

N^o 2008/2

Oslo
3 June 2008

Staff Memo

Norges Bank Financial Stability

A suite-of-models approach to stress-testing financial stability

by

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Postboks 1179 Sentrum

0107 Oslo

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ISSN 1504-2596 (online only)

ISBN 978-82-7553-442-0 (online only)

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Abstract

This paper presents a suite of models developed to stress-test financial stability. A macro model is linked to micro data-based models for households, firms and banks. The macro model includes credit- and consumer confidence-driven house prices and feed-back effects from credit and house prices to the real economy, i.e. a financial accelerator. The consumer confidence effect helps us mimic non-linearity in the housing market. We use the macro model to design stress scenarios, which are fed into the three micro models. The household and firm models enable us to analyse pockets of credit risk. The bank model sums it all up by providing estimates of bank profitability and capital adequacy.

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This paper builds on previous work at Norges Bank by Sigbjørn Atle Berg, Katrine G. Boye, Dag Henning Jacobsen, Thea B. Kloster and ourselves. We would like to thank participants at the Sveriges Riksbank workshop on stress-testing June 2007, the Bank of England CCBS Research Forum: Modelling the financial sector June 2007, the 2nd Expert Forum on Advanced Techniques on Stress Testing in Amsterdam October 2007, Martin Andersson, Alex Bowen, Martin Čihák, Mathias Drehmann, Charles Goodhart, Nigel Jenkinson and Dimitrios Tsomocos for valuable discussions and comments. We also gratefully acknowledge contributions and comments by Sigbjørn Atle Berg, Gunnar Bårdsen and Roger Hammersland. The views expressed in this paper are those of the authors and do not necessarily reflect those of Norges Bank.

1 Introduction

In parallel with the strong growth in financial markets and more frequent instances of widespread financial distress during the last decades, financial stability has become an increasingly important objective in economic policymaking. In addition to a role in crisis resolution, many central banks have a clear mandate to promote financial stability.¹ The financial stability role involves analysis of potential threats to financial stability, assessment of the present situation and the outlook ahead, policy actions based on the risk assessment and external communication.

Financial stability is a complex concept and will in general depend on a wide range of risks and risk drivers. At present, neither academia nor central banks have reached a consensus definition of financial stability, a unified understanding of how to best model and analyse it, or concluded on how to promote financial stability most efficiently.² Probably spurred by the IMF's and the World Bank's Financial System Assessment Programme (FSAP), see IMF and World Bank (2003) and Hagen, Lund, Nordal and Steffensen (2005), many central banks have developed or are developing models for macro stress-testing. The purpose is to analyse the robustness of the financial system if severe negative events should occur. The methodology applied by central banks in this work differs, however.³

Norges Bank, as an inflation-targeting non-supervisory central bank, has adopted a macro-prudential approach to financial stability with strong focus on risks that originate and develop outside the financial system, i.e. external risks.⁴ Previous crises in financial systems have often demonstrated a close linkage between financial stability and the health of the real economy, see, e.g., Crockett (1997).

¹ See, e.g., Roger W. Ferguson Jr., Vice Chairman, Board of Governors of the Federal Reserve System, "Should Financial Stability Be An Explicit Central Bank Objective?", speech given at Challenges to Central Banking from Globalized Financial Systems, Conference at the IMF in Washington, D.C., September 16-17, 2002.

² For a discussion of alternative definitions, see Bank for International Settlements (1998), Schinasi (2004), Allen and Wood (2006) and Aspachs, Goodhart, Tsomocos and Zicchino (2007).

³ For a review and discussion of alternative methodologies, see RTF Stress Testing Subgroup (2008), Sorge (2004), Sorge and Virolainen (2006) and ECB (2006). For the approaches chosen by different central banks, see, e.g., also Boss, Krenn, Pühr and Summers (2006) for Austria; Danmarks Nationalbank (2008, pp. 81-88) for Denmark; Bank of Finland (2007, pp. 33-34); Laviola, Marcucci and Quagliariello (2006) and Marcucci and Quagliariello (2005) for Italy; Bank of Japan (2008, pp. 60-70); De Nederlandsche Bank (2006, pp. 35-41), van den End, Hoerberichts and Tabbæ (2006) and Lelyveld and Liedorp (2006) for the Netherlands; Jiménez and Mencia (2007) for Spain; Sveriges Riksbank (2006, pp. 75-88) and Åsberg and Shahnazarian (2008) for Sweden; Lehman and Manz (2006) for Switzerland; Haldane, Hall and Pezzini (2007) and references therein for UK.

⁴ See keynote address by Governor Svein Gjedrem at the conference "Monetary Policy and Financial Stability", hosted by the Austrian National Bank in Vienna, May 2005, www.norges-bank.no/cgi-bin/pr.cgi.

Due to the complexity of financial stability and its dependence on a wide range of risks and risk drivers, one cannot expect one single model to include all important aspects or to be the preferred model in all analyses. Bårdsen, Lindquist and Tsomocos (2008) list ten desirable characteristics that the ideal financial stability model should possess. A financial stability model that encompasses all important issues would be very complicated, and Bårdsen et al. argue that a suite of models is probably needed. In addition, different datasets, such as aggregate macro data and micro data for different groups of agents, are likely to contain complementary information.

At Norges Bank, we have chosen to follow a suite-of-models approach, which enables us to take advantage of several data sets. The suite of models consists of a small macro model and micro data models for companies, households and banks. Much emphasis is put on linking the different models together as a system. This enables us to develop internally consistent scenarios on the different models. Alternatively, we may use the system to cross-check the output from the different models. All models are applied in the regular assessment and stress-testing of the financial system. Our priorities in the development of this system of models reflect, among other things, Norges Bank's definition of financial stability, as given in the bi-annual financial stability report, see Norges Bank (2007).

Financial stability means that the financial system is robust to disturbances to the economy and is able to channel funding, execute payments and redistribute risk in a satisfactory manner. Experience shows that the foundation for financial instability is laid during periods of strong growth in debt and asset prices. Banks play a central role in providing credit and executing payments and are therefore important to financial stability.

In accordance with this definition, we focus on banks and developments that can adversely affect banks, on credit growth and on asset prices. The emphasis is on external risks, as well as on feed-back effects from financial stability to the real economy.

Loans to domestic firms and households constitute about 70 per cent of the banks' total assets, while interbank and other fixed income instruments claims each constitute about 10 per cent of total assets. Only 1-2 per cent of assets are stocks. We therefore concentrate on credit risk, as driven by the development in debt holders' debt-servicing capability and collateral values.

Market risk, liquidity risk and operational risk can be evaluated in the bank model.⁵ Our system for stress-testing does not include the endogenous risk created by self-enforcing processes between credit, market and liquidity risk that, it is often argued, are present. These processes would have increased the correlation between risks in stress scenarios. Neither does our system include contagion risk, i.e. the risk that difficulties in one financial institution may spread to other institutions and cause system-wide problems. Analyses on Norwegian data show, however, that contagion risk due to banks' credit risk exposures in the interbank market or to common third parties, is in general relatively small. The recent liquidity crisis in the international and domestic markets represented a form of contagion that is hard to model within our framework. See, however, Dungey, Fry, González-Hermosillo, Martin and Tang (2008) for an analysis of contagion in six recent financial crises.

Section 2 describes the suite of models developed at Norges Bank for stress-testing financial stability.⁶ Section 3 presents stress-testing system simulations, and Section 4 summarises. In Appendix 1 and 2 respectively, we describe the small macro model and the bank model in more detail. Appendix 3 gives a detailed description of a bank model simulation.

2 A system for stress-testing

The models developed for stress-testing at Norges Bank, i.e. a small macro model and micro data-based models for the corporate, household and bank sector, can be simulated independently or as an integrated system. The structure of the system is recursive; with output from the macro model being used as input in the firm, household and bank models. We use the macro model to design alternative scenarios for the economy, primarily extreme stress scenarios, and follow the transmission of initial macro shocks through the set of models to get a more detailed picture of the consequences. Hence, we follow a top-down approach to study banks' credit risk. For a discussion of the pros and cons of this approach, see, e.g., Čihák (2007).⁷ The relationship between the models is illustrated in Figure 1 below.

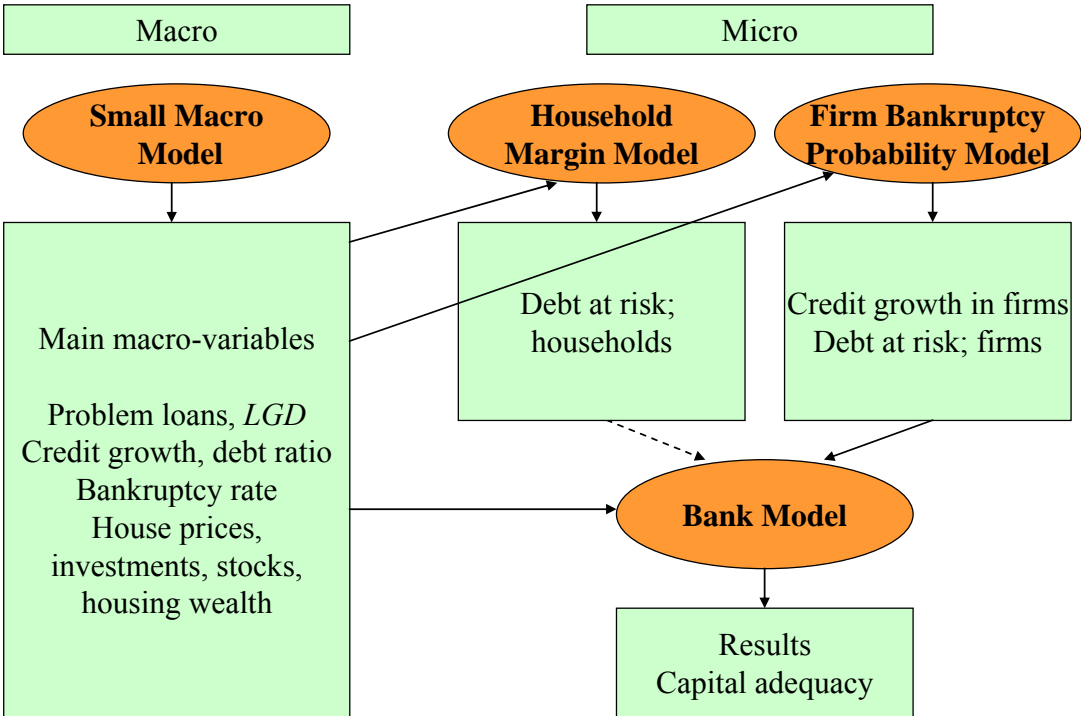
⁵ In addition to the bank model included in the stress-testing system, Norges Bank has developed a risk index for individual banks that predicts the probability of illiquidity or insolvency, see Andersen (2008).

⁶ To allow for interaction with monetary policy (see Haugland and Vikøren, 2006), a financial stability satellite has been developed and linked to a New-Keynesian DSGE model used for inflation forecasting and policy analysis. For a short presentation of the satellite with an application, see Berge et al. (2007).

⁷ Lessons learnt from simulating the micro data-based models may lead to a redesign of the stress scenario in the macro model.

The corporate and household sector models provide estimates of how individual agents or groups of agents are affected by alternative scenarios. These models are used to identify pockets of credit risks. Information on how debt, debt-servicing capability and debt at risk are distributed across firms and households can be important for the assessment of financial stability.⁸ This information can be aggregated to produce estimates of the corporate sector’s and household sector’s debt at risk. These risk measures represent an upper limit to expected losses, since they do not take into account that loss-given-default (LGD) will normally be less than 100 per cent of debt at risk.

