Working Paper no. 282

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November 2005

Bank of England

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This paper represents the views and analysis of the authors and should not be thought to represent those of the Bank of England. We would like to thank Mathias Drehmann, Lavan Mahadeva, Darren Pain, Paul Robinson, Simon Wells, Garry Young, participants at the Expert Forum on Stress Testing, Centre for Central Banking Studies, Bank of England, 17-19 May 2004, and two anonymous referees for helpful comments. We are, of course, responsible for any errors. This paper was finalised on 30 September 2005.

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ISSN 1368-5562

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Abstract

This paper adopts a new approach to stress testing the UK banking system. We attempt to account for the dynamics between banks' write-offs and key macroeconomic variables, through conditioning our stress test on the historical correlation between the variables and allowing for feedback effects from credit risk to the macroeconomy. In contrast to most existing empirical stress testing work, this paper uses a direct measure of banks' fragility – the write-off to loan ratio. We find that both UK banks' total and corporate write-offs are significantly related to deviations of output from potential. Following an adverse output shock, total and corporate write-off ratios increase. Mortgage arrears, on the other hand, appear to be mainly dependent on household income gearing. The results suggest that, even if the most extreme economic stress conditions witnessed over the past two decades were repeated, the UK banking sector should remain robust.

Key words: Macro stress testing, bank fragility, loan write-offs, VAR analysis.

JEL classification: E44, G21.

Summary

Stress tests were performed on the resilience of the UK banking system as part of the IMF Financial Sector Assessment Programme (FSAP). These tests revealed that the UK banking system was robust to a number of adverse shocks. Most of these tests were conducted by the large banks themselves, based on scenarios developed from the Bank of England's Medium Term Macroeconometric Model. To compare the robustness of such a conclusion to the choice of stress test, this paper proposes an alternative test of the resilience of the UK banking sector, which analyses the common developments in a measure of bank fragility and key macroeconomic variables. An advantage of the stress test proposed here is its ability to analyse – within a small system of equations – the increase in bank fragility following a shock to a single macroeconomic variable, allowing for the potential impact on other key macroeconomic variables that may also affect bank fragility. Furthermore, the test allows for feedback effects from an increase in fragility back to the macroeconomy – for example, an increase in the default rate on loans by the household and corporate sectors may cause consumption and investment to fall subsequently.

The stress tests used here, like most other methodologies, may not fully capture structural changes in the banking industry. Nonetheless, the results are robust to a number of checks and uncover some important relationships between macroeconomic dynamics and the loan write-off ratio – our measure of bank fragility. UK banks' aggregate write-offs, and particularly corporate ones, are found to be sensitive to a downturn in economic activity. Household write-offs, on the other hand, are found to be more sensitive to changes in income gearing. The results suggest that, even if the most extreme economic stress conditions witnessed over the past two decades were repeated, the UK banking sector should remain robust.

The approach to stress testing proposed in this paper is straightforward to implement and provides a useful complement to the suite of models used to assess banking sector vulnerability.

1 Introduction

Macroeconomic stress tests of the financial system have been developed in recent years (see Sorge (2004) for a recent survey and discussion). These tests assess the vulnerability of the banking system, or more broadly the financial system, to extreme but plausible adverse macroeconomic shocks. Stress tests are important, from a central bank's perspective, since they are tractable and provide a useful benchmark to assess the risks to the financial system (see Bunn *et al* (2005)).

Recently, as part of the IMF Financial Sector Assessment Programme (FSAP), stress tests were performed on the resilience of the UK banking system. The stress test scenarios were derived from a version of the Bank of England's structural Medium Term Macroeconometric Model (MTMM). The scenarios were then applied to UK banks' aggregate loan book (see IMF (2003) and Hoggarth and Whitley (2003)). The main findings of this analysis were that the UK banking system was robust to a range of plausible adverse macroeconomic developments.

In this paper we adopt a different approach to perform macroeconomic stress tests on the UK banking system and investigate whether the conclusions arising depend on the choice of stress test and on the fragility variable used. We attempt to account for the dynamics between banks' write-off to loan ratio and key macroeconomic variables using a parsimonious vector autoregression (VAR) model. Unlike most existing stress testing work on links between the business cycle and the fragility of the banking system, a direct measure of banks' fragility – the write-off ratio on loans – is employed. The advantage of the VAR is that it estimates how write-offs change in the quarters following adverse business cycle shocks implying that the stress test is conditional on the historical correlation among the variables in the multivariate model. The VAR approach also allows for potential feedback effects from the fragility of banks' balance sheets to the macroeconomy (a potentially important linkage emphasised by, *inter alia*, Sorge (2004)).

No conventional theoretical macroeconomic model describes the relationship from macroeconomic variables to bank write-offs and *vice versa* (for example by affecting the supply of bank credit and thus investment). We attempt to resolve this problem in two steps. First, the paper discusses a macroeconomic model to help guide the choice of a parsimonious number of macroeconomic variables to include in the specification. Second we augment this vector of macroeconomic variables with the write-off data and let them affect one another in an autoregressive manner without restricting the dynamics. Finally the paper considers some alternative financial and economic variables that could affect the write-off ratio and macroeconomic variables. Such robustness checks are important since the conclusions could be misleading if some key variables are left out of the analysis.

This paper conducts one of the first multivariate analyses of how macroeconomic developments affect UK banks' loan write-offs both in aggregate and at the sectoral level. The importance, from a stress-testing viewpoint, of having data on banks' fragility covering at least one full economic cycle is emphasised. Although write-off data are available on a quarterly basis only from 1993, annual data on aggregate write-offs for the major UK banks are available back to the late 1980s. In this paper a number of methods for interpolating these annual data onto a quarterly basis are considered using the available information on the characteristics of the quarterly and annual data in the sample from 1993-2004. Using three alternative interpolation schemes, the multivariate analysis is performed on a sample of quarterly data from 1988 to 2004, therefore covering a full UK economic cycle. Since aggregate data may mask different patterns at the sectoral level, separate sectoral VARs are also estimated for corporate write-offs and household defaults. While the disaggregated approach has the advantage of assessing the impact of stress tests on different components of banks' loan portfolios, it suffers from the drawback that data are available, at the earliest, only from 1993 and thus do not cover a complete economic cycle.

The remainder of the paper is organised as follows. Section 2 reviews the literature on stress testing, Section 3 discusses the choice of variables in our VAR, Section 4 discusses data and estimation issues, and Section 5 contains the main results of the estimations. In Section 6 a number of robustness checks on the results are discussed while in Section 7 the key factors affecting write-offs are decomposed. Section 8 concludes.

2 Literature review

A number of approaches have been used in the past to stress test banks for credit risk. The most common approach used in IMF country FSAPs are single factor sensitivity tests. These look at the impact of a marked change in one variable, such as the exchange rate or the policy interest rate, on banks' balance sheets. However, these stress tests do not allow for the interaction between macroeconomic variables ('scenarios') such as, in the example above, the impact of changes in the interest rate on real activity and thus on banks' loan portfolio. Scenarios can be developed through a number of methods. One approach is to use a structural macroeconomic model. This was done, for example, in a number of IMF FSAPs on developed countries. An alternative avenue is pursued by Boss (2002) to stress test the Austrian credit portfolio. His analysis is based on CreditPortfolioView®, which models the default probability of certain industrial sectors as a logistic function of a sector-specific index, which, in turn, depends on the current value of a number of macroeconomic variables. The parameter estimates derived from this model are then used to assess the future losses on Austrian banks' loan portfolios. A different methodology to assess the impact on the Austrian banking sector of credit and market risk is applied in Elsinger, Lehar and Summer (2002). Their paper analyses the effect of macroeconomic shocks on a matrix of Austrian interbank positions. Specifically, the authors are able to assess the probability of individual bank failures in response to a series of macroeconomic factors while at the same time taking into account the effect that these failures have on the rest of the banking system. This model thus decomposes bank defaults into those that arise directly and those that are a consequence of contagion. The interaction between banks' financial conditions and the macroeconomy is modelled by assuming that macroeconomic scenarios are drawn from a joint probability distribution of interest rate shocks, exchange rate and stock market movements, as well as shocks related to the business cycle.

Pesaran *et al* (2004) and Alves (2004) use a VAR model to assess the impact of macroeconomic variables on firms' probabilities of default. In Pesaran *et al* the VAR includes GDP, consumer prices, the nominal money supply, equity prices, exchange rates *vis-à-vis* the dollar and nominal interest rates for eleven countries/regions over the 1979-99 period. The global VAR is used as an input into simulations for firms' equity returns, which are then linked to the loss distribution of a corporate loan portfolio. A clear advantage of this approach is that it links the credit risk of internationally diversified loan portfolios in a detailed macroeconomic model that allows for differences across country and region. Alves (2004) constructs a co-integrated VAR, using KMV's corporate expected default frequencies (EDFs) as endogenous variables and macroeconomic factors (the twelve-month change in industrial output, the three-month interest rate, the oil price, and the twelve-month change in a broad stock market index) as exogenous variables. The expected default frequency (EDFs) of each EU industrial sector is modelled based on exogenous macroeconomic factors together with the EDFs of other industrial sectors to capture the possibility of contagion.

However, neither of the above VAR models explicitly incorporates measures of the quality of banks' balance sheets. In this paper a VAR system is also used but one that includes a direct measure of banks' fragility – the loan write-off ratio – as well as macroeconomic variables.[1] As the write-offs on loans to private non-financial corporations (PNFCs) and households may be related differently to the business cycle, the VAR is also estimated using sectoral data for households and PNFCs.

3 Choice of macroeconomic variables and estimation

3.1 A small macroeconometric model

As discussed in Bunn *et al* (2005), it is desirable to use some kind of macroeconomic model to link macroeconomic variables and bank write-offs. Here we briefly discuss a small model on which the choice of variables in our VAR is based. It draws on the existing literature on reduced-form macroeconomic models (for example Batini and Haldane (1999), Blake and Westaway (1996), Ball (1998)) and is described by a parsimonious number of equations (see the appendix).

These models are developed mainly as an analytical tool to help answer policy questions but do not necessarily provide a good empirical fit of the data. They also impose restrictions on the dynamics of the multivariate models which have often been shown not to hold empirically. Our approach instead augments the vector of macroeconomic variables with the write-off ratio and alternative variables that could interact with the write-off data. Rather than restricting the number of lags in our VAR, information criteria are used to choose the order of the VAR, which allow for a potentially better empirical fit of the model. The theoretical models are therefore used as a guide to choose the macroeconomic variables to include in the stress-testing VAR rather than as an identification scheme *per se*.

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[1] In the UK FSAP the IMF staff carried out analysis using a similar approach where separate VARs were estimated for the household and the non-financial corporate sectors. This analysis is summarised in IMF (2003).

3.2 *Macroeconomic variables in the stress-testing VAR*

Once macroeconomic variables are selected using the small scale macroeconomic model these are combined with a measure of banks' fragility – the loan write-off ratio – to perform stress tests using the VAR methodology. The VAR can be written in the more general form as:[(2)]

$$Z_{t+1} = \Gamma + \sum_{j=1}^{p} \Phi_j Z_{t+1-j} + \varepsilon_{t+1} \tag{1}$$

where Γ is a constant vector, Φ_j are matrices and ε_{t+1} is a vector of residuals/shocks. Z_{t+1} is the vector of endogenous variables including the output gap, the nominal short-term interest rate, annual RPIX inflation and the real exchange rate. In addition to the macroeconomic variables, Z_{t+1} also includes the aggregate or sectoral loan write-off ratio. The equation in the model for the write-off ratio, and thus the equation defining the shock to the write-off ratio, is as follows:

$$wo_{t+1} = \gamma_{W0} + \phi_{WO} Z_t + \varepsilon_{wo,t+1} \tag{2}$$

where wo_t represents the write-off to loan ratio, $\varepsilon_{wo,t+1}$ is a white noise shock, γ_{WO} is a constant, ϕ_{WO} is a row vector of parameters corresponding to the row of coefficients in Φ_1 in the write-off equation. Z_t is the vector of the variables included in the VAR including the write-off ratio itself. Equation **(2)** describes the determinants of the bank write-off to loan ratio which are lagged values of the variables included in the VAR.

