_1 = \overline{C}_0^i A_1^i + C_0^j A_1^j$. Even though $CFA_2 > CFA_1$ the bank will 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* assets 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 that the bank invests into new projects with the same repricing and risk characteristics once assets mature, 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 between *t-1* and *t* is:

$$CFA_t = \sum_{i=1}^{N} \left(\sum_{b=t}^{T} C_0^{i,b} A_t^{i,b} + \sum_{b=1}^{t-1} \sum_{l=1}^{t-1} I_l \, C_l^{i,b} A_t^{i,b} \right) \tag{17}$$

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 big round brackets sums the expected coupon payments of asset classes which have not been repriced at time *t* and the second term sums expected coupon payments of asset classes which have been repriced the last time 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:

$$WR_t = \sum_{i=1}^{N} LGD^i PD_t^i A_{t-1}^i \tag{18}$$

Equation (17) and (18) highlight how profits are driven by changes in write-offs, exposures and cash flows 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 from non-defaulted assets which have been repriced to reflect the increase in credit risk and risk-free interest rates.

Given our behavioural assumption that depositors are willing to roll over their deposits, *CFL* evolves in line with

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

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 (18), equation (19) sums over all liability classes with the first term in brackets summing the coupon payments of liability classes which have not been repriced at time *t* and the second term summing coupon payments of liability classes which have been repriced the last time in period *l* prior to time *t*.

In theory formulae (1)-(4) 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). We will use 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.

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 security 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 re-pricing assumptions in our simulations.

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

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

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)). Give assumption 4 this implies that

$$\Delta FVL_t = \Delta L_t = \Delta \overline{A}_t - \Delta SF_t = -WR - \Delta SF_t \tag{21}$$

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 but also 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. Throughout the simulation we keep all the assumptions outlined in Section 2.2.3.

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.[13] In our example, we restrict ourselves to UK 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), cost-income ratio and the interest rate sensitivity gap roughly match an average UK 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 3 months to 10 years extracted from the Bank of England yield curve data set.[14] 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 1:

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

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:

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

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:

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[13] For off-balance sheet items we assume no counterparty risk and therefore model them as risk-free instruments.

[14] 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. Data are available from www.bankofengland.co.uk.

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

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 of England base 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.

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 correlation 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.

To capture the interaction between macroeconomic shocks and credit risk we build on a UK PD model described in Bunn *et al* (2005).[15] It is based on models linking aggregate default probabilities to macro economic variables.

The corporate probability of default is modelled as a function of own lagged values, changes in the logarithm of GDP, corporate income gearing, the change in commercial property capital values, first difference of the real interest rate 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 LTV is the loan to value ratio 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. Seasonal dummies are also found significant in explaining the probability of default on credit card loans.

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 the interest rate will not only determine the net interest income but is one of the key drivers of 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 inter-bank loans is 40%, the LGD on mortgage loans to be 30%, the LGD on credit cards to be 80% and the LGD on

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[15] 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).

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 propose a risk-neutral pricing framework to derive coupon rates which we don't 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.[16]

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

At this stage it is hard to derive firm conclusions from the literature. And given that the core our framework it 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 premium 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 introducing a downward bias in the bank's net interest income as we use lower coupon rates. Hence, our 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 REPO 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 form of deposits. In Section 6.3 we modify the hypothetical bank's portfolio by substituting a proportion of its banks and customers' deposits with debt instruments. Debt instruments should be priced

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[16] For example, Saita (2006) estimates the actual 1 year default probability for Xerox in December 2000 was 4.8% whilst he extracts 13% as the 1 year risk neutral default probability. This implies a jump-to-default risk premium of 2.7.

according to formulae (1)-(4) by taking the bank's own credit risk into account. However, there is a circularity problem as a banks' 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.

We therefore use an indirect method: Starting with an initial rating (A+) we forecast the evolution of this rating by applying a rating model developed by Dudley-Smith and Stringa (2006). Similar to Blume *et al* (1998) the authors use an ordered probit model to predict ratings based on factors which are fixed or can be forecasted by our framework such as previous period ratings, return on assets, provisions relative to net interest income, cost income ratio, bank's size and country. Ratings are then mapped 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 Figure A3, Panel A in the Appendix). We use corporate spreads as we do not observe sufficient bank specific spreads for all ratings in the UK.

3.6 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 inter-bank lending, 0.35 for mortgage lending, 0.75 for unsecured lending and 1 for corporate loans.

3.7 Forecasting systematic risk factors

To be able to forecasts PDs and yield curves we need a model that forecasts and captures the correlation of systematic risk factors between each other and 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 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 theses into PD forecasts over the next three years using the models discussed in Section 3.3.[17]

3.8 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 horizon. As base case scenario we use the Bank of England February 2005 Inflation Report

[17] 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.

projections where interest rates are assumed to follow market expectations (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.[18]

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 profitability of our representative bank over a three year horizon.

4.1 Risk-free and credit spread yield curves

In Figure 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, 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.