Figure 1. A system for stress-testing



To calculate the impact of stress scenarios on the five largest banks’ results and capital adequacy, output from both the macro model and the firm model are fed into the bank model. While growth in banks’ losses on loans to firms is taken from the macro model, the distribution of losses across banks is done by matching information from the firm model and the bank model. We match information on how debt at risk is distributed across industries with information on banks’ loans to different industries. Output from the household sector

⁸ Debt at risk is defined as bank debt multiplied by the bankruptcy probability in the corporate model and as the debt held by households with a negative margin in the household model. Household’s margin is defined as income after tax minus standard living costs and interest payments.

model is used as additional information in an ad hoc way when we assess the strength of the banks, see ECB (2006, p. 149). This is illustrated by the dotted line in Figure 1. We will now present the different models in more detail.

2.1 The small macro model: SMM

Rather than developing a new macro model for the Norwegian economy, it was decided to build on an existing model. At Norges Bank Monetary Policy, a New-Keynesian DSGE type of model has been developed to support monetary policy decisions, see Brubakk, Husebø, Maih, Olsen and Østnor (2006). This model has forward-looking rational expectations. To extend this model with variables of interest to us and feed-back effects from financial variables to the real economy is complicated. We therefore decided to work with a model that is simpler in this respect. The chosen model is an estimated equilibrium-correction model, for a presentation of this model, see Bårdsen and Nymo (2008) and Chapter 9 in Bårdsen, Eitrheim, Jansen and Nymo (2005). This model is a macro model with, in general, backward-looking rather than forward-looking rational expectations. This simplifies the model and makes it fairly easy to extend and design the model to better fit our purpose.

Our extended version of the Bårdsen et al. model, which is called the small macro model (SMM), includes households' expectations about their own financial situation and the Norwegian economy, i.e. a consumer confidence indicator. These expectations need not be model-consistent, however, and the household sector may be overly optimistic or pessimistic.⁹ At present, the extended model also includes estimated equations for household debt, house prices, housing investments, firms' bankruptcy rate, banks' problem loans to households and firms respectively and a GDP equation with feed-back effects from credit and house prices to real activity.¹⁰ The interest rate works through three transmission channels; the exchange rate channel, the demand channel and the housing-credit market channel.

⁹ The consumer confidence indicator is based on a quarterly survey by TNS Gallup. If more households are optimistic than pessimistic it takes on positive values, while the opposite is true if most households are pessimistic. It takes the value zero in the neutral case. In stress scenarios, the role of the consumer confidence indicator is to create a mismatch between house prices and the real economy, i.e. to create inconsistent price signals, bubbles and busts. This variable is exogenous in the macro model.

¹⁰ Most of these equations are described in detail in Norges Bank's Economic Bulletin (and in Norges Bank's reports on Financial Stability), see Jacobsen and Naug (2004), Jacobsen and Naug (2005), Jacobsen and Kloster (2005), Jacobsen, Solberg-Johansen and Haugland (2006) and Berge and Boye (2007).

Problem loans consist of non-performing loans, i.e. defaulted loans, and performing loans with a high probability of becoming non-performing in the near future according to banks' financial statements. We use a loss-given-default (LGD) approach to predict banks' book losses, i.e., losses are calculated as a share of predicted problem loans. In simulations, we generally assume the loss-to-problem-loan ratio to be time-varying and reflect the development in collateral values, i.e. house prices, among other things.¹¹ Hence, in SMM, credit risk depends on the macroeconomic variables that determine problem loans and house prices. Internationally, there are a growing number of papers linking credit risk to macroeconomic variables using econometric models, see, e.g., Pesola (2005) or Čihák (2007) for a brief review. Appendix 1 gives a short description of the main equations in the present version of SMM.

Some properties of SMM are of particular interest in financial stability analysis.¹² The house price equation includes credit volume as well as the consumer confidence indicator described above. Hence, both an increase in available credit that gives rise to lending booms and overly optimistic households will boost house prices. Higher house prices increase collateral values, which in turn fuels credit growth. Lending booms typically coincide with highly optimistic agents. In a simple way, SMM internalises the co-movement, and also the procyclicality, of credit, asset prices and agents optimism discussed in the literature, see Borio and Lowe (2002), Allen (2005) and Goodhart and Hofmann (2007, particularly Chapters 1 and 6).

In SMM, house prices and credit volumes affect domestic activity, which is represented by a reduced-form aggregate demand equation. The house price effect includes a wealth effect in households' consumption, since house prices affect household wealth, and a positive effect from house prices to housing investments. The latter is consistent with our housing investment equation. While corporate credit affects GDP in the short run, household credit has

¹¹ We plan to develop an alternative equation for banks' losses with households' and firms' debt at risk from the micro models and collateral values from the macro model as explanatory variables. The system will then give two alternative estimates on banks' losses. By comparing these two loss measures, we can evaluate how important is the information on heterogeneity and the distribution across industries of debt, income and other variables for financial stability analyses. At present, a cross check of the output from the macro and micro models is made on the basis of predictions on problem loans in the macro model and debt at risk in the micro models.

¹² SMM has proven useful also in other analyses than stress-testing. An early version of SMM has been used to analyse the consequences for inflation and financial stability of a house price shock and a credit shock, when the inflation-targeting central bank explicitly takes financial stability into account, see Akram, Bårdsen and Lindquist (2007).

long-run effects on GDP. The short-run effect is interpreted as reflecting frictions in the credit market, while the long-run effect points towards a form of rationing of the household sector.¹³

Through house prices and credit, SMM includes a financial accelerator with feed-back effects from financial markets to the real economy. A boom and subsequent bust in house prices, e.g. caused by changes in consumers' expectations as given by the consumer confidence indicator, will cause or amplify business cycles. Hence, in SMM, house prices have a role as both a source and transmitter of macroeconomic fluctuations. Furthermore, we can design scenarios in SMM with a credit-crunch where credit growth is severely cut back by a tightening of credit supply. For a discussion of the financial accelerator and the role of asset prices, see, e.g., Bjørnland and Jacobsen (2008), Bernanke, Gertler and Gilchrist (2000), Kiyotaki and Moore (1997) and Bernanke and Gertler (1989).

In stress-testing, low probability scenarios are designed, where the consequences of major adverse shocks to key financial stability variables are analysed. When stress-testing within our reduced-form and near-linear type of macro econometric model, we may suffer from the Lucas critique (Lucas, 1976). Agents' behaviour, and hence our reduced form equations, may be non-invariant to big stress events. A solution to this problem is not simple, however. First, even if we formulated a model with 'deep structural parameters', we would need to condition that on a specific representation of the utility function of agents. One can argue that in severe stress events, the utility function itself may shift, and the shift may depend on the specific stress scenario. Second, data from episodes with severe stress that could help us identify stress behaviour are rare, while the information needed to conduct different stress tests that are robust to the Lucas critique seems to be interminable. However, the estimation period of the core of SMM, i.e. the Bårdsen et al. model, includes the previous banking crisis in Norway. These equations pass standard stability tests, and we conclude that the core of SMM is invariant to this particular stress event. The added equations to this core model are in general estimated using a shorter sample, however. This is partly due to a lack of data and partly due to difficulties in finding overall stable equations.

¹³ For a review of the literature on credit market frictions on the firm side, see Hubbard (1998). For a discussion and analysis of household rationing, see Jappelli and Pagano (1989). Even if a high debt-to-income ratio in Norwegian households may suggest that rationing is not very important, the debt compared to their housing wealth, i.e. collateral value, gives some support to the opposite assumption.

Stress-testing is not forecasting, however. It is analysis of the robustness of the financial system to possible, but low-probability, events. The benefit from a stress test should not lie in the model being able to replicate the true consequence of the stress scenario, but rather in the model to help identify risks and how these risks may transmit through the economy and end up as negative events for banks.

Furthermore, SMM, as well as the other models in our stress-testing system, have proven to be helpful tools in our external communication. As a non-supervisory central bank, communication is an important instrument in promoting financial stability. For communication, we need a transparent model that is suitable for designing multivariate scenarios that illustrate major current or future risks to financial stability, see Drehmann (2008). In SMM, both the origin of risks, i.e. the triggers, and important (reduced-form) transmission channels, through which different shocks evolve, are represented. Furthermore, SMM includes variables measuring the fragility of both debt holders and collateral values, which are important for assessing the probability of a crisis and predicting the severity of a crisis if it occurs.

We continue to develop SMM to make it even more useful for designing and conducting stress tests. Much emphasis is put on improving the representation of feed-back effects from credit and housing markets to the real economy and endogenous risks drivers, i.e. second round effects.

2.2 The corporate sector model: SEBRA

SEBRA is a model designed to analyse the default and bankruptcy probabilities of all Norwegian limited liability companies. These probability estimates are used to assess the credit risk associated with bank loans to the corporate sector in more detail than in the macro model. Our data set consists of annual financial statements and bankruptcy information from 80 000-140 000 individual companies, starting in 1988. Bankruptcy probabilities are estimated as a generalised logistic function of accounting-data indicators representing earnings, liquidity, financial strength, industry, age and size of the company. Probabilities of default are estimated using the same variables in combination with a statistical model for

misclassification of the dependent variable.¹⁴ The accuracy rate of the model is relatively high; the error I and error II probabilities are balanced at about 20 per cent of all actual bankruptcies and non-bankruptcies. Furthermore, averaged bankruptcy probabilities are very close to predicting the actual frequency of bankruptcies in any year and in different risk categories. The model is described in more detail by Bernhardsen (2001), Bernhardsen and Larsen (2007) and Bernhardsen and Syversten (2008).

The individual default probabilities are multiplied with the debt held by each company to produce the total *bank-debt at risk* held by companies. In simulations, this risk-measure is combined with a model for loss-given-default on corporate loans at the macro level. The latter is designed to fit our loss-predictions with banks' losses on corporate loans.¹⁵

Output from the macro model is used to project the financial statement of each firm using, to a large degree, estimated equations. The probability of default of each firm is then computed for the baseline scenario and stress scenario using the SEBRA model. By aggregation, debt at risk is derived for each industry. The method for projecting financial statements is described in detail in Bernhardsen and Syversten (2008), which also documents the results of a back-testing exercise of the method. This exercise, which applies the actual development in the macro variables, shows that projections starting in each year between 1988 and 2003, and reaching five years ahead, perform fairly well at the aggregate level.

The predictions in SEBRA on firms' debt growth and debt at risk at the industry level are used as input in the bank model. Hence, in the bank model, output from SEBRA supplement the predictions on macro variables in the macro model. In SEBRA, firms' debt growth is predicted using an estimated equation with the debt growth of a macro firm as the endogenous variable and GDP, inflation and the interest rate on bank loans as explanatory variables. The macro firm is defined by the value-weighted growth rate in moving balanced samples, i.e. by firms that are present at t and $t-1$. (See Bernhardsen and Syversten, 2008.)

¹⁴ See Hausman, Abrevaya and Scott-Morton (1998) for a discussion of the misclassification approach to binary dependent models.

¹⁵ Loss given default (LGD) at the aggregate level is defined by the ratio of bank sector loan losses to potential losses. Although being a heuristic measure, it is model dependent so that an under prediction of potential losses will lead to an over prediction of LGD and vice versa. Thus misalignment of levels will cancel in projections of future loan losses as these are constructed by the product of projected LGD and potential loan losses.