The write-off variable is usually not included in small reduced-form macro models (or indeed large structural ones) but is the variable of interest in this paper. Based on a number of single reduced-form studies, loan write-offs are shown to depend on the output gap and the real interest rate (see Pain (2003)). There might also, in principle, be feedback effects from write-offs to other variables in the model, in particular demand and output and thus the output gap in equation **(1-A)** in the appendix. For example, an increase in write-offs may reflect a general deterioration in the credit quality of borrowers. Profit maximising banks might thus reduce the quantity of loans supplied or increase the lending rate (relative to the official interest rate).[(3)] An increase in write-offs would also

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(2) The model described in the appendix suggests that the data can be represented as a VAR of order 1. However, it has often been found necessary to include more lags than suggested by the theory to obtain a better fit to the actual data. Therefore, standard information criteria are used to choose the number of lags to include in the model.

(3) See Zicchino (2005).

result in banks' capital being lower than otherwise and, *in extremis*, falling to the regulatory minimum. Therefore, banks might have to reduce the loan supply to maintain their capital to risk weighted asset ratio above the regulatory floor or to prevent a credit rating agency downgrade.

3.3 The stress test – impulse response function analysis

Modelling the dynamics of the macroeconomic variables and the write-off ratios on loans using a VAR has the advantage that impulse response analysis can be carried out – the stress test proposed in this paper. By estimating the system, it is possible to simulate various shocks to the macroeconomic variables and consider the feedback from these shocks to the loan write-off ratio and thus total write-offs. Equivalently, one can investigate whether shocks to the loan write-off ratio have an impact on future macroeconomic developments.

Since the variance-covariance matrix of the VAR residuals/shocks is unlikely to be diagonal, the residuals need to be orthogonalised. A common procedure is to apply a Cholesky decomposition, which is equivalent to adopting a particular ordering of the variables and allocating any correlation between the residuals of any two elements to the variable that is ordered first. It is well known that these impulse response functions can be sensitive to the ordering of the variables – this may be considered a disadvantage of our stress test.(4)

The variables in the model were initially ordered in ascendance according to the likely speed of reaction to any particular shock. Variables at the front end of the VAR are assumed to affect the following variables contemporaneously but only to be affected themselves by shocks to the other variables after a lag. Variables at the bottom of the VAR, on the other hand, only affect the preceding variables after a lag but are affected themselves immediately. The financial variables – interest rates and the exchange rate – were ordered at the bottom of the VAR implying that they react instantaneously to shocks in the real side variables whereas the other variables (eg output gap, write-offs) react only after a lag following shocks to the financial variables. The output gap was ordered after write-offs reflecting priors that the economic cycle affects bank losses in the United Kingdom only after a lag (see Hoggarth and Pain (2002) and also Chart 2 in the appendix). As a

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(4) By changing the order of the variables a different structure on the model is imposed. Since similar results are obtained when doing this suggests that the analysis is not sensitive to the precise identification scheme.

robustness check, different orderings of the variables were considered and the impulse responses computed using the 'generalised impulse' function described in Pesaran and Shin (1998). The latter method constructs an orthogonal set of shocks that does not depend on the variable ordering.[5]

4 Data issues

The variables used throughout the analysis are described in Table A1 and plotted in Charts 1-13 of the appendix. The sample periods vary since for some of the variables quarterly data are available only from 1993 (eg banks' write-offs).

4.1 Bank write-offs

Bank write-offs are the losses (net of recoveries) made by UK-owned banks on loans initiated from their UK-resident banking operations.[6] The sample is restricted since quarterly figures on write-offs for the banking system as a whole are available only from 1993 Q1 covering only half of the early 1990s economic cycle – the recovery phase. Some of the variables show little variation over this period – in particular annual retail price inflation and the banks' base rate, have remained in a relatively narrow range of between 1.5%-3.5% and 3.5%-7.5% respectively over the past decade. Annual data on the main UK banks' consolidated published accounts are available back to 1988 – since the main banks are a large subset of the banking system as a whole these data can be used as a proxy for data on all banks back to 1988, which will allow a whole economic cycle to be captured. The annual data of the total write-off ratio for the main UK banks before 1993 are interpolated onto a quarterly basis and these are used as a proxy for the actual quarterly total write-off ratio of all UK banks before 1993. As described in more detail in the appendix and plotted in Chart 1, three different interpolation schemes were considered. The interpolation methods produce slightly different estimates for quarterly write-offs over the 1988-92 period. Whereas using simple quadratic and cubic interpolations imply a total quarterly write-off ratio series which is smoother than the

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(5) The results, reported later, were found to be robust to the orthogonalisation method and thus the standard Cholesky decomposition was preferred following the intuition outlined above. Other results are available on request.
(6) Therefore, the data exclude losses made by overseas branches and subsidiaries of UK-owned banks and losses made by domestically located non-bank business. But the data include losses – from UK-based operations – on loans to overseas residents as well as to domestic ones.

post-1993 (actual) series, the interpolation using information from the data set from 1993 to 2004 to interpolate the 1988-92 sample has more variation and a slightly higher level than implied by the alternative interpolations.

There appears, from Chart 1 and Chart 7, to be a rather extreme outlier in the data in the fourth quarter of 1995. This was due to a one-off specific loss (£300 million) on loans to two companies spread across banks. In the estimated VAR models it was therefore decided to include a dummy variable in 1995 Q4 in all specifications for total write-offs and corporate write-offs to allow for the possibility that the event is an outlier.

4.2 Macro variables

The macroeconomic variables used in the VAR analysis are described in Table A1 in the appendix. The annual rate of change in retail prices (excluding mortgage interest payments) is used as the measure of inflation and the London clearing banks' base rate as the nominal short-term interest rate. The output gap is the difference between the logarithm of actual and potential output. In theory, there is no precise definition of the output gap. The main measure used is derived from a Cobb-Douglas production function with constant returns to scale. Potential output, is represented by the following equation:

$$\bar{y}_{t+1} = C + \log A_{t+1} + \alpha \log L_{t+1} + (1-\alpha)\log K_{t+1}$$

where A is technical progress, L is labour and K is the capital stock. Technical progress is captured by a time trend and α is set equal to 0.7, consistent with the historical average share of income going to labour.(7) This is the measure of the output gap included in the core estimations in this paper.(8)

In Chart 2 in the appendix the inverted output gap is plotted against total write-offs using the cubic spline interpolation method (for 1988-92). A mixed picture on the causation between the two series appears. In the very early part of the sample it seems that the write-off ratio increases before the output gap decreases – during the previous boom – whereas from 1990/91 onwards it seems that the

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(7) See Bank of England (1999).
(8) As robustness check on the results three alternative measures of the output gap were used (see Section 6).

write-off ratio increases (decreases) following decreases (increases) in the output gap. Although this is difficult to detect exactly by eyeballing the data, it can be analysed more thoroughly using the VAR.

4.3 Stationarity of the variables

As can be seen in Charts 1-13 in the appendix, some of the variables appear potentially non-stationary although theory would suggest that most, if not all, of the variables considered should be stationary. The non-stationarity is probably due to the sample period starting during a high inflation regime and when the economy was close to the bottom of a recession, and ending in 2004 when inflation was low by historical standards and output growth was robust. Unit root testing is challenging since most tests have very low power (see Maddala and Kim (1999) for a comprehensive discussion). Thus there is some uncertainty over whether or not the null hypothesis under consideration can be rejected. All variables are tested for stationarity using either the Phillips-Perron or the KPSS test.(9) Whereas the former test has the null of a unit root, the latter has stationarity as the null hypothesis. The results are reported in Tables A2 and A3 in the appendix. The KPSS test rarely rejects the null hypothesis of stationarity using a 99% critical value. Given the low power of these tests and that the series should, in principle, be mean-reverting, they are treated as such and therefore no additional data or model transformations have been performed. If there is some non-stationarity in the data it is most likely that the common trends will be picked up by the VAR.

5 Aggregate and sectoral results

5.1 Aggregate results

In the estimated VAR, the exchange rate, however measured, was found to have little impact on aggregate write-offs, either directly or through the response of aggregate write-offs to the other macroeconomic variables in the VAR. For this reason, the exchange rate was not included in the basic aggregate model. The main model considered in this paper (aggregate basic model) consisted of the following variables:

$$Z_{t+1} = \{WRATIO1, GAP, RPIXAG, NOMIR\}$$

(9) The conclusions from the Phillips-Perron and KPSS test are the same. The data have also been tested for stationarity using other tests (eg the augmented Dickey-Fuller and NG-Perron tests). The results of these are the same and are available upon request.

where *WRATIO1* is the write-off ratio on aggregate loans, *GAP* is the output gap, *RPIXAG* is the annual rate of retail price inflation (excluding mortgage payments) and *NOMIR* is the nominal bank short-term interest rate (see also Table A1 in the appendix). The lag structure of the VAR was chosen using the AIC and the Schwartz criteria. For all estimated VARs considered in this paper the Schwartz criteria suggested a VAR of order 1. The AIC criterion also suggested a VAR of order 1 for the main model (see Tables A4-A5 in the appendix).

Chart 14 in the appendix show the impulse response functions for the aggregate VAR over the 1988 Q1-2004 Q2 period. The parameter estimates from the estimated VAR are shown in Table A (below).[10]

Table A: The estimated parameters from the VAR

		Constant		*WRATIO1*	*GAP*	*RPIXAG*	*NOMIR*
WRATIO1	Γ	0.216 [2.51]	Φ_1	0.529 [6.54]	-0.017 [-4.93]	-0.001 [-2.26]	0.002 [0.75]
GAP		3.232 [3.55]		0.423 [0.50]	1.001 [27.11]	-0.014 [-3.21]	-0.165 [-6.61]
RPIXAG		0.097 [0.04]		0.520 [0.22]	0.054 [0.53]	1.001 [81.69]	0.111 [1.61]
NOMIR		4.662 [3.42]		-0.022 [-0.02]	0.164 [2.95]	-0.023 [-3.52]	0.835 [22.24]

Note: t-statistics are in square brackets. Parameter matrices refer to equation **(1)**.

The estimated VAR shows, in the first row of Table A, a significant relation between changes in output relative to potential (*GAP*) and the aggregate write-off ratio (*WRATIO1*). The write-off ratio falls, after a lag, following an increase in output (relative to potential). Changes in the inflation rate also have a negative, although weaker, effect on write-offs. The impulse response functions suggest that the aggregate write-off ratio increases significantly within six quarters following unexpected adverse shocks to the output gap, with the maximum impact after four quarters, but after only six-twelve quarters following unexpected increases in inflation. Unexpected increases in the nominal interest rate also result in an increase in the aggregate write-off ratio after a one to three year

[10] The write-off series included in the main model (*WRATIO1*) is interpolated between 1988 and 1992 using a cubic spline.

lag. However, no significant relationship is found from changes in aggregate write-offs to economic activity (row 2 of Table A).

From the estimated VAR we conclude that there is a significant relation between GDP (relative to potential) and the aggregate write-off ratio but not *vice versa*. Also the response of the total write-off ratio following a shock to the output gap is similar irrespective of the interpolation scheme employed. The confidence bounds around the response function are slightly wider using interpolation method three (ie the interpolation method that uses the 1993-2004 sample to interpolate back to 1988 – described more fully in the appendix).[11]

Table B below shows the (maximum) impact of shocks to the output gap on the write-off ratio in the basic model.