Figure 1: Annualised credit spread curves before end after the stress

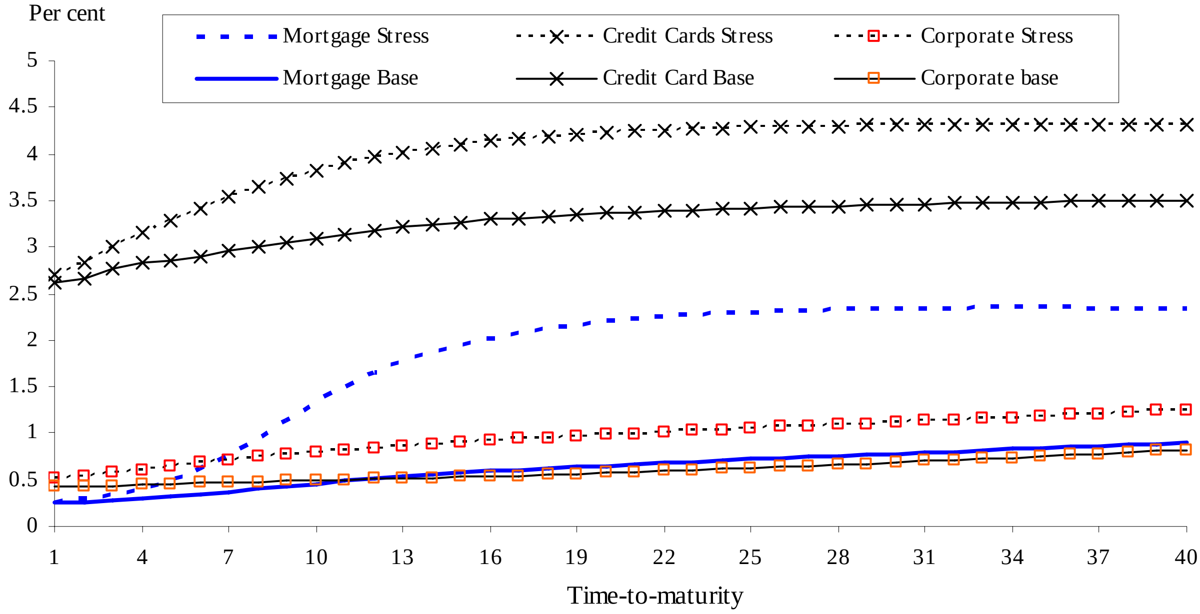


Figure 1 shows the credit spread curves for mortgages, corporate and credit cards. The solid lines represent the spreads after one quarter in the base case and the dashed lines the spreads one quarter after the shock (indicated by 1 in Figure A1). As default rates and LGDs on credit cards are highest,

[18] 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.

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 reasons 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 Figure 2). This increase in credit risk is also reflected in the increasing credit spreads in Figure 1.

Initially, net interest income 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 Figure 2). However, after 1 ½ years, net interest income starts to increase. This follows the gradual repricing of assets reflecting the higher credit risk in the stress scenario.[19]

[19] 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.

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

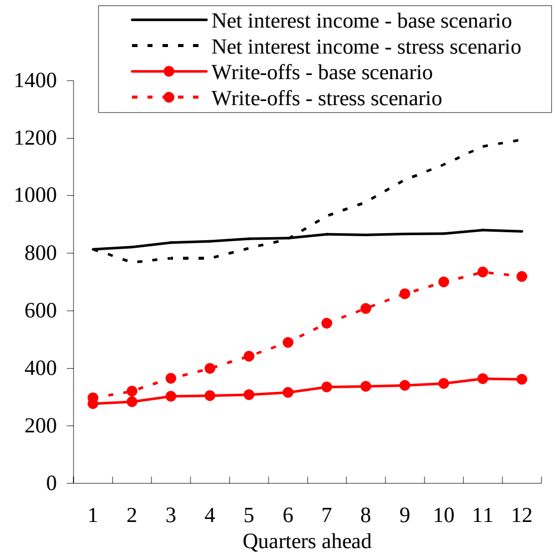
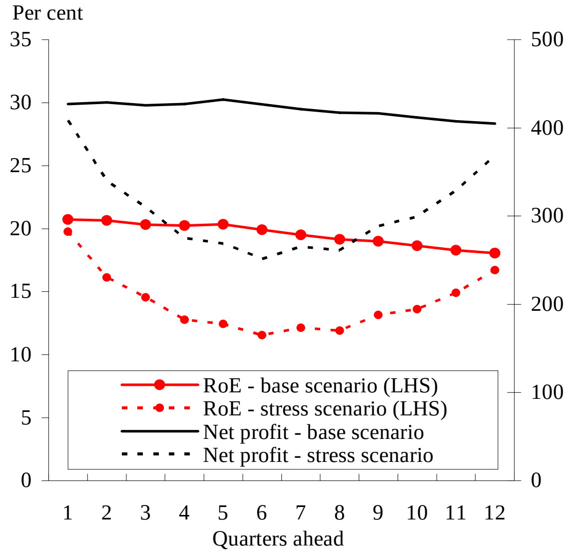