2.3 The household model: Financial margins

The household sector model is designed to predict the probability of households defaulting on their bank loans. We do not observe default by individual households, however, and we instead proxy individual default probabilities by households' financial margins. Financial margin is defined as household income minus taxes, minus interest payments and repayment on debt and minus standard living costs. Repayment is calculated assuming a linear repayment profile over 20 years. The debt of households with a negative margin is termed *debt at risk*. For a discussion of households' margins, see Vatne (2006, 2007).

Our data set consists of annual household survey data from the Income and Property Statistics of Statistics Norway over 1986-2003. This survey includes 8 000-25 000 households per year. From 2004 on, we use tax return data from all Norwegian households. This gives us data for more than 2 millions households per year. Data on standard living costs are mainly from the National Institute for Consumer Research. These costs depend on key characteristics of the household. To these costs we add our own estimates of necessary housing maintenance costs and heating costs.

In forward projections of the household sectors' financial margins in different scenarios, the population is held fixed. Growth in income, debt and interest rates are taken from the macro model, and standard living costs are adjusted for consumer price inflation, which is also taken from the macro model. With respect to income, living expenses and interest rate, the same growth rate is applied for all households. Household debt growth is treated differently, however: If we assume that all households have the same debt growth, too many households with small margins at the outset may be pushed over the edge. Households with small margins are often recent home buyers that do not plan to increase their debt in near future. On the other hand, we do not want to restrict credit growth to households with a relatively large margin only. This problem of distributing debt growth on households is mitigated by dividing the households into 64 groups according to age, income and financial margin before and after new debt. The debt growth from the macro model is then distributed across these 64 groups according to the observed debt growth across the same groups from 2004 to 2005. This procedure gives us a projection of the financial margin of every individual household in the sample, and thus a distribution of households according to their financial position.

In addition, our data enables us to take into account that households' liquid financial wealth may serve as a buffer for households with a negative margin. Our data show, however, that households with a negative margin have relatively small financial buffers. Most of households' liquid financial wealth is held by households that do not experience a negative margin, not even in our stress scenarios. With respect to non-financial assets, i.e. real property, we only have tax-report valuations. These may deviate significantly from market values. At a later stage we expect to receive more reliable data on each household's real property wealth, starting with data from 2006.

2.4 The bank model: The five largest banks

The present bank model is a non-behaviour model. It includes disaggregated annual accounting information from the five largest Norwegian banks, i.e. DnB NOR Bank, SpareBank 1 SR-Bank, Sparebanken Vest, SpareBank 1 SMN and SpareBank 1 Nord-Norge. In 2007, these five banks had 45 per cent of total assets in the Norwegian banking industry. The market share of foreign branches and subsidiaries was 34 per cent.

Each bank is represented by a number of variables that are taken from their annual financial statement, end-year balance-sheet and capital adequacy reports (see Appendix 2 for a more detailed description of the bank model). The banks' accounts are projected forward by linking their main income and cost items to variables determined in the macro model. Banks' results affect their capital position, and the end-output of the bank model are banks' results and capital adequacy. See Appendix 3 for a more detailed description of the assumptions made in the bank model.

The present bank model does not enable us to evaluate how the macro scenarios affect individual bank behaviour. For this we would need a behavioural model of individual banks. For a more complete representation we would also need contagion between banks and feedback effects from bank behaviour to the real economy, see Goodhart, Sunirand and Tsomocos (2004, 2005, 2006a, 2006b).

3 Simulations on the stress-testing system

We will now demonstrate some of the properties of our stress-testing system. First we simulate the macro model assuming three different shocks, and then we put these three shocks together as a multivariate stress scenario. The output from this macro stress scenario is used as input in the firm, household and bank models. We start, however, by describing the background for this scenario.

For several years, the level of economic activity in Norway has been high, while core inflation and interest rates have been low. As a consequence, growth in credit and house prices has been high for a long period. At present, the unemployment rate is very low, around two per cent of the labour force, the debt-to-income ratio of households is very high, around 200 per cent of disposable income, and house prices are high according to most measures; see, e.g., Norges Bank (2007). Since summer 2005, the key policy interest rate has increased from 1¾ per cent to the present 5½ per cent. More recently, inflation in consumer prices has picked up, and growth in house prices and household debt has declined. According to Norges Bank's lending survey, there has been a tightening of banks' credit standards, see Norges Bank (2008a).

We design the stress scenario in the following way: Spurred by the increase in international prices on food and energy, domestic price and wage inflation increase. This sends price inflation above the policy target. In the model, this causes interest rates and unemployment to increase and growth in house prices to decline. Although the isolated macroeconomic implications of our price-wage shock are moderate, we assume that the rise in interest rates and the downward pressure in the housing market trigger a fall in consumer confidence. The fall in consumer confidence builds up to a severe confidence crisis as unemployment increases, and very much due to this, the economy enters a significant downturn. Finally, we assume that the turmoil in international credit markets and the fall in collateral values as house prices decline make banks adopt a much more restrictive lending policy. This generates a severe credit squeeze, as credit supply falls more than credit demand.

In the following we first present the wage and price shock, the shock to households' expectations and the fall in credit supply as three independent shocks. Then we present the multivariate stress scenario, which combines the three shocks. We simulate the model from

first quarter of 2007 to fourth quarter of 2011, denoted 2007Q1 – 2011Q4, and the shocks are introduced from 2008Q1 on. We compare the three shocks and the multivariate stress scenario with a common baseline scenario.

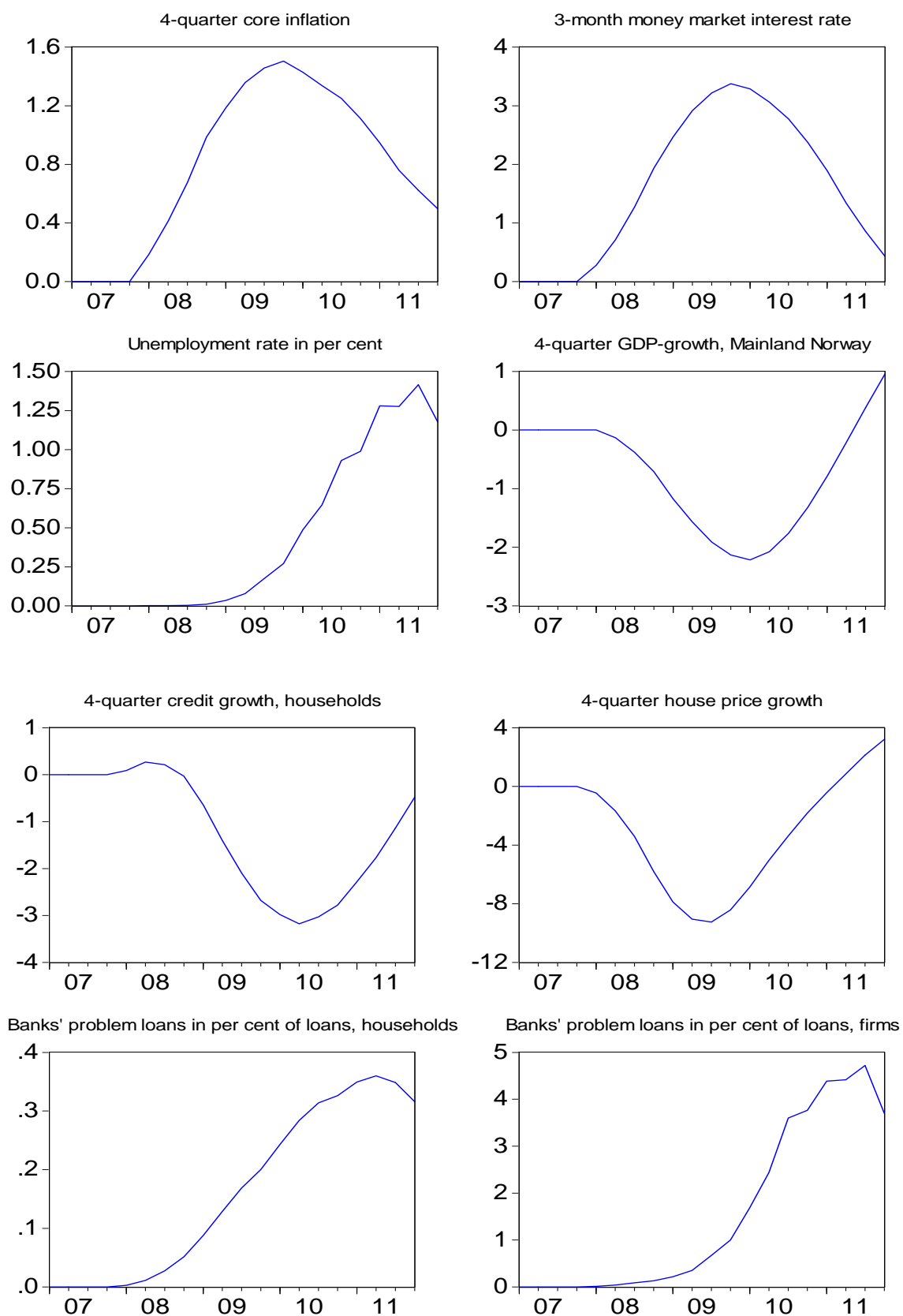
3.1 The wage and price shock

The wage and price shock is assumed to build up and fade out over the simulation period. We do this by adding a sequence of single-quarter shocks to the price and wage growth series. We add a maximum of 0.4 and 0.6 percentage points, respectively, to the four-quarter rise in prices and wages. Figure 2 shows the effect of the wage and price shock on selected variables measured as deviations from our baseline scenario in percentage points.

The four-quarter rise in consumer prices and wages is at most about 1½ percentage points higher than in the baseline scenario. The higher inflation rate causes the central bank to increase the interest rate. The higher interest rate causes the Norwegian krone to appreciate. The *exchange rate channel* of the interest rate dampens the initial price shock through reduced growth in import prices measured in kroner. Due to sticky prices, the real exchange rate also appreciates. As a result, the competitiveness of Norwegian industries deteriorates, output declines, unemployment increases and prices and wage growth decline. Hence, the exchange rate channel affects prices and wages indirectly through GDP and unemployment.

Furthermore, the interest rate affects the real economy through financial markets, where a higher money market interest rate is channelled into banks' lending rates. Higher lending rates affect GDP negatively. This is the *demand channel* found in main-stream monetary policy models, see, e.g., Ball (1999).

Figure 2. The effect of a shock to domestic wage and price inflation on selected variables. Deviations from the baseline scenario in percentage points. Quarterly data¹



¹ Starting in 2008Q1, we add a sequence of single quarter shocks to both price and wage inflation. At the most, we add 0.4 and 0.6 percentage points to the 4-quarter rise in prices and wages respectively.