Table B: Maximum impact of 1% adverse shock to UK output (relative to potential) on UK-owned banks' aggregate annual write-off ratio

Estimation period	**% of total loans**	**% of Tier 1 capital**
	1988 Q1-2004 Q2	
Basic model	0.07	0.86
	1978 Q1-2000 Q4	
Memo		
FSAP top-down results		
Provisions equation[a]	0.15	1.27
	(0.07)	(0.7)

[a] Since the provisions equation (based on Pain (2003)) shows the impact of a change in output growth as a per cent impact on the new provisions/loans ratio these calculations are based on an initial new provisions ratio of 1% per annum assuming a 1% decline in UK and world output growth (UK output growth alone in brackets).

The results are in the same order of magnitude as suggested by the Bank of England's reduced-form provisions equation (see Hoggarth and Pain (2002) and Pain (2003)).[12] Assuming that the relationships are linear across different sized shocks the results suggest that a repeat of the swing in output (relative to potential) of the order seen in the early 1990s' recession – 9% – would increase banks' aggregate write-offs currently by around 0.7 percentage points. This would correspond to a

[11] The VAR result using the alternate methods to interpolate quarterly aggregate write-off data over the 1988 Q1-1992 Q4 period are available on request.

[12] As part of the IMF's Financial Sector Assessment Program (FSAP) on the United Kingdom, the Bank of England estimated the effects on the provisions made against credit losses by the major UK-owned commercial banks in aggregate, using a single-equation econometric model. The reduced-form model describes the relationship between key macroeconomic and bank-specific variables and new provisions.

loss equivalent to around one third of UK-owned banks' average annual pre-tax profits over the past three years.[13]

5.2 Sectoral results

In this section we analyse whether the aggregate write-off data conceal some important sectoral differences following adverse macroeconomic shocks. This comparison though is complicated by the fact that no write-off data are available at the sectoral level before 1993.

5.2.1 Corporate sector models

In the corporate model, as in the aggregate one, the output gap, the annual retail price inflation and the nominal interest rate are included. In addition, capital (or income) gearing are considered since there is evidence that these types of financial variables affect corporate liquidations in the United Kingdom (eg see Vlieghe (2001) and Tudela and Young (2003)).[14] The corporate VAR has the following variables:

$$Z_{t+1} = \{CORPWOR, GAP, KGEAR, RPIXAG, NOMIR\}$$

where *CORPWOR* is the UK-owned banks' write-off ratio on non-public, non-financial corporate (PNFCs) loans and capital gearing (*KGEAR*) is the ratio of PNFCs' debt to market value of equity. The other variables are the same as in the aggregate model. Capital gearing increased markedly from early 1999 reflecting the flattening off and then sharp fall in equity values. As shown in Chart 11 in the appendix, in the last two years this upward trend has been partially reversed – capital gearing is included in one specification of the corporate model and income gearing in another. We estimated the corporate model using a VAR of order 1 as suggested by the Schwarz Information Criterion.[15]

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(13) But the impact on any individual bank, both relative to its loan book and profits, could be larger than these aggregate banking system estimates suggest.
(14) Income gearing is defined as interest payments as a per cent of corporate pre-tax profit and capital gearing is corporate net debt as a per cent of net debt plus net equity.
(15) Although the AIC criterion suggested a VAR of order 2 (Tables A4 and A5 in the appendix) we prefer to use the more parsimonious VAR given the short sample period. Whether choosing a VAR of order 1 or 2 does not qualitatively change the results.

The estimated parameter matrices from this VAR are not reported but the coefficients along the diagonal of the parameter matrix are found to be smaller than in the aggregate VAR.[16] The impulse response functions from the estimated corporate sector model are shown in Chart 15 in the appendix. The banks' write-off ratio on corporate loans was found to increase significantly following unexpected adverse output shocks or increases in the nominal interest rate but not following unexpected increases in capital gearing.[17] The maximum impact from an adverse shock to output (relative to potential) on the corporate write-off ratio occurs after two-three months – more quickly than in the aggregate write-off model. The maximum impact of shocks to the nominal interest rate is found to take longer (four to nine quarters).

Table C: Maximum impact of 1% adverse shock to UK output (relative to potential) and 1% point increase in nominal interest rates on (non-financial) the corporate write-off ratio, 1993 Q1-2004 Q2

	% of total corporate loans	% of Tier 1 capital
	1% fall in output	
Capital gearing model	0.38	0.65
Income gearing model	0.40	0.69
Memo		
FSAP top-down results	0.14[a]	0.24
	1% point increase in nominal interest rates	
Capital gearing model	0.23	0.38
Income gearing model	0.13	0.21
Memo		
FSAP top-down results	0.10[a]	0.17

[a] These estimates – based on the IMF's staff own calculations – were from scenarios for a 2.3% fall in GDP (0.32) and a 5.3% point rise in nominal interest rates (0.52). The coefficients have been scaled down linearly. See IMF (2003) Appendix 1, Tables 1.3 and 2.

Table C presents the impact of shocks to the output gap and the nominal interest rate on corporate write-offs. In the table, results are also reported based on a corporate VAR including corporate income rather than capital gearing. The sensitivity of corporate write-offs to output shocks is very similar in the two specifications.[18] Therefore, and bearing in mind the different sample periods, at first blush write-offs in the corporate sector seem to be more sensitive to adverse output shocks than are aggregate write-offs (reported in Table B).

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[16] A possible reason for this difference is the shorter sample period used for the corporate than the aggregate write-off model.
[17] The models with corporate income rather than capital gearing also did not show a statistically significant impact.
[18] The weaker impact on write-offs of interest rate shocks in the specification including corporate income gearing might be attributable to the high correlation (0.75) between nominal interest rates and income gearing over the estimation period.

Since the corporate sector model covers the period only since 1993, and therefore not a full economic cycle, it is unclear whether it is appropriate to extrapolate these results to assess the impact of a full-blown recession (such as in the early 1990s).

5.2.2 Household sector models

The household write-off to loan ratio is shown in Chart 9 in the appendix, including and excluding unincorporated businesses (UBS). As shown in the chart, the distinction between the two series makes little difference. A household VAR is estimated including a measure of real income (real household disposable income, the unemployment rate or the output gap), household income gearing and the other macroeconomic variables included in the VAR models described above. There has been very little variation in the aggregate household write-off ratio over the past decade – it has remained in a narrow range between 0.05%-0.20%. Not surprisingly, therefore, most shocks are not found to have a discernible impact on household write-offs over this period. Income gearing has a small economic impact and the estimates suggest that for every 1 percentage point unexpected increase in the income gearing ratio then the household write-off ratio rises by only 0.03 percentage points. Because of the limited impact of the macroeconomic variables on household write-offs, the impulse response functions or parameter estimates are not reported here.(19) In contrast to the findings for the aggregate and corporate sector write-offs, the cyclical pattern in total household write-offs since the early 1990s is much smaller which could reflect the impact of two factors.

First, secured housing loans are the largest subcomponent of total household loans – accounting for around 80% of the total over the sample period. Mortgage write-offs are likely to be less cyclical than corporate loans since they are secured.(20) Second, despite the benign macroeconomic environment, since 1997 there has also been an increase in write-offs on unsecured debt, especially on credit cards (see Whitley, Windram and Cox (2004)). This seems to reflect a structural change in the unsecured debt market probably due to an intensification of competition resulting in banks' broadening their lending book to riskier borrowers.

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(19) They are available upon request.
(20) A good proxy for UK banks' mortgage write-offs is the total write-offs of banks whose loan business is predominantly mortgages (ie 'mortgage banks'). During the early 1990s' recession the <u>cumulative</u> write-offs to loan ratio of the mortgage banks (Abbey National, A&L, Halifax and Northern Rock) was only 1% compared with 5% for commercial banks.

Separate data for secured (and unsecured) household write-offs are available only from 1997. Since then, the write-off ratio on secured debt has fallen very gradually from an initial low ratio (around 0.02%) – see Chart 10 in the appendix. Since secured debt is a large proportion of total debt this mainly explains the flat profile for the total household write-off ratio over the 1997-2004 period. Given that secured and unsecured write-off data are available for only a few years we used proxies for bank losses – credit card arrears for unsecured debt and mortgage arrears for secured debt for which a longer time span of data are available.(21) Credit card arrears are defined as the value of credit card balances in arrears by more than three months as a per cent of the value of all credit card balances. Mortgage arrears are the number of arrears of more than six months as a percentage of the number of mortgages outstanding. Credit card and mortgage arrears data are shown respectively in Charts 12 and 13 in the appendix.

The household unsecured lending VAR is estimated including credit card arrears and the other macroeconomic variables included in the aggregate household VAR. No evidence is found that any of the measures of real economic activity affect credit card arrears, which is perhaps not surprising since for most of the 1990s arrears have been increasing despite an improvement in the economic environment (compare Chart 12 with Chart 3).(22) Since very limited evidence is found of shocks to macroeconomic variables affecting credit card arrears, the impulse responses are not reported.(23) Next, secured lending to households is considered. The VAR includes the following variables:

$$Z_{t+1} = \{MORTGAGE,\ REAL\ INCOME,\ IGEARHH,\ RPIXAG,\ NOMIR,\ HPAG\}$$

where *MORTGAGE* is mortgage arrears, *HPAG* is annual house price inflation. The latter is included since house prices affect the collateral value of the mortgage loan and thus may be an important determinant of mortgage arrears. Data on the latter are available only on a semi-annual basis back to

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(21) These measures are proxies of default rather than actual losses and so do not take account of any loan recoveries once default occurs. This is particularly likely in the secured debt market where property is used as the collateral for the loan. Nonetheless, these series are highly correlated with write-offs over the common observation period 1997 Q1-2004 Q2 of 0.75 for secured debt and 0.62 for unsecured debt.

(22) The finding that real activity shocks are not found to be significant in affecting credit card arrears does not mean they are unimportant but rather that over the period of available data, since the early 1990s' recession, the impact of macroeconomic factors seem to have been dominated by structural changes– particularly an increase in competitiveness – in the credit card market. Whitley *et al* (2004) find that allowing for this supply-side proxy then household income gearing has a statistically significant positive impact on credit card arrears over the period.

(23) These results are also available upon request.

1987. These are interpolated onto a quarterly basis using the simple interpolation methods discussed in the appendix on aggregate write-offs.(24)

In contrast to the unsecured lending VAR, a clear statistical impact is found for some macroeconomic variable on the stock of mortgage arrears over the 1988-2004 period (as can be seen from the impulse response functions in Chart 16 in the appendix). The main finding is that income gearing has a statistically significant positive impact on mortgage arrears – a 1% point adverse shock (increase) in income gearing results in a 0.25% point rise in arrears. Put differently, around one half of the (3% point) increase in mortgage arrears witnessed in the early 1990s' recession can be explained by the (5% point) rise in household income gearing at the time. In addition, interest rates were found to have a separate, although weaker, impact on mortgage arrears. Moreover, mortgage arrears were found to rise in periods after unexpected negative shocks to the output gap suggesting that they also depend, albeit less strongly than corporate and aggregate write-offs, on the position in the economic cycle. No evidence was found of shocks to house prices or any of the alternative measures of real income measures in affecting future mortgage arrears.

Therefore, the disaggregated estimates reveal sectoral differences masked by the VAR of aggregate write-offs. In particular, the corporate write-off ratio appears to be significantly related to changes in output (relative to potential) – more so than suggested by the aggregate write-off data – whereas the household write-off ratio (on secured debt) is found to be more sensitive to changes in income gearing than in economic activity *per se*.

6 Robustness checks

In this section the robustness of the previous results are assessed focusing particularly on the aggregate write-off VAR.

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(24) Once again a VAR of order 1 is used, as suggested by the Schwarz criterion, although the AIC criterion suggests a VAR of order 4 (see Tables A4 and A5 in the appendix). A VAR of such high order would greatly limit the confidence in the results, due to the limited number of data available for the estimation.