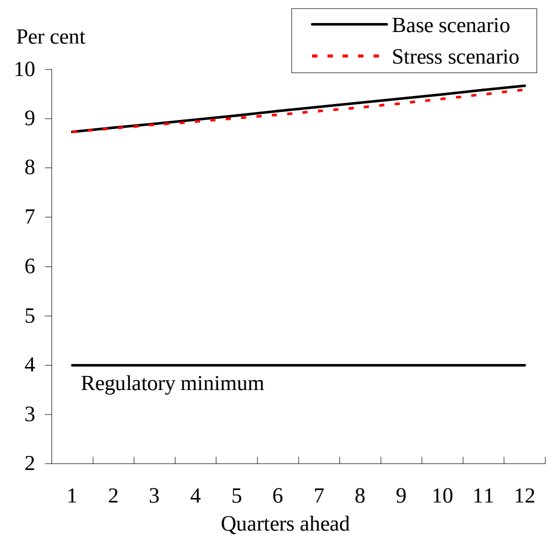
Figure 3: Evolution of annualised net profit and return on equity per quarter (RoE)



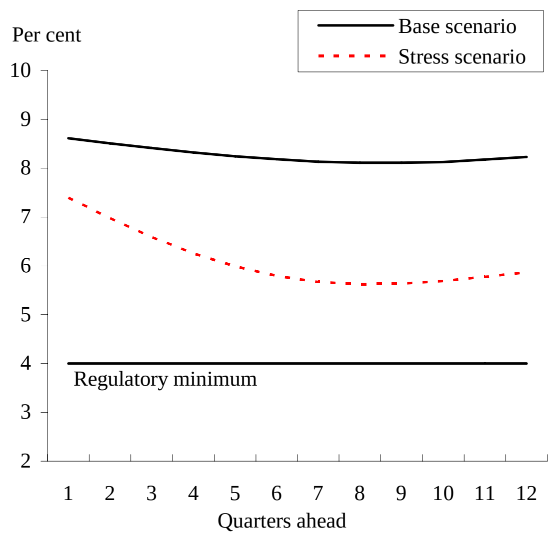
The combined impact of write-offs and net interest income imply that net profits fall by about 50% in the sixth quarter but nearly recover to the base line after 3 years (Figure 3). As we will discuss in more detail in the next section, it is clear from Figure 2 that interest rate and credit risk have to be assessed jointly. For example, focusing on pure default risk by only looking at write-offs leads to an underestimation of risk in the short term and an overestimation of risk in the long run. To capture risks fully, the initial margin compression and the subsequent repricing has to be taken into account.

Figure 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



The impact of the shock can also be summarized in terms of return on equity (RoE) as illustrated in Figure 3 (dotted line).[20] Compared to an initial RoE of around 20% in the base line scenario, the shock nearly halves the bank's RoE in the worst quarter 1 ½ 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 Figure 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 (Figure 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.

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.

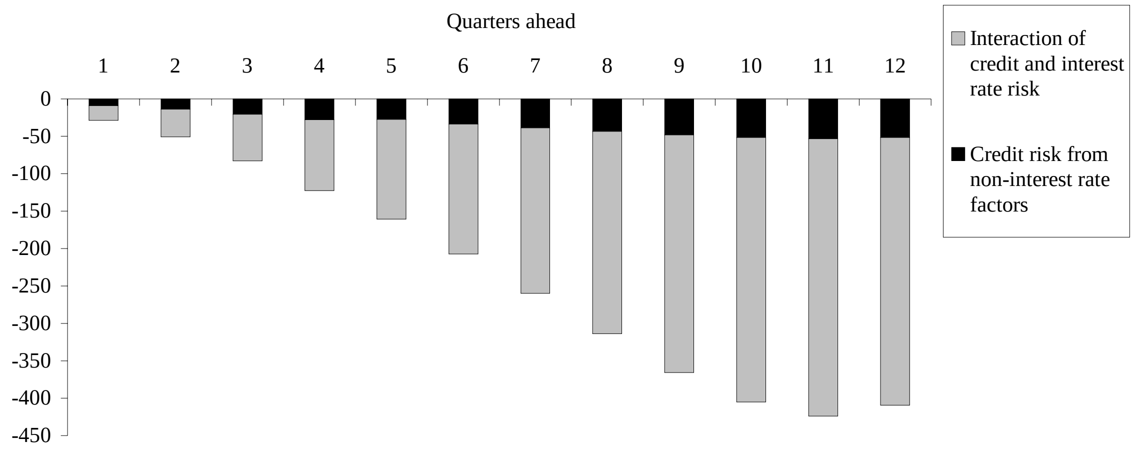
To assess (A) we calculate PDs conditional on all systematic risk factors changing to their stressed levels and interest rates remaining at their base case scenario level. Hence, (A) highlights the importance of all non-direct interest rate factors. (B) is similar to interest sensitivity analyses run 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).