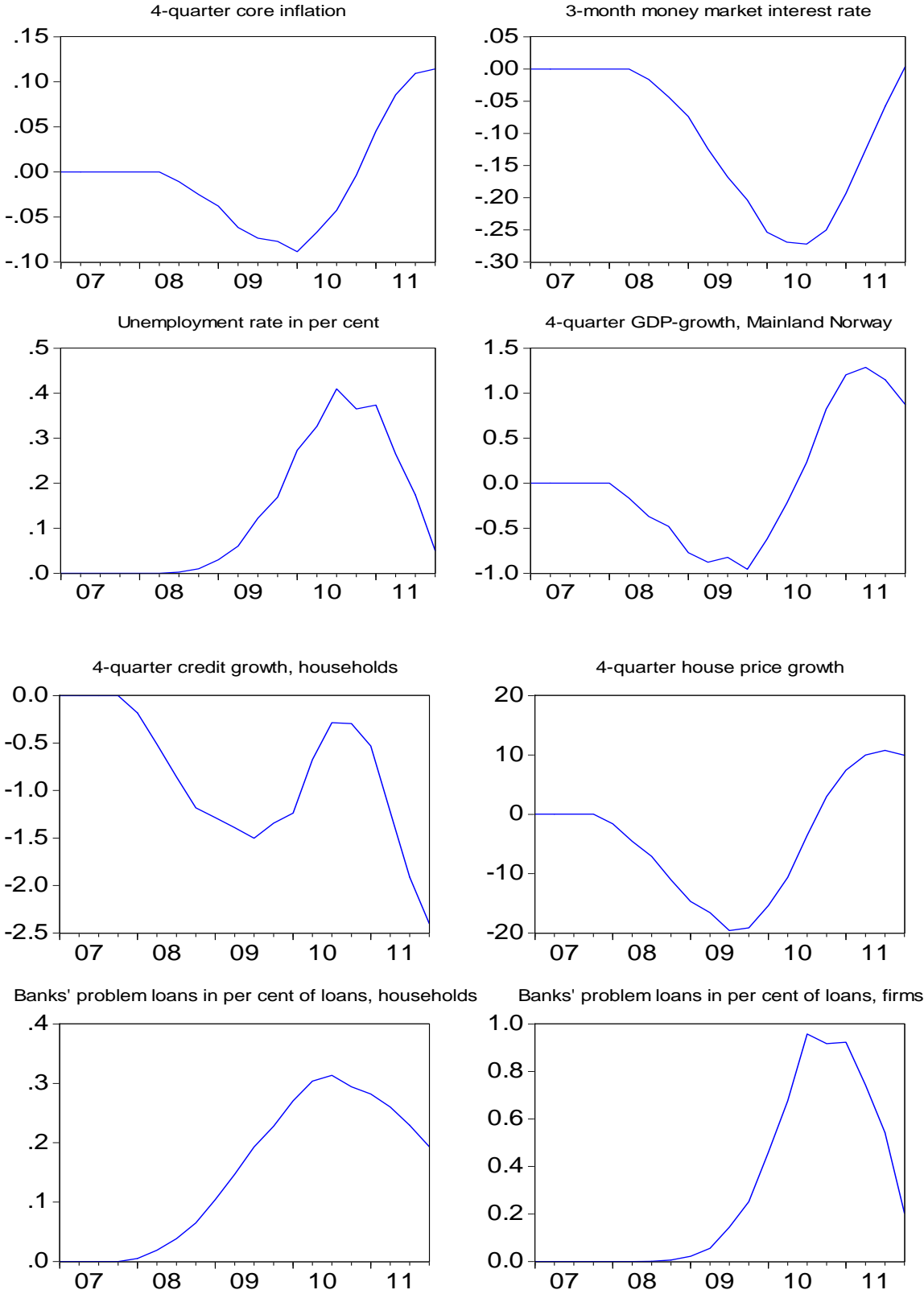
The model also includes a *housing-credit market channel* that is related to the financial accelerator, whereby interest rates affect output through house prices and credit. Higher interest rates increase the user cost of housing consumption, and as a result, housing demand and house prices decrease. Falling house prices reduces the collateral value of housing and affects consumption, housing investments and credit growth negatively. This drives down growth in GDP. A credit effect in the house price equation implies that interest rates also affect house prices indirectly through reduced credit growth. The interpretation of this effect is as follows: As interest rates increase, the debt-servicing capacity of home buyers falls and available credit in the housing market declines. This curbs the rise in house prices.

The volume of problem loans increases. Compared to the baseline scenario, the increase in the problem loans of households is very small, less than $\frac{1}{2}$ percentage point at the most. Hence, despite an increase in the debt-servicing burden as interest rates increase by as much as $3\frac{1}{2}$ percentage points, this does not cause large problems as long as the increase in unemployment stays modest. Firms' problem loans increase by more, and become close to 5 percentage points higher than in the baseline scenario. This increase reflects the higher interest rate, the stronger krone, which reduces domestic firms' competitiveness, and also reduced domestic demand due to higher unemployment. Hence, increased unemployment is likely to hit banks through the corporate sector rather than through the household sector of the economy. In Norway, about 80 per cent of total household debt is mortgages. Households that experience reduced financial margins and debt-servicing problems tend to cut back on consumption spending rather than default on their mortgage loans. The main effect of the deteriorated financial position of households is thus on firms' sales, income and debt-servicing capability.

3.2 A negative consumer confidence shock

In this simulation, we want to create a significant collapse in the housing market, and we do this by designing a drop in consumer confidence. (See footnote 8 for an explanation of the consumer confidence indicator and its role.) Our shock to consumer confidence starts in 2008Q1, builds up and fades out over three years. We calibrate the shock based on experiences from the spring of 2003, when house prices and consumer confidence both fell.

Figure 3. The effect of a shock to consumer confidence on selected variables. Deviations from the baseline scenario in percentage points. Quarterly data¹



¹ Starting in 2008Q1, we add a sequence of single quarter shocks the consumer confidence indicator. The value of the indicator is: 2008: (0.5, 1.0, 1.0, 1.5); 2009: (2.0, 2.0, 2.5, 2.0); 2010: (1.5, 1.0, 0.5, 0.0); 2011: Zero, which is the neutral value of the indicator.

The negative shock to the consumer confidence indicator is about three times the amplitude of spring 2003. In addition, the indicator stays negative, indicating pessimistic households, for a longer period. Figure 3 shows the effect of the consumer confidence shock on selected variables, measured as percentage point deviations from our baseline scenario.

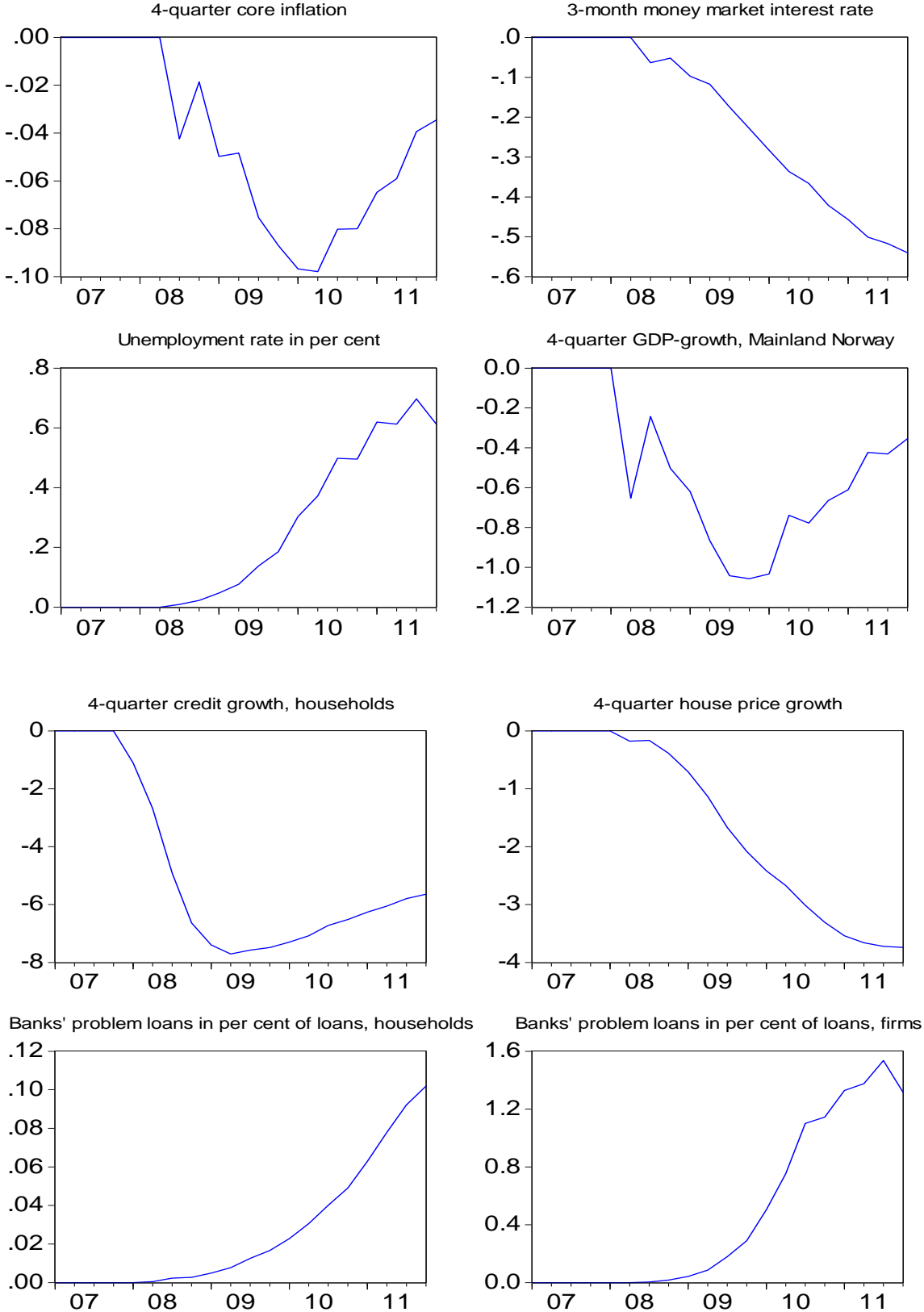
The macro model predicts that the fall in consumer confidence has a direct negative effect on growth in house prices, and compared to 2007, house prices are down by about 20 per cent in 2010. The fall in house prices affects growth in GDP negatively, and as a consequence, unemployment increases and domestic price and wage inflation falls. The decline in house prices also dampens households' credit growth. The central bank responds by lowering the interest rate, which stays below the rate in the baseline scenario until the very end of the simulation period. A lower interest rate helps the economy to recover, and growth in GDP, credit and house prices increases again. The development in these variables also reinforces each other, as explained in section 2.1.

Compared to the baseline scenario, this shock to consumer confidence increases households' and firms' problem loans at the most by only 0.3 and 1.0 percentage points respectively. The effect on households' debt-servicing capability and domestic demand is modest, since the increase in unemployment and fall in wage growth are relatively small, and since interest rates are reduced. Furthermore, firms are helped by a depreciation of the exchange rate that increases domestic firms' competitiveness relative to foreign firms.

3.3 A credit squeeze

We now look at the effects of a credit squeeze in our small macro model, i.e. a situation where credit supply to households and firms falls significantly. A more restrictive lending policy by banks can be motivated by the uncertainty from the continuous turmoil in international credit markets and from expected falls in collateral values as house prices decline.

Figure 4. The effect of a shock to credit supply on selected variables. Deviations from the baseline scenario in percentage points. Quarterly data¹



¹ Starting in 2008Q1, we add a sequence of single quarter shocks to credit growth to both households and firms. We reduce the 4-quarter growth in household credit and firm credit by 2 (in general) and 20 (at most) percentage points respectively.