6.1 *Additional variables in the VAR*

Since the aggregated model was rather parsimonious, it is worth considering alternative specifications with additional variables. The inclusion of house price inflation in the aggregate VAR was considered since it might be expected to affect bank write-offs and shows some variation over the past decade.(25) An unexpected increase in house price inflation would have positive wealth effects and one would thus expect the write-off ratio to fall. However, the inclusion of house price inflation had little impact on the main results and was not found to interact with the total write-off ratio. This is perhaps not surprising given that house price inflation was also insignificant in the secured lending VAR.

In principle, most macroeconomic models also have a role for the real exchange rate. However, including changes in the real effective exchange rate – whether measured on an annual or quarterly basis – was found to have little impact on the overall results.(26) As shown in the top panel of Table D, including either house price inflation or the exchange rate has little effect on the sensitivity of the write-off ratio to output shocks.

6.2 *Estimation period*

As discussed earlier, it may be misleading to compare the sensitivity of corporate and aggregate write-offs to a given output gap shock since the corporate VAR is estimated over the shorter (post-1993) period. The second part of Table D below, therefore, shows the (maximum) impact of shocks to output on the aggregate write-off ratio on the VAR estimated since 1993 only. The maximum increase of the total write-off ratio (following a given adverse shock to the output gap) is still only half the size as for corporate write-offs alone reported earlier (Table C). Nonetheless, the sensitivity of the aggregate write-off ratio to a given output shock is twice as large over the 1993-2004 period than in the 1988-2004 period.

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(25) Including house price inflation in the VAR makes the so-called price puzzle, ie that in VAR analysis retail price inflation tends to increase following interest rate shocks, less severe.
(26) An *ex-post* real interest rate was also included in the aggregate VAR. Shocks to the real interest rate were not found to have an impact on the future aggregate write-off ratio but output and inflation shocks retained their significance - this may indicate that the significance of the interest rate is due to inflation dynamics during the sample period.

Given that very large adverse shocks to output have not occurred since 1993, caution is needed when interpreting the results that a large adverse output shock has a much bigger impact on bank fragility in the later period.(27) Put another way, it seems that the results from this shorter sample period may exaggerate the impact of output on write-offs during a deep recession.

Table D: Maximum impact of 1% adverse shock to UK output (relative to potential) on UK-owned banks' aggregate annual write-offs

Estimation period	% of total loans	% of Tier 1 capital
	1988 Q1-2004 Q2	
Basic model	0.07	0.86
Basic model plus house price inflation	0.08	0.94
Basic model plus real exchange rate	0.09	1.07
	1993 Q1-2004 Q2	
Basic model	0.18	2.18
Basic model plus house price inflation	0.19	2.29
Basic model plus real exchange rate	0.18	2.15

Therefore, this justifies our attempt to interpolate the data back to cover a whole economic cycle. Part of the explanation for the smaller impact of an output shock in the longer sample period is that some UK banks chose to increase their write-offs in the late 1980s boom period on their bad LDC debts incurred earlier in the decade.(28) Chart 17 shows the sensitivity of write-offs to output shocks when the starting point of the estimation period is varied from 1988 Q1 through to 1993 Q1. The chart confirms that the sensitivity of write-offs to output shocks is lowest when the late 1980s boom period is included. Nonetheless, it still shows that bringing the starting point of the estimation forward to the start of the recession in 1990 (ie excluding the previous boom period) gives estimates of the sensitivity of aggregate write-offs to output shocks that are almost one half of those estimated in the post-1992 period, which does not capture the down phase in the early 1990s' economic cycle.

(27) A period when the variance of output shocks has been much lower may emphasise the necessity of including an entire business cycle when using an econometric model to perform stress tests.

(28) As mentioned in Hoggarth and Pain (2002), the initial increase in write-offs in the late 1980s boom was partly due to some banks (especially Midland, Lloyds-TSB and Standard Chartered) taking the opportunity of a strong balance sheet to write-off their bad debts built up previously in Latin America.

6.3 Measures of the output gap

The output gap is a commonly used measure of activity. However, there is no unambiguous correct method of measuring excess capacity in the economy.

Table E: Maximum impact of 1% negative shock to UK output (relative to potential) or unemployment rate on UK-owned banks' annual write-offs

	—Output gap measure—				
	Cobb Douglas	**Based on linear trend**	**OECD**	**HP-filter**	**Unemployment rate**
	Total write-offs 1988 Q2–2004 Q2				
Basic model	0.07	0.07	0.06	0.08	0.06 [Not significant]
Basic model plus house price inflation	0.08	0.08	0.07	0.07	0.15
Basic model plus real exchange rate	0.09	0.09	0.08	0.09	0.10
	Corporate write-offs 1993 Q1–2004 Q2				
Capital gearing model	0.38	0.38	0.42	0.25 [Not significant]	0.31
Income gearing model	0.40	0.40	0.42	0.28 [Not significant]	0.21

Note: *Not significant* model means that shocks to this measure of the output gap yield an impulse response function on the total write-off ratio that is statistically insignificant at all times. Note that the output gap based on the Cobb-Douglas function is the one used for all the results presented previously in the paper.

As a check on the results, alternative measures of excess capacity were considered. Table E shows the production function-based measure of the output gap used earlier together with three alternatives – one published by the OECD, an output gap measure where potential output is computed using a HP filter and one computed using a simple linear time trend. The unemployment rate is also shown as an alternative indicator of real activity.[29]

For the VAR including aggregate write-offs, the alternative measures of the output gap produce similar, albeit slightly weaker, results. For the corporate VAR, the OECD measure yields similar results. Hence the impact of shocks to the output gap on bank fragility is robust across measures of the output gap.

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[29] In discussions with the major UK banks they often emphasise the importance of the unemployment rate in affecting their decision whether or not to write off a loan.

7 Variable decomposition

In this section the variance and historical decompositions from the estimated aggregate and corporate VARs are shown and the sensitivity of the estimation results to different sample periods is considered. This should yield some further insights into the relationship between the write-off ratio on loans and the output gap.

7.1 Variance decomposition

The variance decompositions of the various model specifications confirm the main results (see Table F). The main explanatory power is attributable to the write-off ratio itself. However, aside from this, in most specifications of the aggregate model, the output gap explains most of the variation in the write-off ratio 10 and 20 periods later. In the corporate write-off model including capital gearing, the short-term interest rate also explains a significant part of the change in the write-off ratio. Finally, in the secured debt household model, changes in income gearing explain more than half of the variation in mortgage arrears ten quarters ahead.

Table F: Per cent of variation in the write-off ratio (5, 10 and 20 quarters ahead) explained by each variable[(a)]

Aggregate VAR							
	Quarters ahead	*WRATIO1*	*GAP*	*RPIXAG*	*NOMIR*		
Basic model 1988 Q1 to 2004 Q2	5	87.6	5.9	1.6	4.9		
	10	69.1	6.7	12.1	12.1		
	20	52.5	19.3	13.6	14.6		
Basic model 1993 Q1 to 2004 Q2	5	67.8	27.7	2.4	2.1		
	10	54.0	34.6	6.6	4.8		
	20	50.3	35.0	7.4	7.4		
Sectoral VARs							
Corporate model 1993 Q1 to 2004 Q2		*CORPWOR*	*GAP*	*RPIXAG*	*NOMIR*	*KGEAR*	*IGEAR*
Capital gearing	5	63.4	22.6	2.5	10.1	1.5	
	10	51.3	21.6	2.7	20.63	3.8	
	20	48.7	20.6	2.7	24.2	3.9	
Income gearing	5	62.1	27.7	3.8	4.5		1.9
	10	51.9	30.1	6.1	7.7		4.3
	20	48.8	29.7	6.6	10.4		4.6
		MORTGAGE	*GAP*	*IGEARHH*	*RPIXAG*	*HPAG*	*NOMIR*
Household secured lending model 1988 Q1 to 2004 Q2	5	36.0	11.4	38.3	2.5	1.4	10.5
	10	14.3	8.3	51.5	15.9	4.0	5.6
	20	18.0	17.9	29.0	21.0	11.0	3.1

(a) The abbreviations in the first row of each model are described in Table A1 in the appendix.

7.2 Historical decomposition

The VAR, equation **(1)**, can be inverted to obtain the moving average representation:

$$Z_{t+j} = \sum_{s=0}^{j-1} \Psi_s \varepsilon_{t+j-s} + \left(\sum_{s=j}^{\infty} \Psi_s \varepsilon_{t+j-s} + \Gamma^* \right) \quad \textbf{(3)}$$

Each variable can be decomposed into two parts. The component in brackets is known at time *t* (the part of the write-off ratio that can be forecast based on past information) and the first term is the part that is due to new shocks. Such decomposition allows a more thorough analysis of the contribution to the write-off ratio from new shocks to the macroeconomic variables, and how the contributions change over time. The decomposition is performed for the total and corporate write-off ratios only. In Charts 18 and 19 in the appendix the historical decomposition of the write-off ratio is plotted for the two models.

Some interesting features are revealed in these plots. A substantial part of the new shock in the total write-off ratio is due to unidentified shocks to the write-off ratio itself. However, it is interesting to note that during the 1990-93 period, and more recently in the 2001-03 period, new shocks to the output gap account for a relatively large part of the unexpected shock to the total write-off ratio. During the recession period, a larger proportion of the shock to the total write-off ratio was due to unfavourable shocks to output (relative to potential) and the same was the case in the period from 2001 to 2003 which was also a period when the output gap fell (see Chart 2 in the appendix) and the VAR produced negative residuals in the equation of the output gap. Similar results are obtained for the corporate write-off ratio. This, together with the fact that the forecast component captures the effect from lagged values of shocks to the macroeconomic variables (including to the output gap), emphasises the conclusion from the previous section that part of the changes in the aggregate and corporate write-off ratios is due to shocks to output and that the impact from these shocks on the write-off ratio occurs more quickly than is the case for the other macroeconomic shocks. However, in both historical decompositions, some of the effects from the various shocks cancel each other out. This suggests that one of the advantages of using the VAR approach is that – following an adverse shock to the output gap – the impact on total write-offs may be lessened if, in the same period, there are favourable shocks to one or more of the other key macroeconomic variables.

8 Conclusions

This paper proposes an additional tool for performing stress tests of the robustness of the UK banking system to adverse macroeconomic shocks. A VAR approach is used to estimate the impact of changes in macroeconomic variables on banks' aggregate losses since the late 1980s and sectoral losses since the early 1990s. Unlike most of the existing work, this paper uses a direct measure of bank fragility – the write-off to loan ratio.

For the aggregate write-off model, a clear and significant negative relationship is found between changes in output (relative to potential) and the write-off ratio – although not *vice versa*. Shocks to output are found to have a significant impact on the write-off ratio up to six quarters ahead, with the maximum impact occurring after one year. The bank write-off ratio is also found to increase following shocks to nominal variables such as annual rate of retail price inflation and nominal interest rates although here the impact is only significant at a longer time horizon (after four-six quarters).

The results suggest that following a shock to the output gap of the same magnitude experienced in the early 1990s, the aggregate write-off ratio of UK banks would increase by around 0.7 percentage points. This, of course, is non-trivial but would still only equate to one third of the major UK banks' average pre-tax average annual profits over the past three years. Therefore, according to these results, the UK banking system as a whole would appear to be robust to large adverse macroeconomic shocks.

Over the common shorter (post-1993) sample period, the corporate sector write-off ratio is found to be twice as sensitive to output shocks as the aggregate write-off ratio. Household write-offs, on the other hand, seem to be more sensitive to changes in income gearing than changes in economic activity *per se*, even though the economic impact is quite small. This result is confirmed when separate VARs are estimated using arrears on credit cards and on mortgages. While the impact of income gearing on mortgage arrears is statistically and economically significant, credit card arrears do not respond to income gearing shocks. This result may be attributable to a more than offsetting structural change in the household unsecured borrowing market over the more recent period.