In Figure 5 we show that in comparison to other macroeconomic factors interest rates are the key driver of the rise in credit risk in our scenario. Figure 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.[21] However, 'pure interest rate risk' does not take

[20] ROE declines slightly over time in the baseline scenario mainly because write-offs are forecasted to rise inadvertently from the very low initial level. Furthermore positive retained earnings also increases the denominator of ROE.

[21] 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

Figure 5: Impact on write offs[a]



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

Figure 6: Impact on net interest income

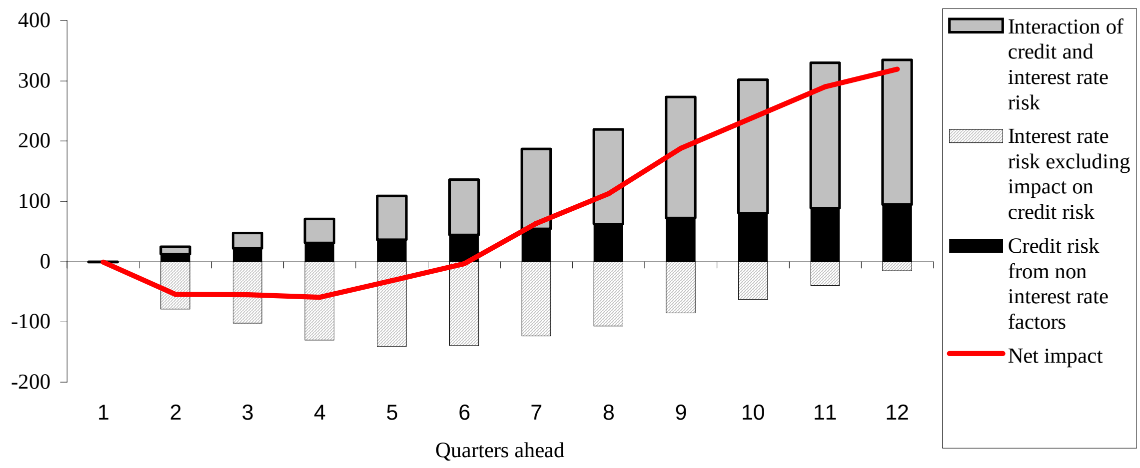
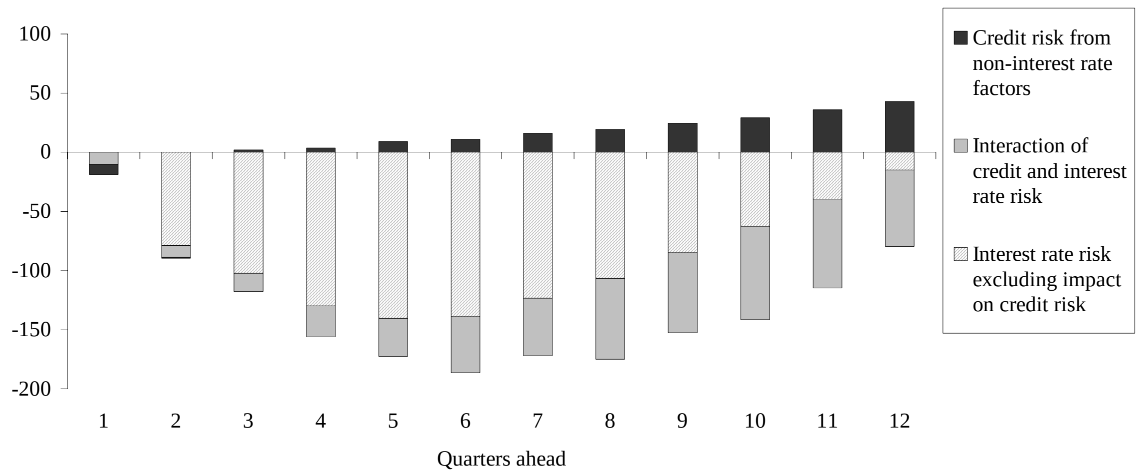


Figure 7: Impact on profits



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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.

account of the impact of interest rates on credit quality nor the correlation of interest rates and other credit risk drivers in a stressed scenario. 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 the 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 (Figure 7) it is evident that in this 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. Hence, the combined impact of correlated credit and interest-rate risk is the key determinant of the bank's risk profile.

The magnitude of these effects depends on the initial balance sheet conditions and our behavioural assumption. But it is clear from the discussion why risks have to be assessed jointly. For example, a simple gap analysis is not sufficient for risk assessment as it only looks at the striped area in Figure 6 ignoring all other effects on net profits. Similarly, focusing on credit quality only, for example by projecting expected write-offs, is also misleading. Such an analysis does not account for the initial fall and subsequent increase in net interest income as shown in Figure 6.

6 Sensitivity analysis

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.[22]

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 the change 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 analyze 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.