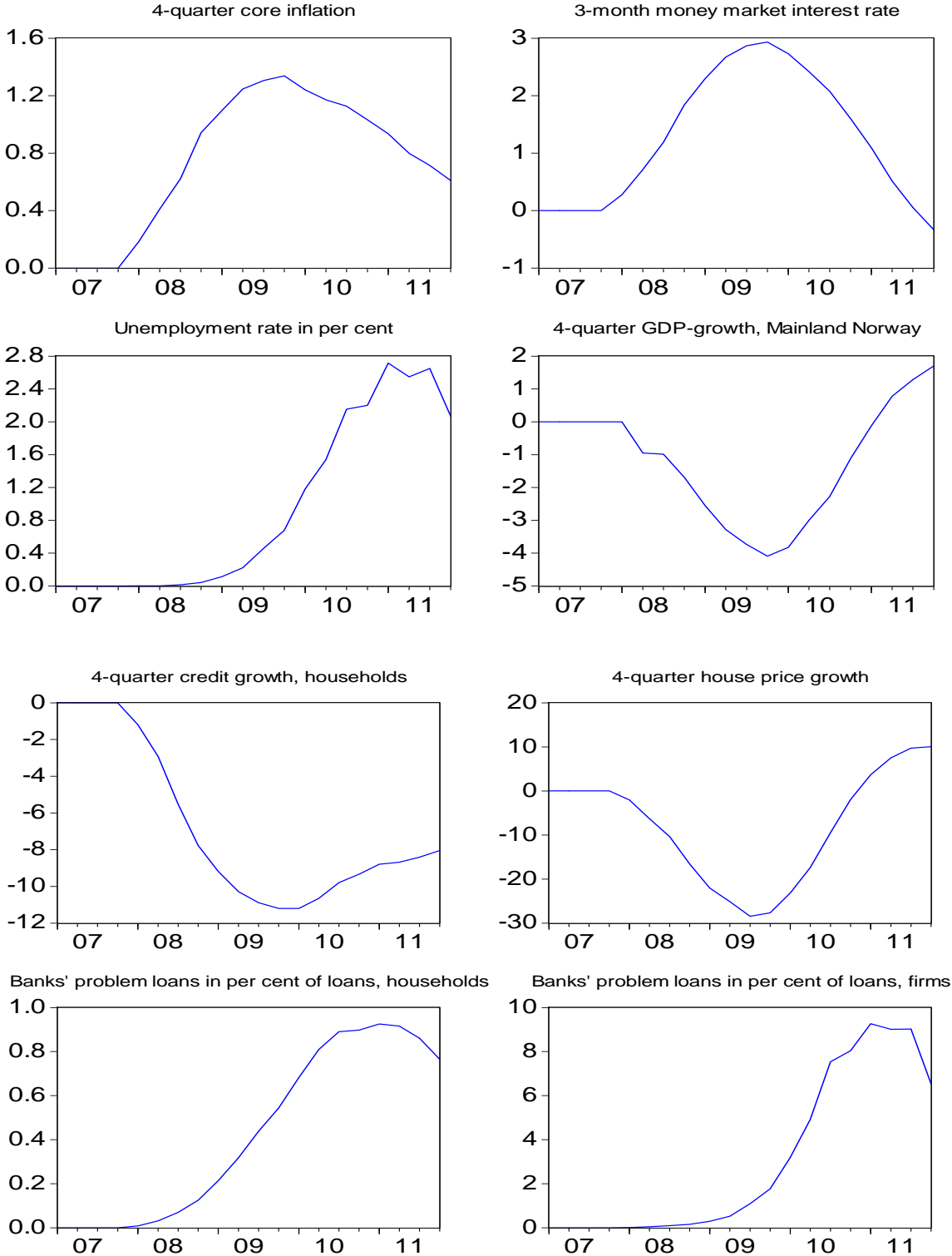
Figure 4 shows the results of the simulated fall in credit growth. The decline in credit growth has a direct negative effect on house prices and GDP, which cause inflation to decline, unemployment to increase, credit growth to fall even more, and the interest rate to be reduced. Monetary policy helps the economy improve, but banks' problem loans increase. Problem loans to households increase by only 0.1 percentage points compared to the baseline scenario, but problem loans to firms increase by more than 1½ percentage points compared to the baseline scenario. Firms' debt-servicing capability is hit by the fall in domestic demand caused by the reduction in available credit and increase in unemployment. This negative effect is partly counteracted, however, due to improved competitiveness as the real exchange rate depreciates when the interest rate falls.

3.4 A multivariate stress scenario

Finally we simulate a multivariate shock, where wage and price inflation increases, consumer confidence is eroded and banks' lending policy tightens to become a credit squeeze. This stress scenario combines the three shocks shown in Figures 2 - 4. The effects of this scenario on some selected variables are presented in Figure 5.

In this stress scenario, the positive impulse to monetary policy from the price and wage shock dominates the negative impulses from the fall in consumer confidence and credit growth. As a result, the three-month money market interest rate increases by close to 3 percentage points compared to the baseline scenario. This causes the exchange rate to appreciate, which erodes the competitiveness of domestic firms. As a result, GDP-growth declines even more and unemployment increases by almost 3 percentage points. This combined shock causes the housing market to collapse, and house prices fall by 35 per cent from 2007 to 2010. This is comparable to the experience from the 1988-1992 banking crisis in Norway, when house prices fell by about 30 per cent. The higher interest rate and negative demand shocks curb inflation, and the interest rate starts falling. This causes growth in GDP to pick up, unemployment to fall and the housing market to improve.

Figure 5. The effect on selected variables of a combined shock with high wage and price inflation, a fall in consumer confidence and a credit squeeze. Deviations from baseline scenario in percentage points. Quarterly data¹



¹ Starting in 2008Q1, we add a sequence of single quarter shocks to price and wage inflation, to consumer confidence and to credit growth to households and firms. At the most, we add 0.4 and 0.6 percentage points to the 4-quarter rise in prices and wages respectively. The value of the consumer confidence indicator is: 2008: (0.5, 1.0, 1.0, 1.5); 2009: (2.0, 2.0, 2.5, 2.0); 2010: (1.5, 1.0, 0.5, 0.0); 2011: Zero, which is the neutral value of the indicator. We reduce the 4-quarter growth in household credit and firm credit by 2 (in general) and 20 (at most) percentage points respectively.

In this multivariate scenario, households' problem loans increase by about 0.9 percentage points compared to the baseline scenario. Households' capability to service their debt declines as both the interest rate and the level of unemployment increase significantly. The fall in house prices also contributes to the increase in problem loans. This effect may reflect that banks' credit supply declines as house prices fall, or that the willingness of households to service debt declines as the 'debt to value' ratio increases.

Firms' problem loans increase by close to 10 percentage points compared to the baseline scenario. This implies a default rate not far from the relatively high levels in the mid-nineties, i.e. just after the previous banking crisis in Norway. As with households, firms are hit by several factors that all contribute to reduce their ability to service their debt. The higher interest rate has a direct effect and also hits indirectly through the effect on the exchange rate and hence competitiveness. Higher unemployment has an additional strong effect.

3.5 Taking the multivariate stress scenario to the micro models

We now take the results from the macro model in the multivariate stress scenario to the micro models. This enables us to identify distributional effects and pockets of risk, and to evaluate the impact on the five largest Norwegian banks. We use the output from SMM as explanatory variables in the micro models. In the corporate sector model, i.e. SEBRA, we use the predictions on GDP (Mainland Norway), CPI inflation, wage growth, firm borrowing rate, the real exchange rate, and house prices as a proxy for commercial property prices. In the household-margin model, we use the CPI inflation, the wage growth, the interest rate charged on household loans and the household credit growth. In the bank model we use banks' loan losses, the three month money-market interest rate, the growth in credit to households, and the per hour wage growth. In addition, the bank model takes firms debt growth and the distribution of debt at risk from SEBRA as input.

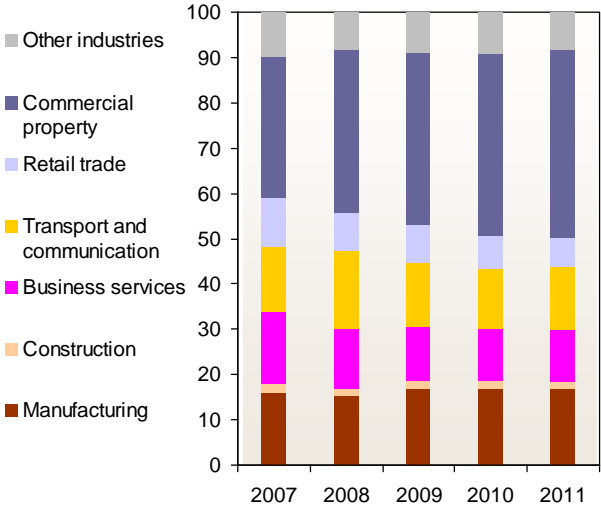
Norges Bank's view on the economic development is published in the tertiary Monetary Policy Report, see, e.g., Norges Bank (2008b). Norges Bank publishes a baseline scenario based on models developed to support monetary policy and on judgement. In general, the baseline scenario that we produce in SMM may deviate from the official baseline scenario. When publishing results from our stress-testing exercise, we therefore adjust the scenarios to become consistent with the official baseline scenario in the latest available Monetary Policy

Report. This is relatively simple, since SMM is nearly linear. In the following, when results from the micro models are shown in level form, they have been adjusted to correctly represent deviations from the official baseline scenario in Norges Bank (2008b).

The corporate sector model; SEBRA

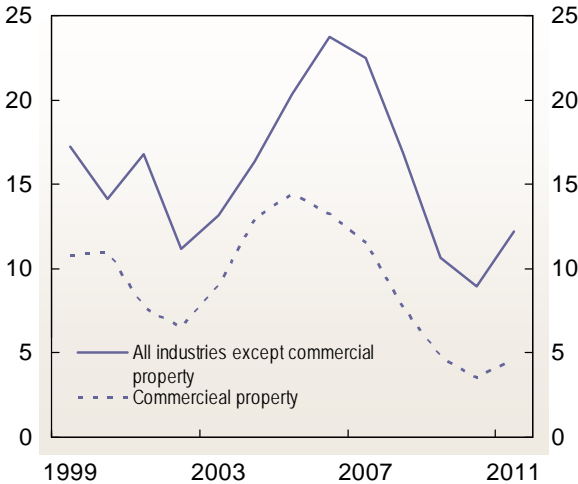
Figures 6 and 7 illustrate how SEBRA identifies pockets of risk in the corporate sector. These figures show that commercial-property firms are highly vulnerable to the shocks in our stress scenario. The increase in losses that banks suffer is very much a result of the fall in the debt-servicing capability in the real-estate sector. This sector is highly leveraged and thus heavily exposed to the increase in interest rates. Our assumption that commercial property-prices fall in line with house prices also contributes to the losses.

Figure 6. Banks’ losses on loans to different industries as a share of total losses on loans to non-financial firms. Stress scenario, annual data



Source: Norges Bank

Figure 7. Debt-servicing capability of firms in the commercial property sector and other non-financial firms. Stress scenario, annual data



Source: Norges Bank

The household model

The household-margin model is used to identify households or groups of households that are likely to experience large increases in debt at risk in stress scenarios. We can split the households according to various characteristics that we find interesting.

In Figure 8 we show the share of households with a negative margin and their share of households' total debt. The three sets of bars to the right illustrate the results in 2010, since, in our scenario, households' situation improve somewhat again in 2011. 'Base' is our baseline scenario, 'stress' is our stress scenario, while 'stress + increased living expenses' is our stress scenario with the additional assumption that the annual rise in prices on basic consumption doubles compared to the stress scenario. According to the household model, close to 10 per cent of the households have a negative financial margin in our stress scenario, and they have 7½ per cent of total debt. In the 'stress + increased living expenses' case, 12 per cent of the households will have a negative margin. These households have 9 per cent of total debt. Hence, many households are vulnerable to the development in consumer prices, particularly if an increase in living expenses comes on top of an increase in interest rates and unemployment.