It is also noticeable that the sensitivity of aggregate write-offs to adverse output shocks is twice as large when the model is estimated in the post-1993 period than in the full sample from 1988-2004.

This could imply that it is misleading to use estimates from the more recent sample period to assess the impact on banks' balance sheets of a repeat of the early 1990s' recession. The result is interesting though since one might have expected, *a priori*, that the impact of a given-sized output shock on write-offs to be larger during recessions if there is a non-linear impact during times of stress.

This issue of differences between stress and tranquil periods is worth investigating in future work as well as incorporating, if possible, structural changes in the banking industry (such as improvements in risk management). Nonetheless, we believe, that this VAR approach is a useful addition to the suite of models used to assess the fragility of the banking system to adverse macroeconomic shocks.

Appendix

The macroeconomic model

The model on which the VAR specification is based can be described by the following equations:

$$\bar{y}_t = \alpha \bar{y}_{t-1} + \beta(i_{t-1} - E_{t-1}\pi_t) + \gamma x_{t-1} + \varepsilon_{IS,t} \quad \textbf{(1-A)}$$

where $\bar{y}$ is the output gap, i is the nominal interest rate, $E_{t-1}\pi_t$ is the expectation at time $t-1$ of inflation at time *t* (and therefore $i_{t-1} - E_{t-1}\pi_t$ is the real interest rate), x_{t-1} is the log of the real exchange rate, and $\varepsilon_{IS,t}$ is a white noise shock.

$$\pi_t = \pi_{t-1} + \delta \bar{y}_{t-1} + \phi \Delta x_t + \varepsilon_{\pi,t} \quad \textbf{(2-A)}$$

where Δx_t is the first difference of the logarithm of the real exchange rate, and $\varepsilon_{\pi,t}$ is a white noise shock.

$$\Delta x_{t+1} = i_t - E_t \pi_{t+1} + \varepsilon_{UIP,t} \quad \textbf{(3-A)}$$

where $\varepsilon_{UIP,t} = \Phi_t - i_t^* + E_t^* \pi_{t+1} + u_{RAUIP,t}$, which is assumed to be a white noise shock.(30) Since the UIP condition does not hold empirically, rather than attempting to resolve the UIP puzzle we model the mean equation of the growth in the exchange rate as follows:

$$\Delta x_t = \alpha_{X0} + \alpha_X{}' z_{t-1} + \varepsilon_{U,t} \quad \textbf{(3'-A)}$$

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(30) Φ_t can be interpreted as the risk premium in the FOREX market for the UK investor including a Jensen correction from using logarithmic changes in the exchange rate or it can be interpreted as the difference in the risk premium of the UK and foreign investor (see Smith and Wickens (2001)). The uncovered interest parity (UIP) assumes this term to equal zero. $i_{t-1}^* - E_{t-1}^* \pi_t$ is the foreign real interest rate. Since we use the effective real exchange rate this variable is difficult to compute. It has often been found that UIP does not hold and it has also been found very difficult, if not impossible, to measure the risk premium (see Smith and Wickens (2001)). It is often decided to treat $\varepsilon_{UIP,t}$ as a white noise residual.

where α_{X0} is a constant, α_X is a vector of parameters and z_{t-1} is the vector of the variables included in the VAR. Hence, one can interpret the lagged variables as capturing the risk premium potentially accounting for the failure of the UIP condition. Equation **(3'-A)** could be specified as a VAR of any order and is just written of order 1 for simplicity. One could also specify the equation as:

$$x_t = \alpha_{X0} + \alpha_{X1} x_{t-1} + \alpha_X{}' z_{t-1} + \varepsilon_{U,t} \qquad \textbf{(3''-A)}$$

so not forcing the coefficient on the lagged log real effective exchange rate to equal 1.
As in Batini and Haldane (1999), equation **(1-A)** corresponds to the IS curve, implying that the current output gap depends on its lagged level, the real interest rate and the real exchange rate. Equation **(2-A)** is an open economy aggregate supply curve. It corresponds to the Phillips curve in the Batini-Haldane model where the coefficient of next period expected value of inflation and exchange rate is set equal to zero. A fully backward-looking Phillips equation has been used, among others, by Ball (1998). While New Keynesian theory represents the Phillips curve as forward-looking, using a backward-looking aggregate supply equation can be justified for the United Kingdom, where inflation is highly autoregressive. The small-scale macroeconomic model must be completed by a policy rule. One possibility is a modified Taylor rule for open economies, given by:

$$i_t = \vartheta i_{t-1} + \xi(\pi_t - \overline{\pi}) + \mu \overline{y}_{t-1} + \upsilon x_t \qquad \textbf{(4-A)}$$

where $\overline{\pi}$ is the target inflation rate. It has been shown that the Taylor rule is not a perfect description of how monetary policy is conducted. However it is a widely used reduced-form representation of monetary policy.

Interpolations

Data on total write-offs for all UK banks are available on a quarterly frequency from 1993 only while annual data are available for a longer period for the eleven largest UK banks. Since 1993 is at the beginning of the recovery phase from the UK recession it seems desirable to attempt to exploit the information in the available annual data to interpolate the quarterly series back to 1988 so that a whole economic cycle is present in the sample. Interpolation is not a straightforward task and three simple interpolation schemes were considered.

The first scheme matches the observation in the last quarter of the total write-off ratio of all UK banks to equal the annual write-off ratio (of the largest eleven UK banks) divided by four. The series for the other three quarters are then connected using a standard cubic spline. The second scheme fits the lower frequency series using a quadratic polynomial to fit the higher frequency data subject to the constraint that the sum of the four quarterly observations (on the total write-off ratio of all UK banks) should equal the actual annual total write-off ratio of the eleven largest UK banks. These two interpolation schemes rely on the following assumptions. First, and probably the least strong assumption, the annual write-off ratio for the eleven largest UK banks is assumed equal to that of all UK banks from 1988-92. Interpolation scheme 1 further assumes that the total write-off ratio of all UK banks in the fourth quarter, in the period from 1988-92, is equal to the annual write-off ratio of the eleven largest UK banks divided by four. Interpolation scheme 2, on the other hand, assumes that the sum of the quarterly write-off ratios of all UK banks is equal to the annual write-off ratio of the eleven largest UK banks.

The final interpolation scheme attempts to exploit the actual information in the available quarterly data (ie after 1993) to construct the series from 1988-92. First, using the available quarterly data from 1993 to 2004, it is of interest to compute the quarterly average deviation of the actual quarterly total write-off ratio of all UK banks from the quarterly average of the annual write-off ratio of the eleven largest UK banks (in a given year). It has been argued that 1995 Q4 is an extreme outlier and it is thus desirable to account for that when computing the average deviations. This is done by estimating a simple regression of the form:

$$\left(\omega_{ij,t+1} - \frac{v_{j,t+1}}{4}\right) = \sum_{i=1}^{4} \alpha_i I_{i,t+1} + \beta I_{1995:Q4,t+1} + u_{t+1}$$

where I_i is an indicator function taking the value of one in quarter i and zero otherwise. $I_{1995:Q4}$ is an indicator function taking the value of one in the fourth quarter of 1995 and zero otherwise. u_{t+1} is the residual in the regression. ω_{ij} is the quarterly write-off ratio of all UK banks in quarter i, year j, and ν_j is the annual write-off ratio of the eleven largest banks in year j. Hence α_i measures the average deviation of the actual quarterly write-off ratio for all UK banks from the quarterly average (in the year) of the annual write-off ratio of the eleven largest UK banks for the period of common data availability (1993-2004) in quarter i. The estimated α_i can then be used to adjust the annual write-off ratios for the eleven largest UK banks over the 1988-92 period. In this way information from the actual series for the write-off ratio for the eleven largest UK banks after 1993 is used to construct a proxy for the actual quarterly data from 1988-92.

Although interpolations will always be subject to criticism, the three interpolation schemes suggested allow us to evaluate the extent to which the results of the paper differ subject to the interpolation scheme used. We refer to the total write-off ratio series of all UK banks using interpolation scheme 1 (before 1993) as *WRATIO1*. The series using interpolation scheme 2 will be referred to as *WRATIO2* and the series using interpolation scheme 3 will be referred to as *WRATIO3*. The three series are plotted in Chart 1 together with the series *WRATIO4*. This latter series assume that the quarterly total write-off ratio of all UK banks is equal to the annual total write-off ratio of the eleven largest UK banks divided by four. This latter series is included only for illustrative purposes and no econometric analysis has been performed using it.

Table A1: Variable definitions

Abbreviation	Description
CORPWOR	Quarterly UK-owned banks' write-off/loan ratio for non-public, non-financial corporations (PNFCs).
WRATIO	Quarterly UK-owned banks' write-off/loan ratio. The loan and write-offs data before 1993 Q1 are compiled from the major banks' published accounts.
WRATIO1	Quarterly WRATIO with interpolation scheme 1 before 1993.
WRATIO2	Quarterly WRATIO with interpolation scheme 2 before 1993.
WRATIO3	Quarterly WRATIO with interpolation scheme 3 before 1993.
WRATIO4	Quarterly WRATIO with interpolation scheme 4 before 1993.
NOMIR	London clearing banks' base rate, short-term interest rate.
GAPHP	Percentage deviation of GDP from trend using HP filter.
GAP88	Percentage deviation of GDP from trend using linear trend.
GAP	Output gap derived from Cobb-Douglas production function.
GAPOECD	OECD measure of output gap.
UNEMPLOYMENT	UK unemployment rate.
RRIXAG	Real exchange rate (using GDP deflator measure). RRX= EER/(WPX/PGDP), where EER is the sterling effective exchange rate index, WPX is M6 export prices (exogenous), and PGDP is GDP deflator at factor cost. Annual growth relative to same quarter, previous year.
RRIXQG	Real exchange rate (GDP deflator measure). RRX= EER/ (WPX/PGDP), where WPX is M6 export prices (exogenous), and PGDP is GDP deflator at factor cost. Growth relative to previous quarter.
LRRIX	Logarithm of the real exchange rate index.
RPIXAG	Annual inflation rate constructed from RPIX - Retail Price Index (January 1987=1) excluding mortgage interest payments. Annual growth relative to same quarter in the previous year.
RPIXQG	Quarterly inflation rate constructed from RPIX - Retail Price Index (January 1987=1) excluding mortgage interest payments. Growth relative to previous quarter.
HPAG	House price inflation rate - UK house prices (Average of Nationwide and Halifax house price indices). Annual growth relative to same quarter in the previous year.
HPQG	House price inflation rate - UK house prices (Average of Nationwide and Halifax house price indices). Growth relative to previous quarter.
KGEAR	PNFCs' debt to market value of equity ratio.
IGEAR	PNFCs' interest payments to pre-tax profits ratio.
IGEARHH	Total household interest payments to household disposable income ratio.
MORTGAGE	Quarterly mortgage arrears of over six months as a percentage of all mortgages.
CCARREARS	Quarterly credit card arrears by more than three months as a per cent of the value of all credit card balances.