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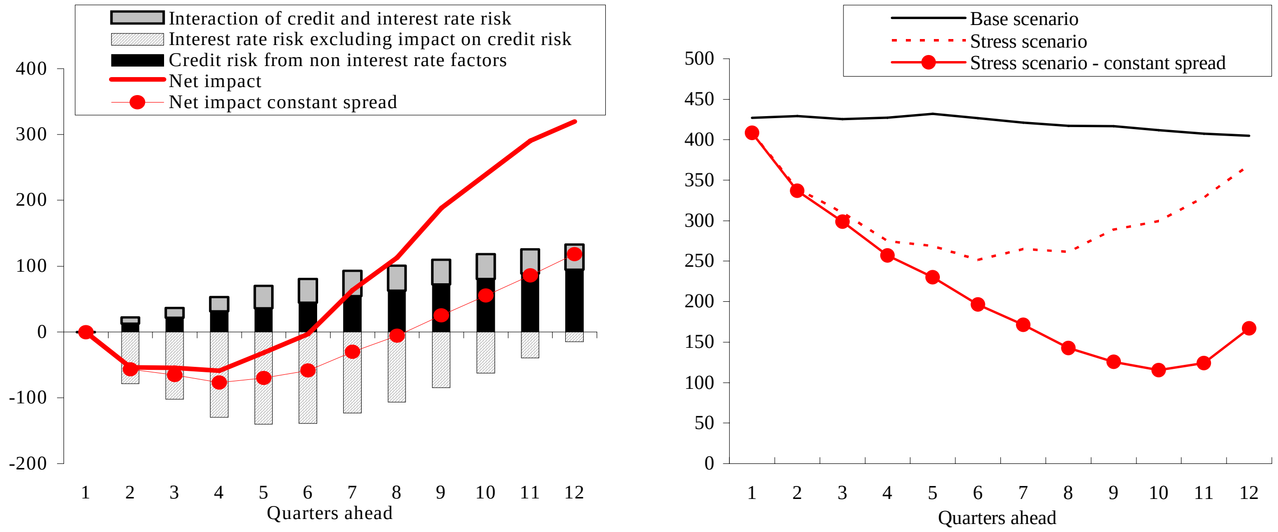
[22] We also undertook further sensitivity tests. For example, we changed characteristics of the hypothetical bank's balance sheet to increase in the customer-funding-gap We also considered sticky dividends as suggested by the literature (see eg. Allen *et al*, 2000). The direction of the results was intuitive and in no case was the financial stability of the bank threatened. These results are available on request.

Figure 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 Figure 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 can not 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 115 in quarter ten (Panel B in Figure 8). However, the bank continues to make positive net profits and satisfies the economic value as well as both capital adequacy conditions. But this result highlights that, even when risk characteristics in terms of PDs and LGDs dynamics remain the same, re-pricing characteristics of exposures can have a substantial impact on the financial strength of a bank.

6.2 Cyclical LGD

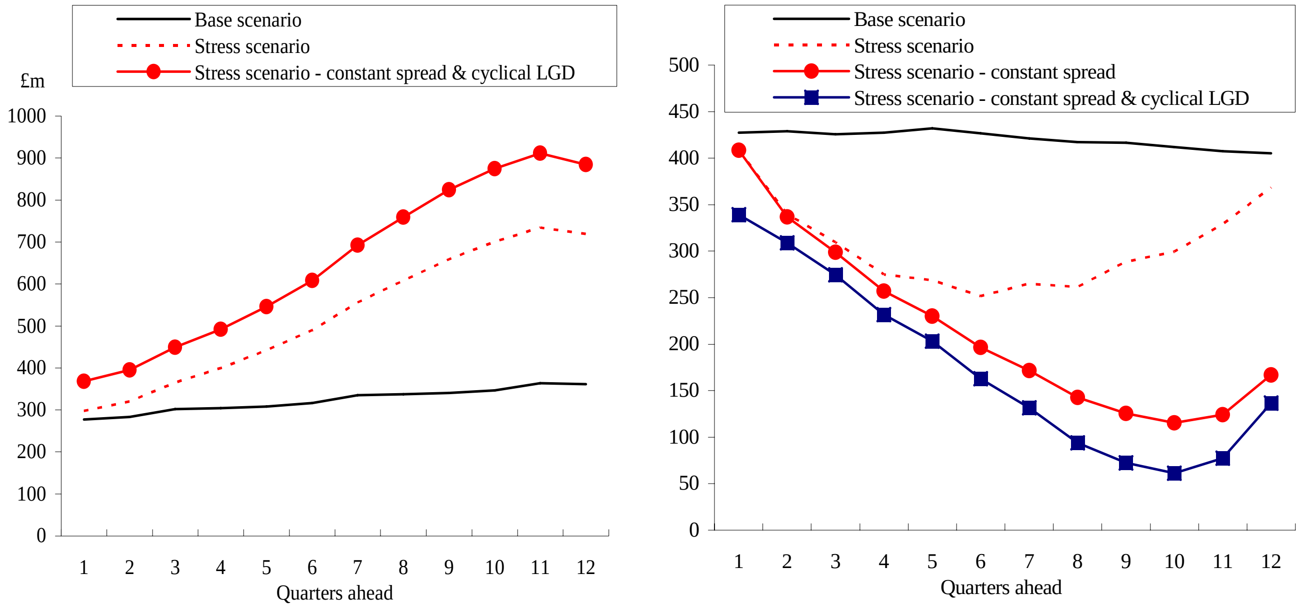
A recent book edited by Altman *et al* (2005) provides strong evidence that recovery rates are low when aggregate default rates are high. For example, Schuermann (2005) finds that recovery rates are one-third lower in recessions. Frye (2003) supports this evidence by showing that the LGD in high default 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 are fixed and not changing 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 Frey. Given it is unrealistic that LGDs remain at the highest level forever, we assume that they gradually revert to their baseline levels over the following ten years. In addition, we assume that the bank must hold a constant spread on the variable rate mortgages as in the previous section.