Figure 8. Percentage of households with negative margin and their debt in per cent of total debt. Annual data¹

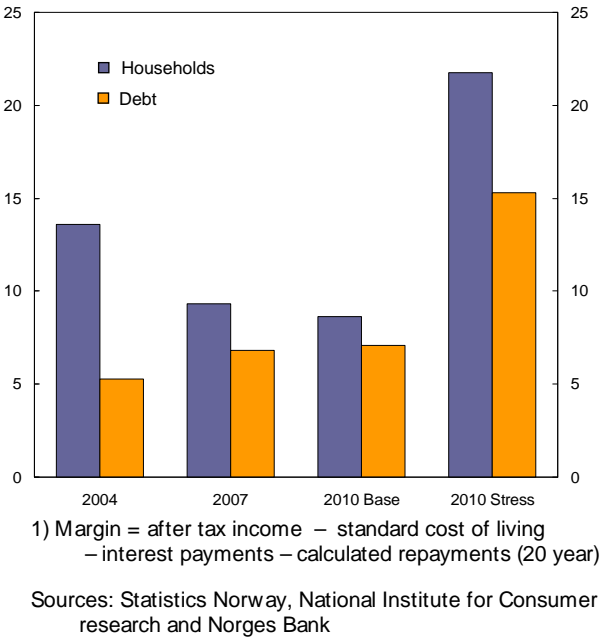
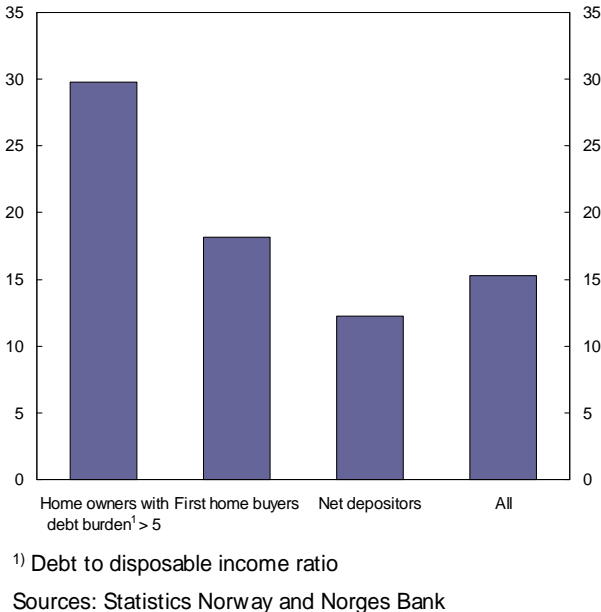


Figure 9. Debt in households with a negative margin in selected groups¹. Percentage of group debt. In 2010 in stress scenario



It is often argued that households with a high debt to income ratio and first-time home buyers are most vulnerable to negative events. At the same time, it is argued that many households with debt also have financial wealth that can help them out if negative events should occur. Figure 9 shows the situation in 2011 given our stress scenario. The first bar shows that about

13 per cent of the debt held by households with a debt-to-income ratio above 5 will be at risk, i.e. held by households with a negative margin. The second bar shows that about 11 per cent of total debt held by first-time home buyers will be at risk. The third bar shows that only 4-5 per cent of total debt in households with positive liquid net financial wealth will be at risk in our terminology. Liquid net financial wealth is defined as bank deposits minus debt. Hence, households with a buffer that can be drawn on in difficult times are less likely to run into a situation with a negative margin. Households with a high debt-to-income ratio and first-time home buyers are, as expected, vulnerable to negative events. In difficult times, liquid financial wealth is not mainly at the hands of those who may be needing it most.

The bank model

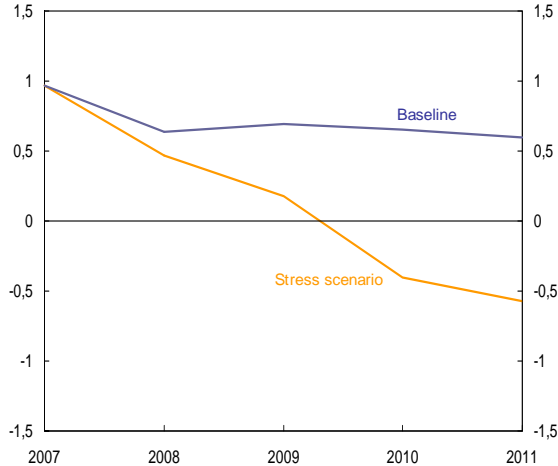
From the bank model we get the impact of the stress scenario on the five largest Norwegian banks' results and capital adequacy. The aggregate results are shown in Figure 10 and 11. Based on the baseline scenario for the Norwegian economy, banks' results after tax are expected to fall in 2008, and then remain at about 0.65 per cent of average total assets in the following years. Both in the baseline and the stress scenario, the banks' results after tax fall in 2008 due to a decline in other operating income. The main drivers behind the reduction are a decline in fee income and net losses on securities. In addition, DnB NOR had a 1.4 billion NOK gain on a property sale during the fourth quarter of 2007. As this is a one-time gain, other operating income is adjusted down by the same amount from 2007 to 2008.

In the stress scenario, bank's results after tax will fall substantially in 2009, and be negative as from 2010. The steep rise in loan losses is the main driver behind the negative results during the last two years of the stress scenario. Furthermore, the spread paid above the money market rate for market funding is assumed to be increasing in 2008 and again in 2009, and then falling somewhat in each of the years 2010 and 2011. This reduces the net interest income in the stress scenario.

Despite weaker results, capital adequacy ratios for the five banks as a group are not substantially weakened. This is due to the assumption that lending growth falls markedly, which reduces the capital adequacy requirements for these banks. One of the banks falls just below the minimum requirement of 8 per cent. However, a closer look at that bank indicates that its situation in the stress scenario is less critical than suggested by the model. At any rate, banks will not be passive bystanders to negative developments, as implicitly assumed in the

bank model. (From the macro model we have a fall in credit growth, however.) Banks can raise capital and subordinated debt in order to increase their capital adequacy. In addition, with loan losses of 1.9 per cent in 2010 and 2.3 per cent in 2011 banks may react by increasing their lending margins even more than what is assumed in the stress scenario.

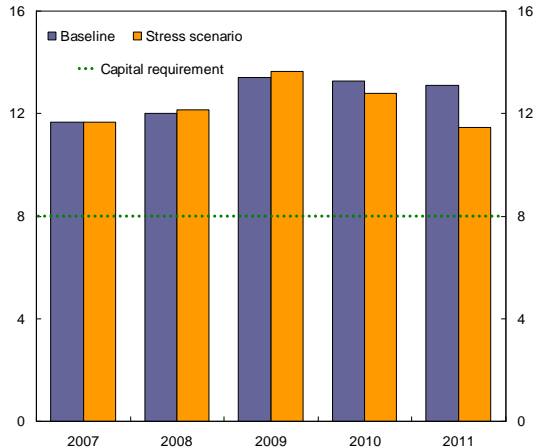
Figure 10. Projections of post-tax profit as a percentage of average total assets in Norway’s five largest banks.¹ Annual data



¹) DnB NOR Bank (excl. branches abroad), SpareBank 1 SR Bank, Sparebanken Vest, SpareBank 1 Nord-Norge and SpareBank 1 SMN

Source: Norges Bank

Figure 11. Projections of capital adequacy in per cent in Norway’s five largest banks. Annual data



¹) DnB NOR Bank (excl. branches abroad), SpareBank 1 SR-Bank, Sparebanken Vest, SpareBank 1 Nord-Norge and SpareBank 1 SMN

Source: Norges Bank

4 Summing up

This paper presents a system developed for stress-testing purposes, where an aggregative macro-model is linked to micro data-based models for households, firms and banks. The model structure is recursive; with output from the macro model being used as input into the micro data-based models. This enables us to follow the transmission of initial macro shocks through the set of models and to get a more detailed picture of the consequences. Information on how debt and probability of default are distributed across firms and households can be very important for the assessment of financial stability. The household and firm models are used to analyse pockets of risk. The bank model enables us to evaluate the consequence of different negative events on the five largest Norwegian banks’ results and capital adequacy.

In addition to equations for the main macroeconomic variables, the macro model includes equations for household debt, house prices, housing investments, households' and firms' problem loans and firms' bankruptcy rate. The house price equation includes households' expectations about own financial situation and the Norwegian economy, i.e. a consumer confidence indicator. These expectations need not be model-consistent. While overly optimistic agents will fuel the rise in house prices, the opposite is true if agents are pessimistic. In addition to this consumer confidence effect on house prices, our macro model also includes other important properties from a financial stability assessment perspective. These are a credit driven house price effect, a long lasting effect of a rise in house prices on credit growth, and a feed-back effect from credit and house prices to the real economy. Hence, our macro model includes a financial accelerator.

Four simulation exercises on the macro model are presented; a wage and price shock, a shock to households' expectations, a credit crunch and a multivariate shock that combines the three shocks. As a consequence of the multivariable shock, households' problem loans increase, but by less than one percentage point compared to the baseline scenario. An increase in firms' problem loans by close to ten percentage points compared to the baseline scenario is rather dramatic, however. This implies a default rate on bank loans not far from the relatively high levels in the early nineties, i.e. at the end of the previous banking crisis in Norway. The multivariate shock is also fed into the firm, household margin and bank models. The predictions of the firm model are that the largest increase in debt at risk comes in the commercial real-estate sector. This result reflects that this sector is highly leveraged, and that commercial real-estate property prices are assumed to follow the fall in house prices. The household model predicts that the largest increase in debt at risk comes in households with a very high debt-to-income ratio and among first-time home buyers. Liquid financial wealth, i.e. bank deposits, is in general not at the hands of those households that will be mostly affected by our stress scenario.

The five largest banks' results deteriorate significantly in our stress scenario, very much due to the increase in losses. Despite weaker results, capital adequacy ratios for the five banks as a whole are not substantially weakened. This is due to the assumption that lending growth falls markedly, which reduces the capital adequacy requirement for these banks.

Although our model system has many favourable properties as a stress-testing tool as it stands today, it also has its weaknesses. We therefore continue to develop and improve the different models and the way they interact with each others. In the near future, the development of the bank model is a prioritised task. We would want to include more of the largest banks, to strengthen the relationship between the bank model and the household and corporate sector models and to include behavioural equations in the bank model.

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Appendix 1: The main equations of the small macro-econometric model

The small macro model is an extension of the model reported in Bårdsen and Nymoen (2008) and Bårdsen et al. (2005).¹⁶ It is a macro-econometric model estimated on quarterly data. The model explicitly takes into account several channels of interplay between output, inflation and financial stability. The equations are in equilibrium-correction form, with backward-looking expectations formation.

We present a stylized version of the model in Equations (1)-(13). Small letters denote natural logarithms of the variable, Δ denotes the first difference operator, Δ_j denotes the j -period difference operator, and foreign variables are denoted with starred superscripts. In general, intercept terms and seasonal effects have been omitted from the equations for ease of exposition. The identities that complete the model are not reported.