Table A2: Phillips Perron test on variables included in aggregate VAR (1988 Q1 – 2004 Q2)

	Abbreviation	None	Intercept	Trend and intercept
Write-off ratio using interpolation 1	WRATIO1	-0.49 [0.4987]	-1.66 [0.4419]	-2.49 [0.3303]
Write-off ratio using interpolation 2	WRATIO2	-0.46 [0.5111]	-1.69 [0.4291]	-2.55 [0.3058]
Write-off ratio using interpolation 3	WRATIO3	-0.55 [0.4732]	-1.03 [0.7387]	-2.47 [0.3428]
Write-off ratio using interpolation 4	WRATIO4	-0.64 [0.4380]	-1.60 [0.4809]	-2.53 [0.3144]
Output GAP using HP filter	GAPHP	-2.76 [0.0065]	-2.74 [0.0722]	-2.73 [0.2273]
Output GAP using trend	GAP88	-1.78 [0.0715]	-1.77 [0.3921]	-1.69 [0.7441]
Output GAP using Cobb Douglas	GAP	-2.00 [0.0442]	-1.99 [0.2919]	-1.94 [0.6241]
Annual RPI Inflation	RPIXA	-0.87 [0.3370]	-1.25 [0.6496]	-2.02 [0.5808]
Quarterly RPI inflation	RPIXQ	-2.13 [0.0330]	-3.79 [0.0048]	-5.49 [0.0001]
Short-term interest rate	NOMIR	-0.93 [0.3117]	-1.04 [0.7341]	-2.46 [0.3476]
Annual change in the log real effective exchange rate	RRIXAG	-2.85 [0.0051]	-3.06 [0.0350]	-2.99 [0.1418]
Quarterly change in the log real effective exchange rate	RRIXQG	-5.90 [0.0000]	-6.12 [0.0000]	-6.07 [0.0000]
Log real effective exchange rate	LRRIX	-1.75 [0.0768]	-0.73 [0.8305]	-1.98 [0.5960]
Annual house price inflation	HPAG	-2.33 [0.0201]	-2.32 [0.1688]	-5.61 [0.0001]
Quarterly house price inflation	HPQG	-1.73 [0.0779]	-1.72 [0.4171]	-5.15 [0.0005]
Mortgage arrears	MORTGAGE	-3.46 [0.0527]	-1.04 [0.7350]	-0.73 [0.3952]
Corporate capital gearing	KGEAR	0.43 [0.8025]	-1.73 [0.4133]	-1.89 [0.6465]
Household income gearing	IGEARHH	-0.52 [0.4895]	-1.32 [0.6150]	-2.23 [0.4685]

Note: p-values in []. Null hypothesis is the presence of a unit root.

Table A3: KPSS test on variables included in aggregate VAR (1988 Q1 – 2004 Q2)

	Abbreviation	Intercept	Trend and intercept
Write-off ratio using interpolation 1	WRATIO1	0.39 *	0.17 **
Write-off ratio using interpolation 2	WRATIO2	0.46 **	0.17 **
Write-off ratio using interpolation 3	WRATIO3	0.54 **	0.14 *
Write-off ratio using interpolation 4	WRATIO4	0.54 **	0.16 **
Output GAP using HP filter	GAPHP	0.06	0.06
Output GAP using trend	GAP88	0.19	0.19 **
Output GAP using Cobb Douglas	GAP	0.15	0.15
Annual RPI Inflation	RPIXA	0.65 **	0.16 **
Quarterly RPI inflation	RPIXQ	0.63 **	0.19 **
Short-term interest rate	NOMIR	0.75 ***	0.11 **
Annual change in the log real effective exchange rate	RRIXAG	0.65 **	0.16 **
Quarterly change in the log real effective exchange rate	RRIXQG	0.63 **	0.19 **
Log real effective exchange rate	LRRIX	0.92 ***	0.12 **
Annual house price inflation	HPAG	0.44 *	0.16 **
Quarterly house price inflation	HPQG	0.49 *	0.15 **
Mortgage arrears	MORTGAGE	0.43 *	0.18 **
Corporate capital gearing	KGEAR	0.34	0.17 **
Household income gearing	IGEARHH	0.63 **	0.13 *

Note: Null hypothesis is the absence of a unit root. * indicates rejection using 0.90 critical value, ** using 0.95 critical value and *** using 0.99 critical value.

Table A4: AIC criteria for selection of VAR order, annual growth rates

Lag length	Aggregate model 1993-2004	Aggregate model 1988-2004	Corporate model capital gearing	Mortgage arrears model
1	-0.68	**0.52**	-4.87	5.07
2	**-0.84**	0.79	**-5.10**	4.64
3	-0.19	0.86	-4.61	4.32
4	0.47	1.43	-3.70	**4.11**

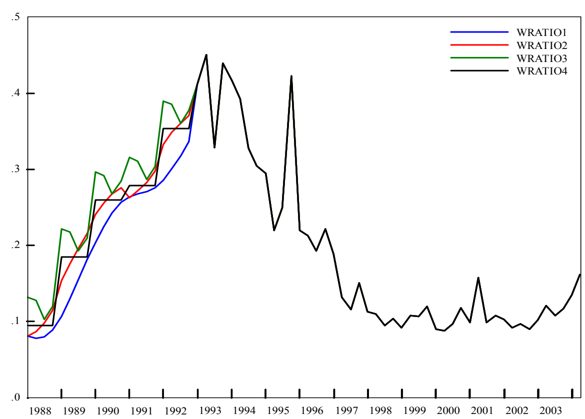
Note: Models using annual growth rates of RPIX and house prices.

Table A5: AIC criteria for selection of VAR order, quarterly growth rates

Lag length	Aggregate model 1993-2004	Aggregate model 1988-2004	Corporate model capital gearing	Mortgage arrears model
1	1.60	**2.77**	**-4.57**	8.96
2	**1.47**	3.01	-4.50	8.97
3	1.92	3.06	-3.86	**8.82**
4	2.37	3.57	-2.87	8.85

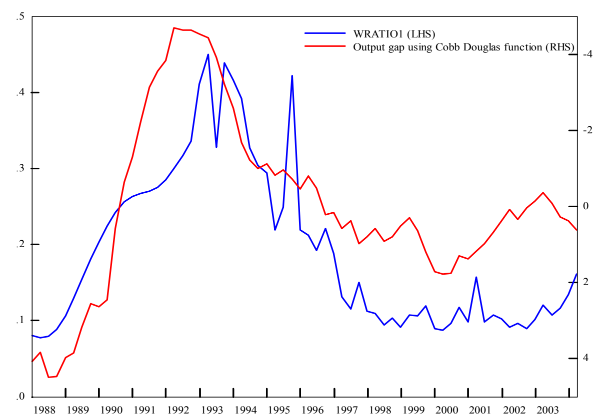
Note: Models using quarterly growth rates of RPIX and house prices.

Chart 1: Total write-off/loan ratio



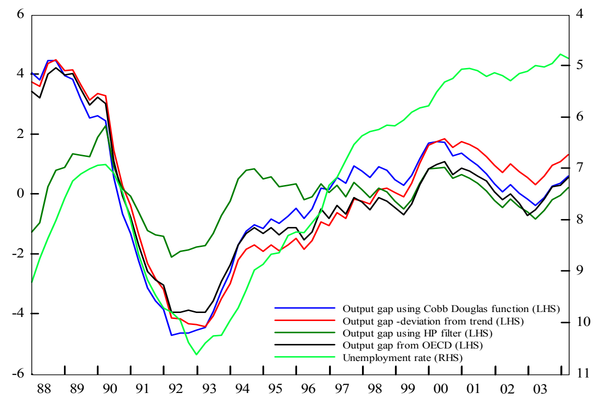
Note: In per cent.

Chart 2: Total write-off/loan ratio and the inverted output gap



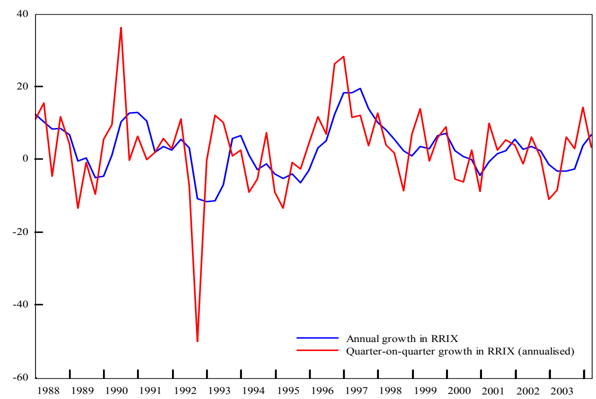
Note: In per cent.

Chart 3: Alternative measures of the output gap and the inverted unemployment rate



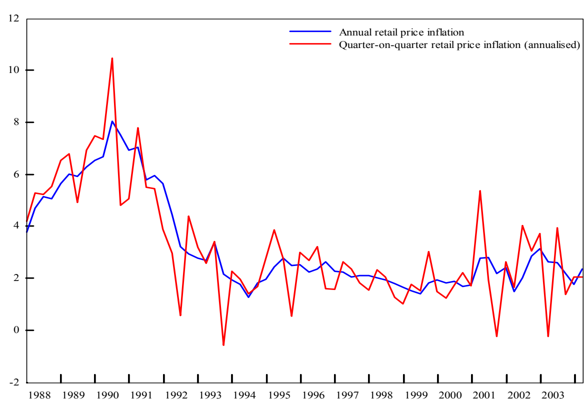
Note: In per cent.

Chart 4: Annual (RRIXAG) and quarter-on-quarter (RRIXQG) growth of real effective exchange rate



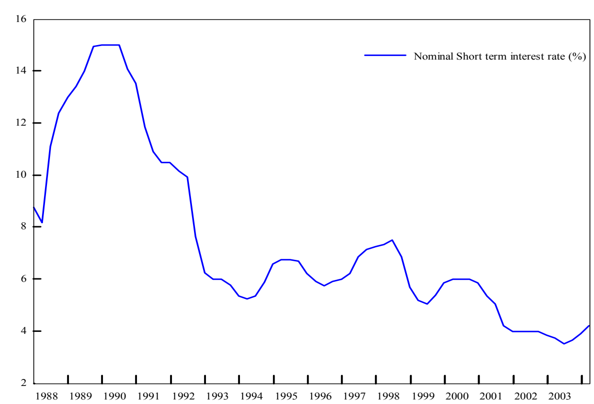
Note: In per cent.

Chart 5: Annual (RPIXAG) and quarter-on-quarter (RPIXQG) growth of the retail price index



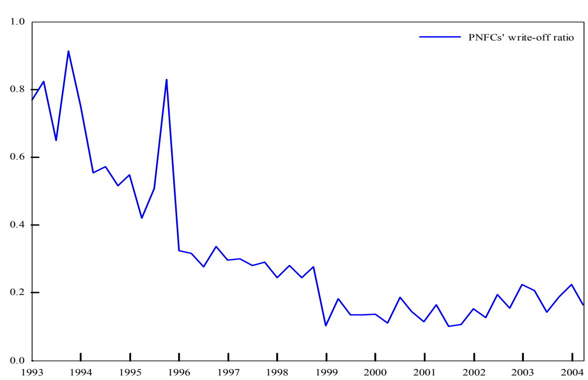
Note: In per cent.

Chart 6: Short-term nominal interest rate (NOMIR)



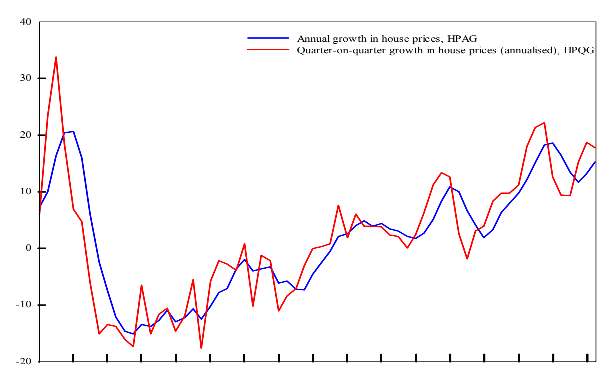
Note: In per cent.

Chart 7: Write-off/loans (CORPWOR) for private non-financial corporations (PNFCs)



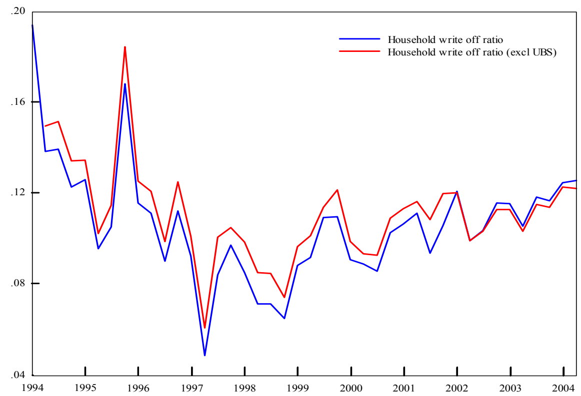
Note: In per cent.