One of the effects of higher LGDs is a rise in write-offs (Panel A in Figure 9). Although credit spreads increase in response to higher LGDs, they do not fully offset the higher write-offs during the horizon we consider. The net result is a further fall in net profits to a minimum of 61 in quarter ten. However, the bank continues to make positive net profits over all quarters. Therefore, the LGD assumption does not have a material impact on shareholder funds as a proportion of RWA under the constant-risk weights approach. On the other hand, under the internal rating based approach RWA do increase and the capital ratio falls to a minimum of 4.4% in the eighth quarter versus a minimum of 5.8% with constant LGDs in the same quarter. This is a sharp fall but the bank still satisfies the capital adequacy condition. The economic value of the bank also falls by about 24%, but it remains positive. Hence, the long term financial stability of the bank is not seriously threatened either.

Figure 9: Bank's profitability, constant LGD versus rising LGD

Panel A: Write-offs and net interest income   Panel B: Net profits



6.3 Including debt instruments

In the previous sections we assumed that all liabilities of the hypothetical bank are in form of deposits. However, debt instruments usually account for a sizeable proportion of banks' liabilities. For example, on average 27% of the largest nine UK banks' total liabilities are in the form of debt instruments. In this section we modify the hypothetical bank's portfolio by substituting a proportion of its banks and customers' deposits with debt instruments. The new balance sheet is shown in Table A2 in the Appendix.[23] In order to leave the banks ' profitability and RoE roughly constant and ensure some degree of comparability with previous results we decrease the bank's fixed costs, and thus its cost-income ratio.

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 problem that this implies, we use an indirect approach by forecasting ratings which in turn determine the spread on debt instruments. In the baseline scenario we assume that credit spreads in each rating category remain constant over the forecasting period. To reflect not only possible rating changes of the bank but also higher spreads for each rating category we increase spreads in the stress scenario in line with the rise in LGDs for

[23] Although we modify the balance sheet of the hypothetical bank, we ensure that shareholder funds, off balance sheet items, and the interest rate sensitivity gap are unchanged.

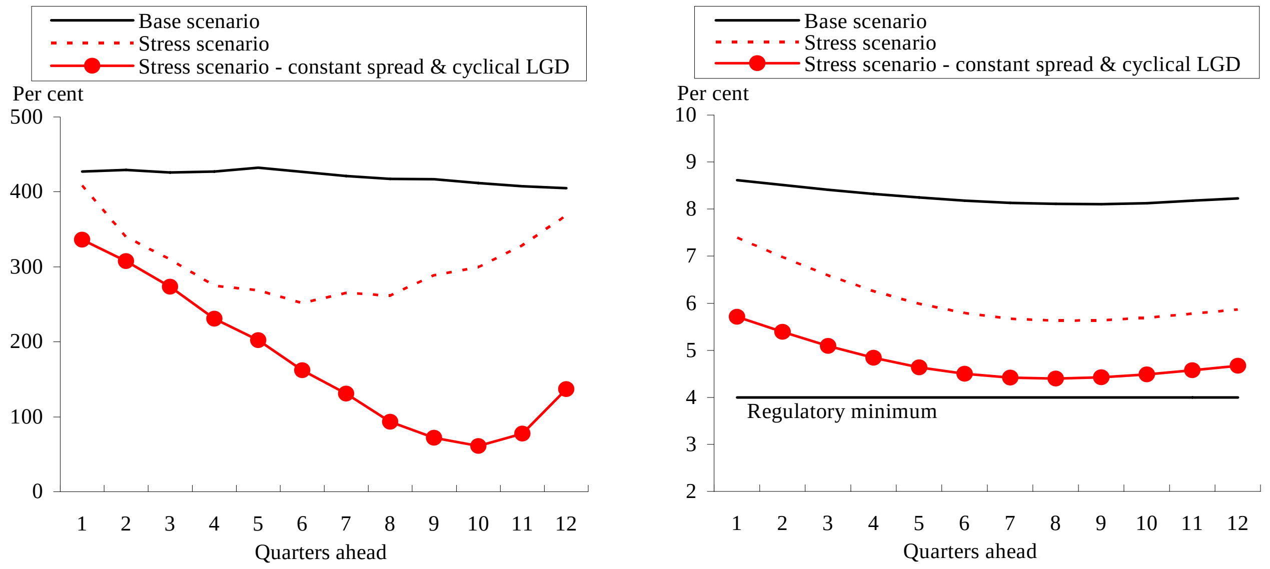
corporates as discussed in section 6.2. The increase in spreads for an A+ rating can be seen in Figure A2, Panel B in the Appendix.