Aggregate demand

$$\begin{aligned}\Delta y_t = & -0.6\Delta y_{t-1} + 0.7\Delta g_t + 0.4\Delta g_{t-1} \\ & + 0.1\Delta(ph - p)_{t-1} + 0.1\Delta(cr^e - p)_{t-1} + 0.2\Delta(cr^h - p)_{t-3} \\ & - 0.3[(y_{t-2} - 0.8g_{t-2} - 0.1(v + p^* - p)_{t-1} - 0.1(cr^h - p)_{t-4} + 0.01(RL - \pi)_{t-1}] \\ & \text{Estimation period 1991Q1-2006Q4}\end{aligned}\tag{1}$$

Exchange rate

$$\begin{aligned}\Delta v_t = & \varphi(-0.04\Delta R_t + 0.05\Delta R_t^* - 0.1\Delta po_t - 0.07u_{t-1}) \\ & - 0.1[(v + p^* - p)_{t-1} + 0.03((R - \pi)_{t-1} - (R^* - \pi^*)_{t-1}) + 0.1(po + usd - p)_{t-1} - \mu_v] \\ & \text{Estimation period 1994Q2-2007Q2}\end{aligned}\tag{2}$$

Import prices

$$\begin{aligned}\Delta pi_t = & 0.4\Delta v_t + 1.3\Delta pi_t^* \\ & - 0.4[(pi - pi^* - v)_{t-1} - 0.6(p - p^* - v)_{t-1}] \\ & \text{Estimation period 1990Q1-2007Q2}\end{aligned}\tag{3}$$

¹⁶ The presentation of the core part of the macro model is based on Bårdsen and Nymoen (2008).

Unemployment

$$\begin{aligned}\Delta u_t &= 0.4u_{t-1} - 1.6\left(\Delta_4 \frac{1}{2} \sum_{j=1}^2 y_{t-j} - \text{mean}\left(\Delta_4 \frac{1}{2} \sum_{j=1}^2 y_{t-j}\right)\right) \\ &\quad - 0.03[u_{t-2} - 11.1\Delta(w-p)_t] \\ \text{Estimation period } &1979\text{Q3-}2007\text{Q4}\end{aligned}\tag{4}$$

Wages

$$\begin{aligned}\Delta w_t &= \Delta z_t - 0.5\Delta(w_{t-1} - z_{t-1}) \\ &\quad - 0.1[w_{t-2} - p_{t-1} - z_{t-2} + 0.001u_{t-1} - \mu_w] \\ \text{Estimation period } &1978\text{Q4-}2007\text{Q4}\end{aligned}\tag{5}$$

Consumer prices

$$\begin{aligned}\Delta p_t &= 0.3\Delta p_{t-2} + 0.1\Delta y_{t-1} + 0.1\Delta(w_{t-1} - z_{t-1}) + 0.1\Delta p e_t \\ &\quad - 0.06[p_{t-3} - 0.65(w_{t-3} - z_{t-2}) - 0.35p_{t-1} - \mu_p] \\ \text{Estimation period } &1978\text{Q4-}2007\text{Q4}\end{aligned}\tag{6}$$

Money market interest-rate

$$\begin{aligned}\Delta R_t &= 1.5(\pi_t^c - 2.5) - 0.6(R_{t-1} - R_{t-1}^* - 1) + 0.4\Delta R_t^* - 0.5\left(\frac{1}{4} \sum_{j=1}^4 u_{t-j} - 2\right) \\ \text{Estimation period } &1991\text{Q1-}2007\text{Q2}\end{aligned}\tag{7}$$

Banks' lending rate

$$\Delta RL_t = 0.8\Delta R_t + 0.2\Delta R_{t-1} - 0.35[RL_{t-1} - (R_{t-1} + RLM)]\tag{8}$$

Household debt

$$\begin{aligned}\Delta(cr^h - p_t) &= -0.01(\Delta RL_{t-2} + \Delta RL_{t-3}) + 0.3\Delta(inc - p)_{t-1} \\ &\quad + 0.1(\Delta(ph - p)_t - \Delta(ph - p)_{t-3}) \\ &\quad - 0.04[(cr^h - p)_{t-1} - 0.7(ph - p)_{t-4} + 0.04RL_{t-4} - 1.2(inc - p)_{t-2}] \\ \text{Estimation period } &1991\text{Q1-}2007\text{Q2}\end{aligned}\tag{9}$$

House prices

$$\begin{aligned}\Delta ph_t &= 0.2\Delta inc_t - 0.03\Delta RL_t - 0.02\Delta RL_{t-1} + 0.03H_t^e \\ &\quad - 0.1[ph_{t-1} + 0.05RL_{t-1} + 0.5u_t - 1.3(inc - hs)_{t-1} - 0.3cr_{t-1}^h] \\ \text{Estimation period } &1990\text{Q2-}2006\text{Q4}\end{aligned}\tag{10}$$

Housing investments

$$\begin{aligned} \Delta j_t = & -0.04\Delta_4(RL - \frac{1}{3} \sum_{j=-1}^1 \pi^c_{t-j})_t - 0.01(RL - \frac{1}{3} \sum_{j=-1}^1 \pi^c_{t-j})_{t-4} \\ & - 0.1[(j_{t-1} - hs_{t-10}) - (ph - p)_{t-4} - (inc - p)_{t-1} - (pj - p)_{t-4}] \end{aligned} \quad (11)$$

Estimation period 1991Q1-2007Q4

Household default rate

$$\begin{aligned} \Delta(d^h - cr^h) = & -0.2\Delta_3(d^h - cr^h)_{t-1} + 0.02\Delta_2(RL - \pi)_t \\ & + 0.02\Delta_2(RL - \pi)_{t-2} - 0.5\Delta_4(ph - p)_t \\ & - 0.2[(d^h - cr^h)_{t-4} - 0.4u_{t-3} - 0.08(RL - \pi)_{t-4} \\ & + 1.2(inc - p)_{t-1} + 1.2(ph - p)_{t-4}] \end{aligned} \quad (12)$$

Estimation period 1993Q1-2005Q4

Firm default

$$\begin{aligned} \Delta(d^e - p)_t = & -0.3\Delta_2(d^e - p)_{t-1} + 0.02\Delta_2(RL - \pi)_t + 0.9\Delta u_t + 0.7\Delta u_{t-1} \\ & + 1.5\Delta(cr^e - p)_{t-3} - 0.4\Delta(po + usd - p)_t - 0.5[(d^e - p)_{t-3} \\ & - (cr^e - p)_{t-4} - 0.05(RL - \pi)_{t-3} \\ & - 1.7u_{t-2} + 0.7(v + p^* - p)_{t-3} + 0.5(po + usd - p)_t] \end{aligned} \quad (13)$$

Estimation period 1992Q1-2005Q4

where $\pi = 100 \frac{\Delta_4 P_t}{P_{t-4}}$ is the inflation rate ; $\pi^u = 100 \frac{\Delta_4 P^u_t}{P^u_{t-4}}$ is the core inflation rate, i.e.

inflation adjusted for changes in energy prices and taxes; $\pi^* = 100 \frac{\Delta_4 P^*_t}{P^*_{t-4}}$ is the foreign

inflation rate.

Growth in real aggregate demand (Δy) is modelled in Equation (1). Aggregate demand is affected by the real interest rate ($RL - \pi$), real government expenditure (g) and the real exchange rate ($v + p^* - p$). Thus, a change in the nominal exchange rate would directly affect aggregate demand. Aggregate demand is also affected by house prices and credit. Changes in real house prices ($ph - p$) have short run effects on aggregate demand through a wealth effect on consumption and through housing investments not captured by the real interest rate.

Real corporate credit ($cr^e - p$) affects GDP in the short run, while real household credit ($cr^h - p$) has long-run effects on GDP. The short-run effect is interpreted as reflecting frictions in the credit market, while the long-run effect points towards a form of rationing of the household sector.

The exchange rate (in logs denoted v) expresses the number of domestic currency units per unit of foreign currency. The equation of growth of the nominal effective exchange rate (Δv) in Equation (2) reacts to deviations from PPP ($v + p^* - p$) and hence contributes to stabilizing the real exchange rate. φ is a dummy for inflation targeting, and takes the value 0 up until 2001Q1 and the value 1 from 2001Q2. In the long run, the nominal exchange rate reflects the difference between domestic and foreign prices and the difference between domestic and foreign real interest rates ($R - \pi$) - ($R^* - \pi^*$). Accordingly, domestic inflation becomes fully reflected in the nominal exchange rate in the long run.

Import prices measured in domestic currency (pi) are a homogenous function of the nominal exchange rate (v) and foreign producer prices measured in foreign currency (pi^*). On the other hand, import prices increase if the real exchange rate (in terms of consumer prices) appreciates. This is due to pricing-to-markets in import price setting.

The unemployment rate (u) follows output growth (Δy) in the short run as an Okun's law relationship, see Equation (4). In addition, it exhibits slow reversion towards its equilibrium rate; an intercept term has been omitted.

There is a pass-through of consumer price inflation (Δp) to nominal wage growth (Δw) in the short run; see Equation (5). In each period, nominal wages adjust towards their long-run relationship where there is a full pass-through of consumer prices and productivity (z). However, the mark-up of wages on prices and productivity is inversely related to the unemployment rate (u).¹⁷

¹⁷ The constant mark-up term is suppressed. In the full econometric model, productivity (z) is an endogenous variable that depends on real wages ($w - p$), unemployment (u) and a deterministic trend.

In the short run, consumer price inflation varies with changes in aggregate demand (Δy) and to some extent nominal wage growth (Δw); see Equation (6). In addition, it adjusts to deviation from the long-run relationship for consumer prices. In the long run, consumer prices (p) reflect a weighted average of domestic and imported costs, represented by unit labour costs ($w - z$) and import prices ($v + p^*$). It follows that the initial effect of a change in nominal exchange rate on aggregate demand would become modified over time due to the exchange rate pass-through to inflation, which would have an effect opposite that of the nominal exchange rate on the real exchange rate. The model also includes an equation for the underlying, i.e. core, inflation rate (p^c), which is linked to consumer price inflation.

The three-month money market interest rate (R) follows an estimated Taylor-type rule in Equation (7). Since March 2001, Norwegian monetary policy is aimed at targeting the annual core inflation rate (π^c) at 2.5 per cent. Despite the fact that Norwegian monetary policy has changed over time, see, e.g., Akram (2004)¹⁸, the estimated equation is stable over the estimation period 1991-2006. The interest rate responds to deviation from target in domestic core inflation and to deviation in unemployment from 2 per cent. This unemployment gap represents the output gap. If the interest rate deviates from the foreign interest rate inclusive a premium of 1 percentage point, this also affects the interest rate.

Banks' lending rate (RL) is defined to follow the money market rate. A lending margin (RLM), i.e. the margin between the lending rate and the money market rate, is an exogenous variable in the model. The coefficients of this equation are calibrated and not estimated.

The relationship explaining movements in household debt in Equation (9) builds on the work presented in Jacobsen and Naug (2004). Growth in household debt (Δcr^h) reacts positively to growth in income (Δinc) and housing prices (Δph), and decreases with higher interest rate on loans (RL) see Jacobsen and Naug (2004) for further details.

The model of house prices (ph) in Equation (10) is based on Jacobsen and Naug (2005). The growth rate of nominal house prices (Δph) is explained by growth in nominal income (inc)

¹⁸ At the very beginning of the sample, NOK was pegged to the ECU, but went floating in December 1992. Although inflation targeting was formally introduced in March 2001, it is a common view that this regime was gradually introduced from early 1999 on.

and household expectations about their own financial situation and the Norwegian economy (H^e), i.e. a survey based consumer confidence indicator, as well as interest rate changes (ΔRL) and deviations from steady state. In steady state, house prices (ph) are mainly determined by income (inc) and housing capital (hc) in addition to the interest rate (RL), the unemployment rate (u), and household debt (cr^h).