Chart 8: Annual (HPAG) and quarter-on-quarter (HPQG) changes in house prices



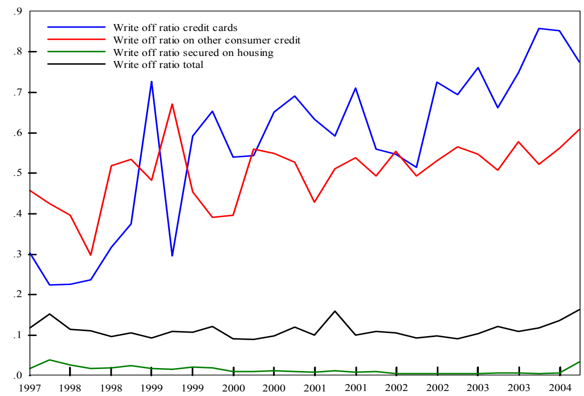
Note: In per cent.

Chart 9: Household write-off ratio including and excluding unincorporated businesses (UBS)



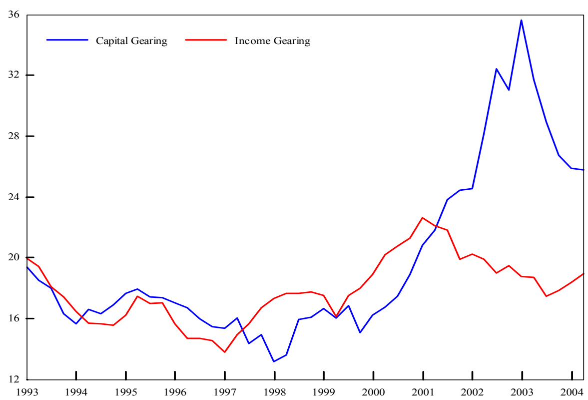
Note: In per cent.

Chart 10: Household write-off ratios



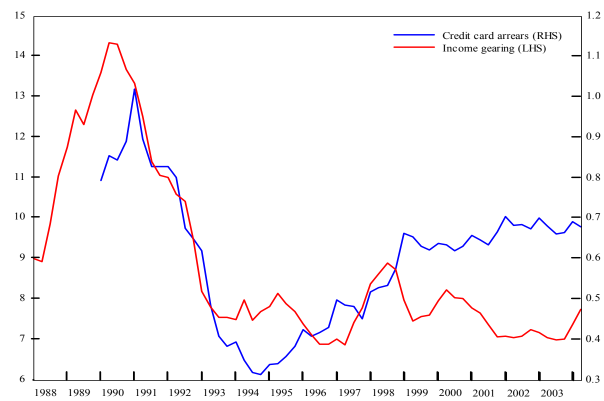
Note: In per cent.

Chart 11: Corporate sector income (IGEARCORP) and capital gearing (KGEAR)



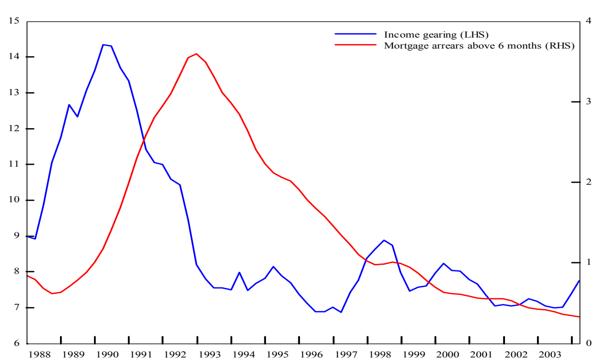
Note: In per cent.

Chart 12: Credit card arrears (CCARREARS) and household income gearing (IGEARHH)



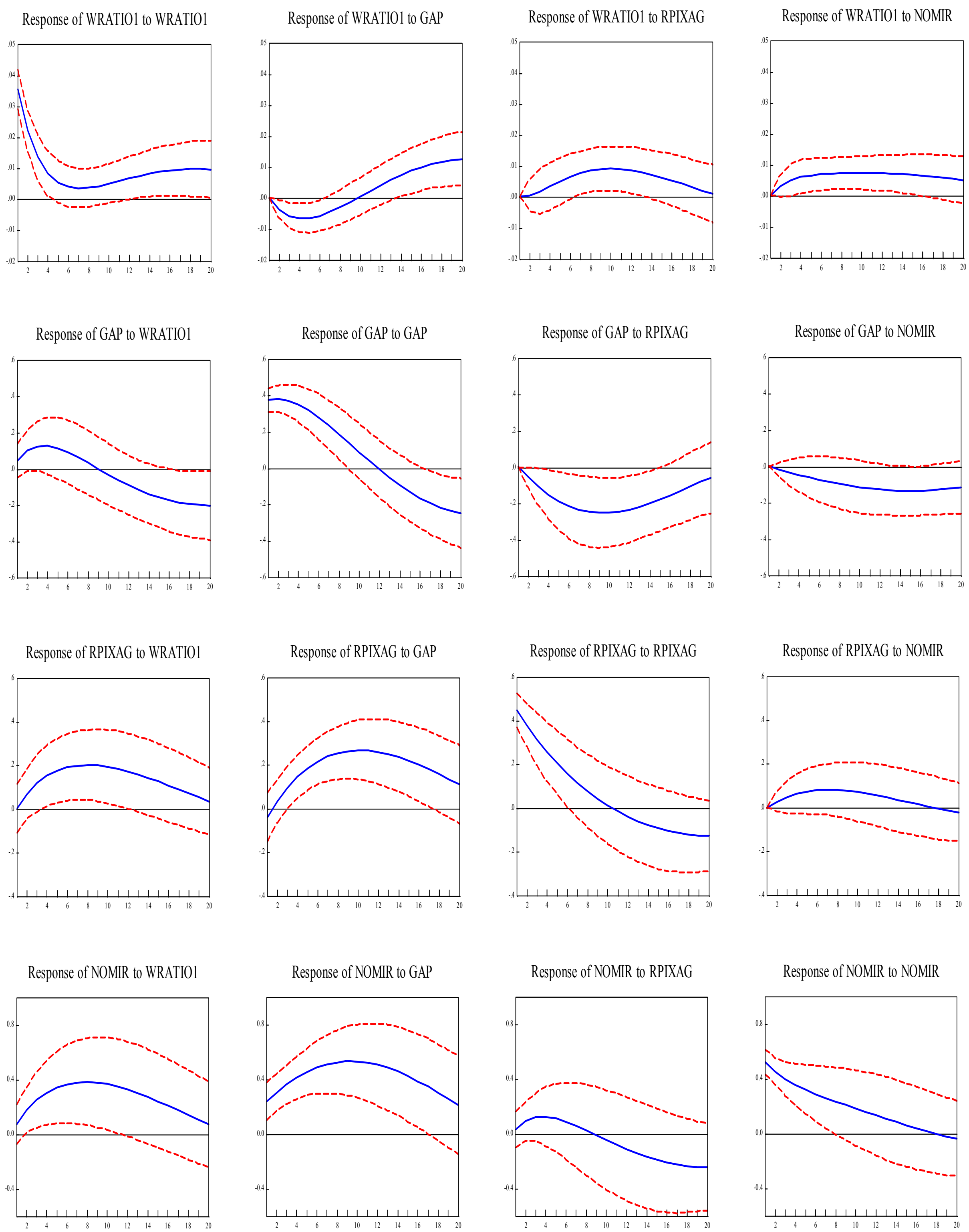
Note: In per cent.

Chart 13: Number of mortgage arrears (MORTGAGE) and household income gearing (IGEARHH)



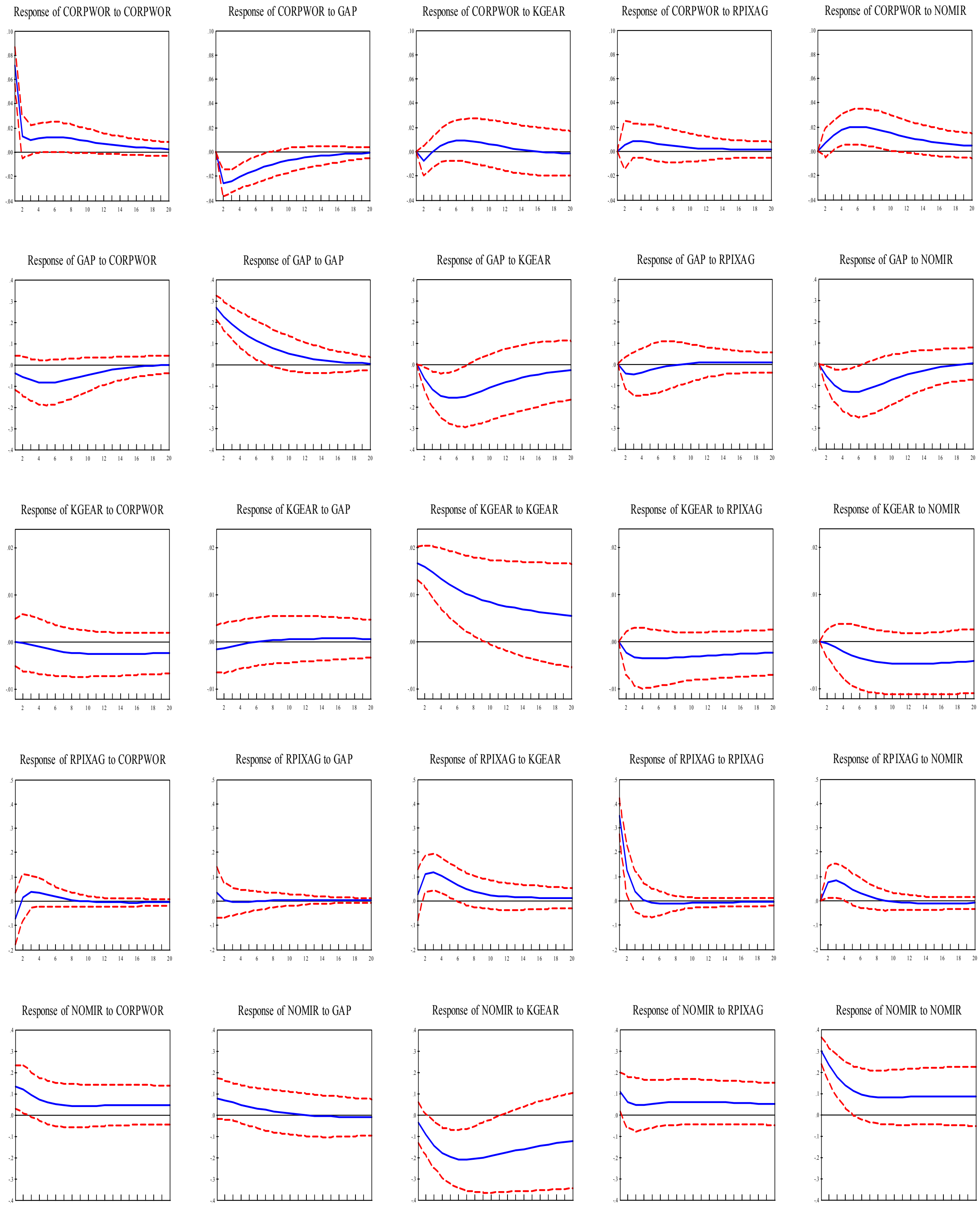
Note: In per cent.