Given that the liability side of the hypothetical bank's portfolio now differs substantially from that used in the previous sections, the results of this section are not directly comparable to those of the previous sections. Therefore, we re-estimate the results using the modified balance sheet for the baseline scenario, for the stress scenario as in the main section, and for the stress scenario with constant mortgages' credit spreads and cyclical LGD as in section 6.2 (Figure 10).

Figure 10: Bank's profitability and capital adequacy with subordinated debt

Panel A: Net profits

Panel B: Capital adequacy – Internal approach



The pattern of net profits for all scenarios (Panel A, Figure 10) is very similar to that shown in Figure 9. Since the deterioration in the bank's fundamental is not large enough to trigger a downgrade. Therefore, the increase in the spreads the bank has to pay on its debt instruments is driven exclusively by the widening spread of each rating category. Given that the bank continues to make positive profits, the bank's capital adequacy under the constant risk weights approach is always satisfied. On the other hand, when we consider time-varying risk weights the banks capital adequacy ratio falls considerably. But it remains just above the 4% regulatory minimum (Panel B, Figure 10). It is interesting to note that given the rating model a downgrade would have been highly likely if the bank's capital ratio fell below 4%, decreasing net interest income and capital buffers even further.

This is the case when the cost-income ratio is not adjusted. In this scenario, the bank is expected to be downgraded in the eighth quarter following the stress. As a result, the fall net profits fall even further (see Figure A3 in the Appendix). However, if in this case the bank profits remain positive throughout the scenario.

The broken and dotted lines in Figure 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 satisfied the capital adequacy condition. Similarly, after the shock crystallises the bank's economic value falls by more than 25% 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 correlated, they cannot be measured separately. Surprisingly, most studies focus on the correlation between interest rate risk and default risk of 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 impact of correlated credit and interest rate risk on risk-adjusted discount rates and cash flows contributions to earnings. The essence of our framework is relatively simple but at the same time holistic.

In the second part of our paper 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 correlated 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 in the stress scenario, 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 miss-match 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 test. 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 customer, 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 correlation 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 models of UK corporate and household PDs proposed by Drehmann *et al* (2006) and May and Tudela (2005) respectively. 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 these extensions will refine the exact estimation on the 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 that it is crucial to capture the whole portfolio, including the repricing characteristics of assets, liabilities and off-balance sheet items.

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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.

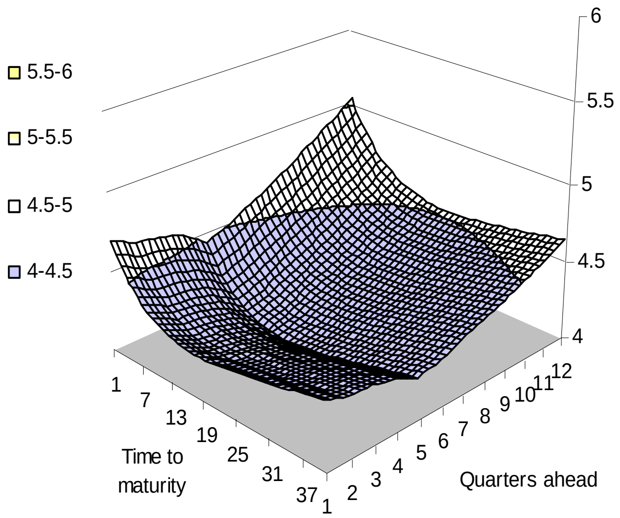
C) A 15% (initial) unanticipated depreciation in the trade-weighted sterling exchange rate. This scenario entails a fall in the demand for sterling owing to an increase in the perceived relative riskiness of sterling assets (in other words, a rise in the sterling risk premium). Sterling depreciation 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 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 graphs

Figure A1: Evolution of the risk-free term structure over the next 12 quarters in the base and stress scenario respectively