Chart 14: Impulse response functions for basic model, 1988 Q1-2004 Q2



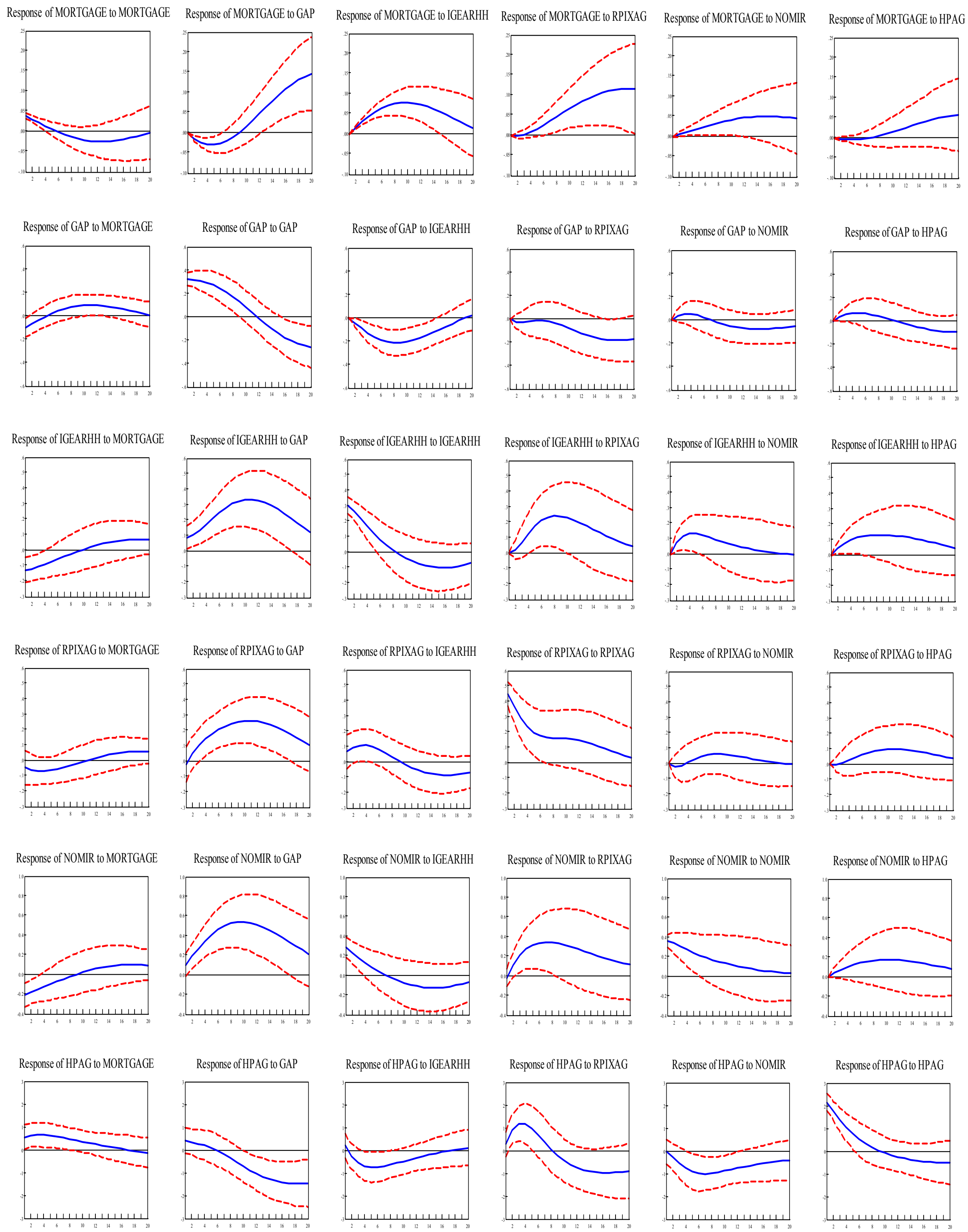
Note: Cholesky decomposition is used. 95% confidence bounds are given by the dashed lines. The x-axis measures quarters following the shock.

Chart 15: Impulse response functions for corporate model including capital gearing, 1993 Q1-2004 Q2



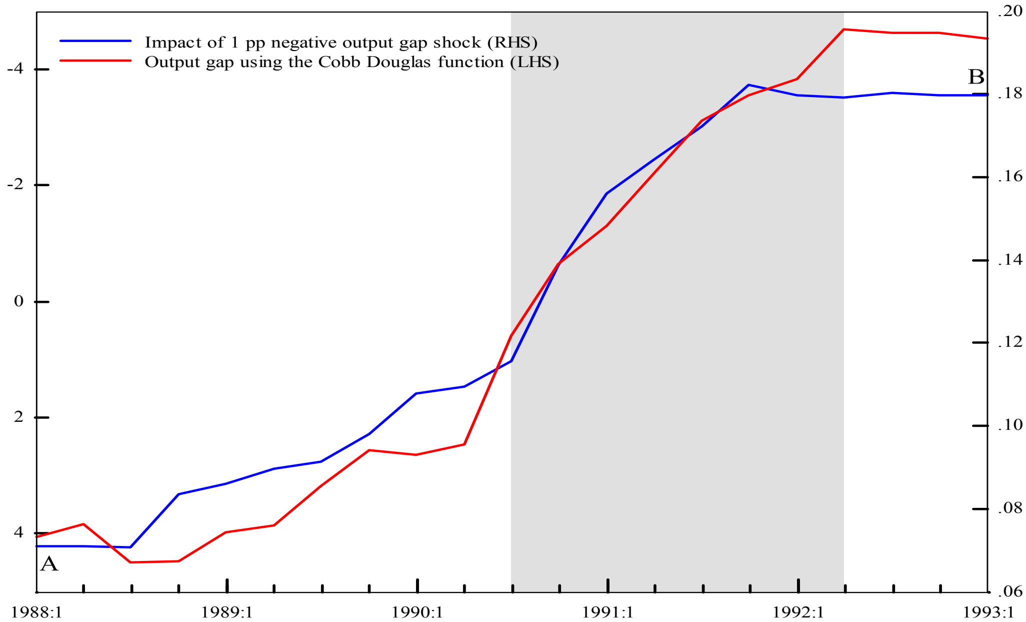
Note: Cholesky decomposition is used. 95% confidence bounds are given by the dashed lines. The x-axis measures quarters following the shock.

Chart 16: Impulse response functions for the secured lending model, 1988 Q1-2004 Q2



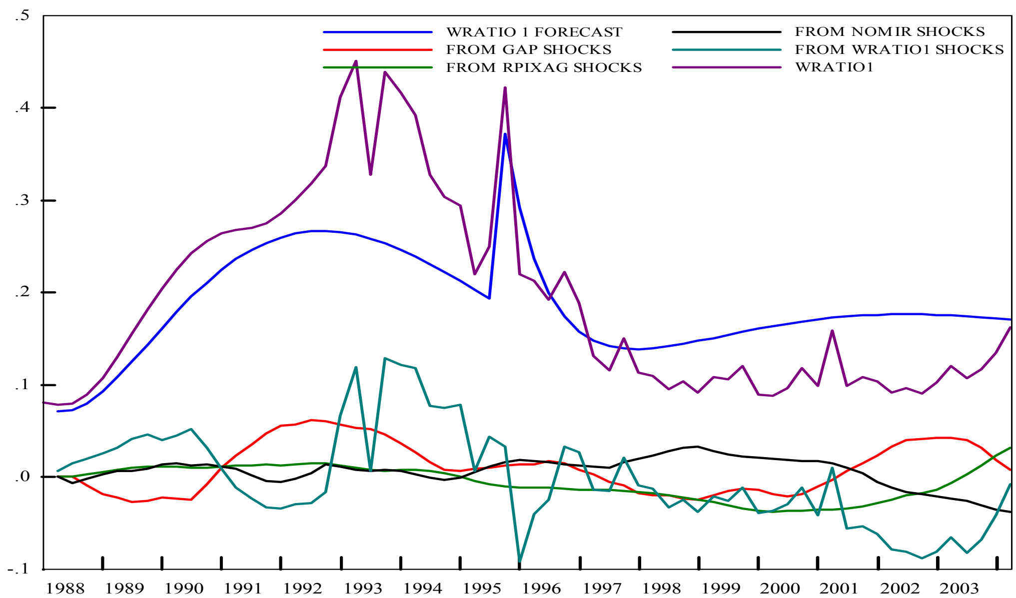
Note: Cholesky decomposition is used. 95% confidence bounds are given by the dashed lines. The x-axis measures quarters following the shock.

Chart 17: The sensitivity of the aggregate write-off ratio to a 1 percentage point negative output gap shock (for different estimates starting dates to end date 2004 Q2) and the (inverted) output gap



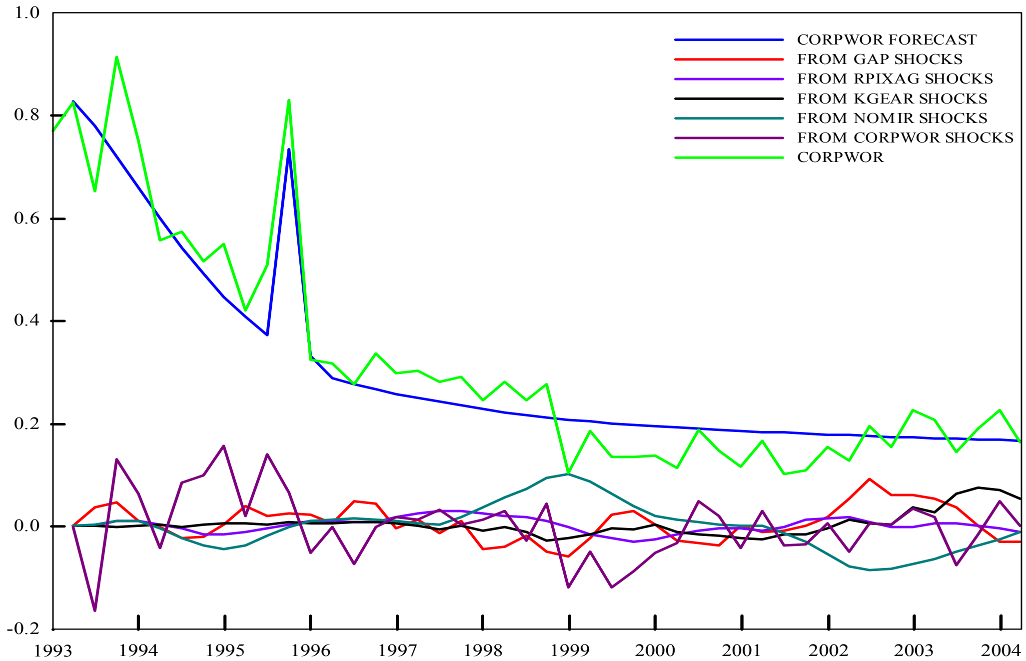
Note: The shaded area indicates the recession period from GDP peak to trough.
A: Estimated coefficient from 1988 Q1-2004 Q2, B: Estimated coefficient from 1993 Q1-2004 Q2.

Chart 18: The historical decomposition of the total write-off rate, 1988 Q1-2004 Q2



Note: WRATIO1 is the actual total write-off ratio, WRATIO1 FORECAST is the component of the write-off ratio in equation **(3)**, in the main text, which can be forecast, FROM VARIABLE SHOCKS is the contribution to the shock to the total write-off ratio from shocks to VARIABLE – ie the component of WRATIO1 that cannot be forecast.

Chart 19: The historical decomposition of the corporate write-off rate, 1993 Q1-2004 Q2



Note: CORPWOR is the actual total write-off ratio, CORPWOR FORECAST is the component of the write-off ratio in equation **(3)**, in the main text that can be forecast, FROM VARIABLE SHOCKS is the contribution to the shock to the total write-off ratio from shocks to VARIABLE – ie the component of CORPWOR that cannot be forecast.

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