Panel A: Baseline



Panel B: Stress

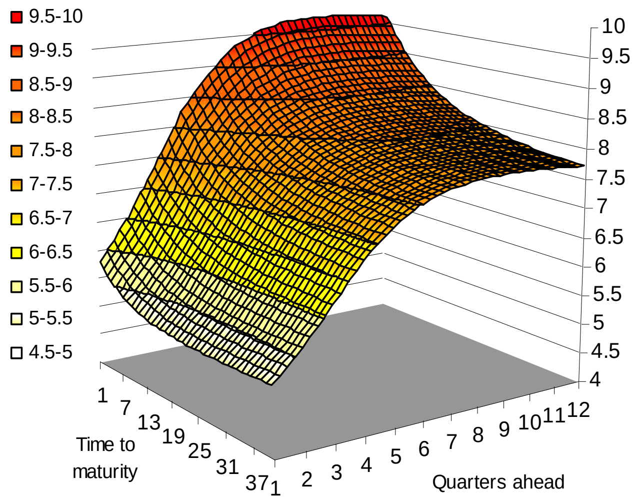
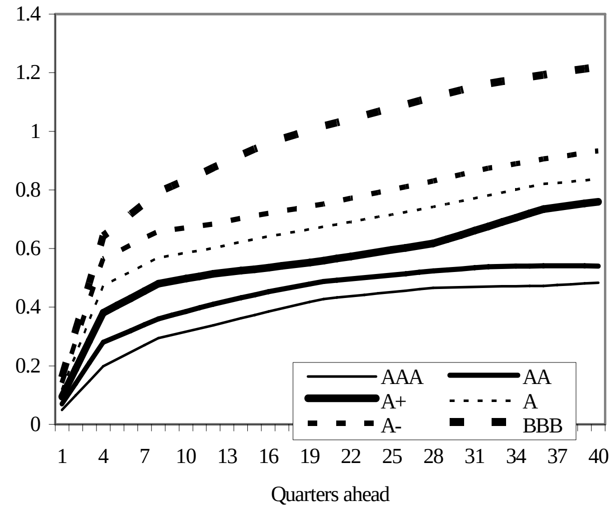
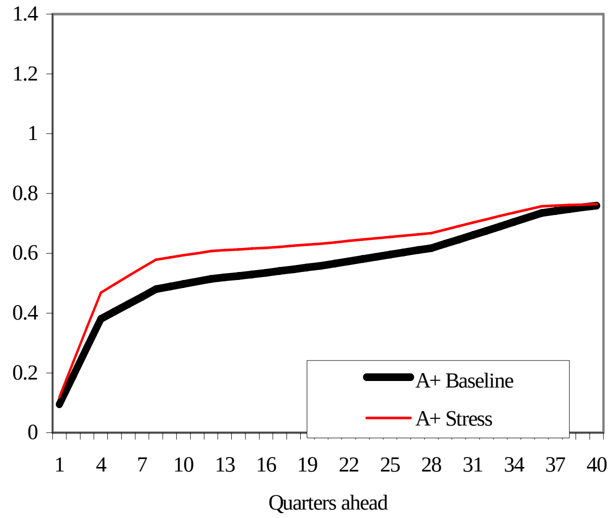


Figure A2: Corporate spreads

Panel A: corporate spreads for different rating categories



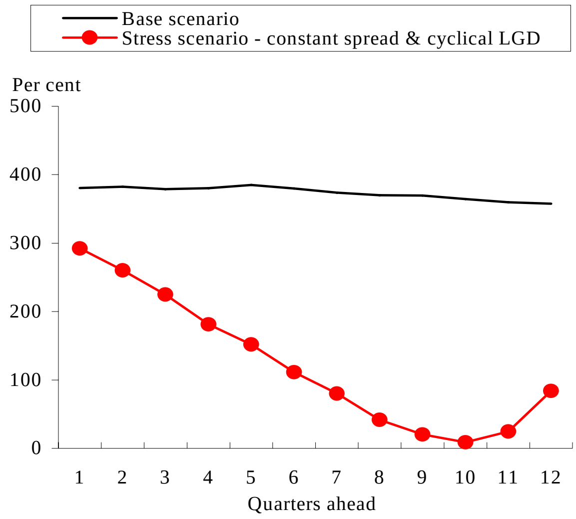
Panel B: A+ rating in baseline and stress scenario[(a)]



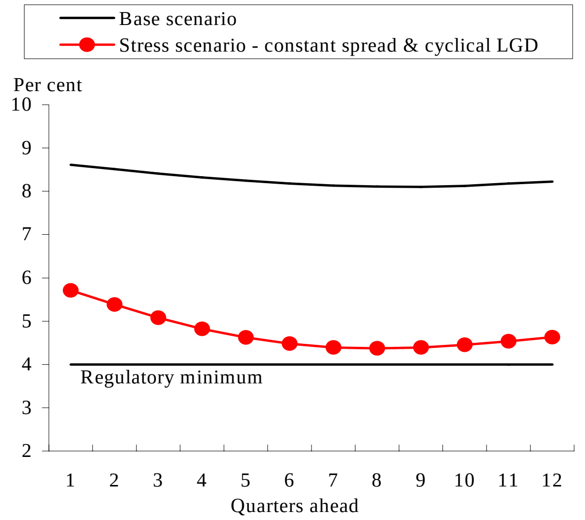
(a) We assume that the LGD on subordinated debt increases proportionally to the corporate LGD. It then falls gradually to reach the baseline spread after 10 years as usual.

A3: Bank's profitability and capital adequacy with subordinated debt an no adjustments to the cost income ratio

Panel A: Net profits



Panel B: Capital adequacy – Internal approach



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 UK 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