The equation for gross fixed housing investments (j) is based on Jacobsen, Solberg-Johansen and Haugland (2007), see Equation (11). Growth in gross fixed housing investments (Δj)

depends on the change in the real lending rate $\Delta_4(RL - \frac{1}{3} \sum_{j=-1}^1 \pi^c_{t-j})_t$. In steady state, gross fixed investments depend on the level of housing capital (hs) due to replacement investments, real house prices ($ph - p$), real investment price ($pj - p$), households' real wage income ($inc - p$) as a proxy for land costs, and the real lending rate

$$(RL - \frac{1}{3} \sum_{j=-1}^1 \pi^c_{t-j})_{t-4}.$$

The equations of default¹⁹ by households and firms in (12) and (13) respectively are based on Berge and Boye (2007). Households' default rate ($d^h - cr^h$), i.e., default as a share of total household bank debt, depends on households' real income ($inc - p$), unemployment (u), the real interest rate ($RL - \pi$) and real house prices ($ph - p$). With respect to firms' default, there is not homogeneity between default and debt in the short run, only in the long run. Firms' default, measured in real terms ($d^e - p$), depends on the level of debt ($cr^e - p$), the real interest rate ($RL - \pi$), domestic demand proxied by the unemployment rate (u), the real exchange rate ($v + p^* - p$) as a measure of competitiveness and the real oil price ($po + usd - p$). The latter variable captures that the level of activity and investments in the oil sector affect other industries.

In addition, SMM includes estimated equations for bankruptcies in firms adapted from Jacobsen and Kloster (2005), productivity (z), and bond rates (RB).

¹⁹ Our data on problem loans include both default and loans with a high probability of default as reported by the banks.

Appendix 2: The bank model

The bank model is a static non-behaviour model consisting of three main components, namely a profit and loss account, a balance sheet and a capital adequacy calculation.

1. The profit and loss account

The profit and loss account includes the following items:

- Net interest income
- Other operating income
- Other operating costs
- Loan losses

The profit before taxes and dividends is given by:

Profit before taxes and dividends = Net interest income + Other operating income – Other operating costs – Loan losses

Net interest income has become less important since the mid 1990's, but still remained the dominant component with 67 per cent of banks' operating income in 2007. This makes it particularly important to make as good predictions of net interest income as possible. Thus, the bank model includes a detailed net interest income calculation, based on projections of lending and deposit interest rates and interest rates on other interest bearing assets and liabilities. The growth rates of loans, deposits and other interest bearing assets and liabilities also affect the calculated net interest income. The net interest income is computed as:

$$\begin{aligned} \text{Net interest income}_t &= ((\text{Loans}_{t-1} + \text{Loans}_t)/2) * \text{Average lending rate}_t \\ &+ ((\text{Other interest bearing assets}_{t-1} + \text{Other interest bearing assets}_t)/2) \\ &* \text{Average interest rate on other interest bearing assets}_t \\ &- ((\text{Deposits}_{t-1} + \text{Deposits}_t)/2) * \text{Average deposit rate}_t \\ &- ((\text{Other interest bearing liabilities}_{t-1} + \text{Other interest bearing liabilities}_t)/2) \\ &* \text{Average interest rate on other interest bearing liabilities}_t \end{aligned}$$

Subscript t denotes the year of the predicted result. Notice that 'Other interest bearing liabilities' include both market funding, subordinated loans and other debt. It follows from the equation that a rise in the interest rates on loans and other interest bearing assets increases the net interest income, while an increase in the interest rates on deposits and other interest bearing liabilities pulls the net interest income in the opposite direction. In addition to this

price effect, a positive volume growth in the assets and liabilities boosts the net interest income, given that the marginal interest rates on interest bearing assets are higher than the marginal interest rates on interest bearing liabilities.

Other operating income consists of fee income and capital market income, i.e. net gains and dividends on securities, currency trade and derivatives. Other operating income is given by:

Other operating income = Fee income + Net gains and dividends on securities + Net gains on currency trade + Net gains on derivatives + Other gains and income

Fee income has in recent years accounted for about 20 per cent of total bank income.

Apart from the funding costs included in the net interest income calculation, *Other operating costs* are the dominant cost component in the profit and loss account. 55 per cent of Other operating costs were labour costs in 2007. *Loan losses* have been close to zero in recent years. However, banks losses may increase substantially. During the Norwegian banking crisis of 1988-93 bank losses were by far the major cost component.

2. The balance sheet

The asset side of the balance sheet includes the following items:

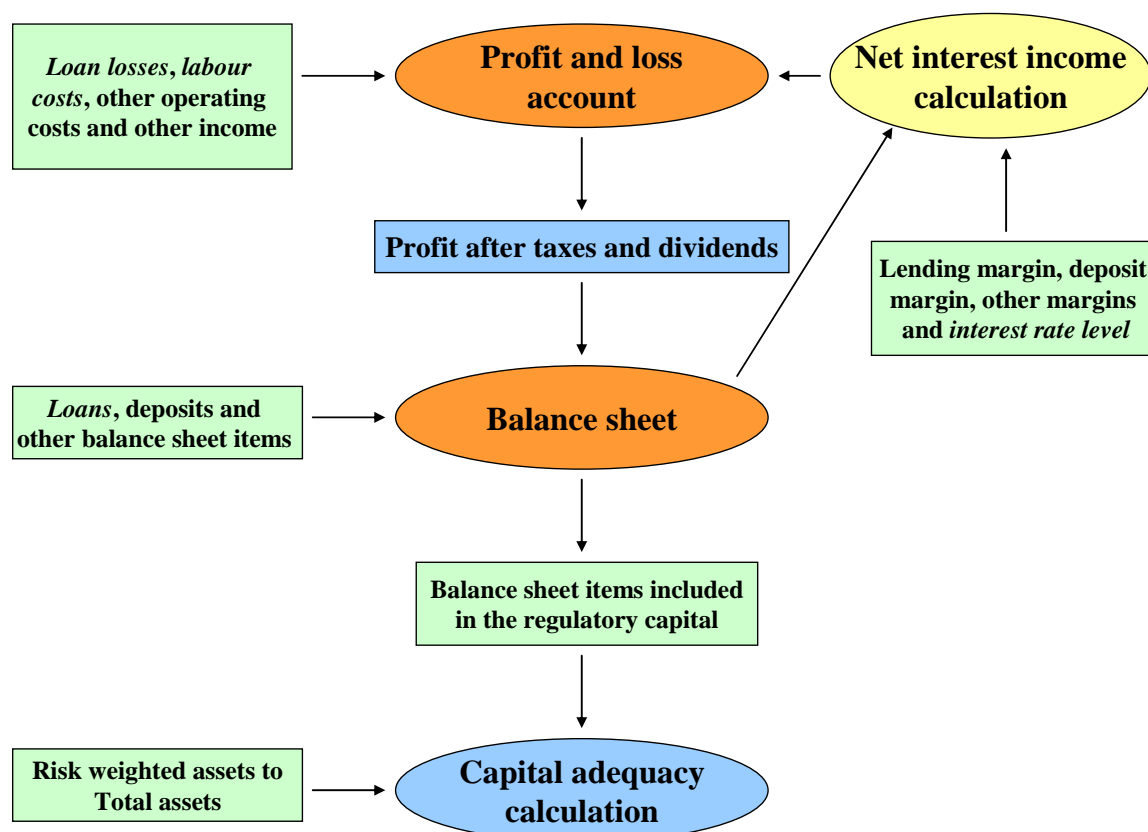
- Loans to households and enterprises
- Securities and deposits
- Other assets

The liability side of the balance sheet includes the following items:

- Deposits
- Market funding
- Other debt
- Subordinated debt
- Equity

While loans are the dominant component on the asset side (67 per cent of total assets in 2007), deposits is the dominant component on the liability side (62 per cent of total liabilities in 2007). Market funding includes bonds, short-term paper and loans from financial institutions.

Figure A1



Banks' results after taxes and dividends affect their capital, and the balance sheet growth affects the risk weighted assets, confer figure A1 above. The end-output of the bank model are banks' results and capital adequacy.

3. The capital adequacy calculation

The future capital adequacy ratio is calculated based on projections of the regulatory capital and the risk-weighted assets. The regulatory capital is approximated based on balance sheet items. However, it is not possible to identify every single regulatory capital component in the balance sheet. Thus, a residual, i.e. the difference between the last reported regulatory capital and the sum of the regulatory capital components identified in the last reported balance sheet, is being predicted as well.

The risk-weighted assets are approximated based on the assumption that the ratio of risk-weighted assets to total assets remains constant during the simulation period. Thus, it is assumed that the risk parameters and composition of the banks' assets remains the same

during the prediction period. This runs contrary to the hypothesis that the risk parameters are responsive to the business cycle. Studies simulating the internal rating based approach of Basle II find significant cyclicity in the capital requirements caused by internally estimated risk parameters. Thus, a natural extension of the bank model would be to calculate risk-weighted assets based on risk parameters from the enterprise sector model which are responsive to the development in bankruptcy probabilities.

Appendix 3: Simulations on the bank model

In simulations, the bank model builds on projections of money market interest rates, loan losses, labour cost growth and loan growth to households from the macro model. The loan growth to the enterprise sector and the distribution of loan losses from different industries is predicted by the SEBRA enterprise sector model, which is a satellite to the macro model. We apply predictions of fee income from a separate error correction model estimated on macro variables (the GDP level, the GDP growth and the difference between the five year and the three month real yield on Treasuries)²⁰. Projections of the remaining variables are based on analysis undertaken in Norges Bank.

1. The balance sheet

The bank model builds on projections of *loan growth to households* from the macro model for both the baseline and the stress scenario, see table 1. The *loan growth to the enterprise sector* is in both scenarios predicted by the enterprise sector model. The macro model predicts a steep increase in loan losses from the enterprise sector in the stress scenario. Due to these predicted problems in the enterprise sector, both the loan supply from the banks and the loan demand from the enterprises may fall substantially. Therefore, the loan growth to the enterprise sector is adjusted down in the enterprise sector model from 8.1 to 3.0 per cent in 2010 and from 16.6 to 5.0 per cent in 2011 in order to be in line with the predicted steep increase in loan losses from the enterprise sector. This is more in line with the experiences from the Norwegian bank crisis of 1988-93 when the loan growth to the enterprise sector remain below 5 per cent until 1996.

Securities and other assets are assumed to be growing at the same rate as the loan growth. This assumption keeps the composition of the banks' assets unchanged and is, in turn, consistent with the assumption that the ratio of risk-weighted assets to total assets remains constant during the simulation period.

As a simplification, *deposit growth* is assumed to mirror the wage growth from the macro model. Finally, the growth of *other interest bearing liabilities* (bonds, short-term paper, loans from financial institutions, subordinated debt and other debt) is set as a residual in order to

²⁰ $\Delta \ln Fee\ income_t = -5.000 - 0.380 \ln Fee\ income_{t-1} + 0.616 \ln GDP_{t-1} + 1.721 (Five\ year\ real\ yield - Three\ month\ real\ yield)_{t-1} + 0.847 \Delta \ln GDP_t + 0.032 Second\ quarter + 0.024 Third\ quarter + 0.030 Fourth\ quarter$

make the total liabilities equal to the total assets. The growth of *equity capital* is endogenously determined by the profit after taxes and dividends.

While the total asset growth is higher than the deposit growth (and the labour costs growth) in the baseline scenario, the opposite is true in the stress scenario. Thus, the assumptions above make the growth rate of market funding higher than the deposit growth in the baseline scenario. This is in line with the fact that the Norwegian banks' use of market funding has grown faster than their deposits during the last decade. However, the banks' need for market funding is substantially lower in the stress scenario due to the low loan growth. Thus, the above assumptions make the growth rate of market funding lower than the deposit growth in the stress scenario.

2. The profit and loss account

The *net interest income* is calculated based on projections of lending and deposit interest rates and interest rates on other interest bearing assets and liabilities. The growth rates of loans, deposits and other interest bearing assets and liabilities also affect the calculated net interest income. Projections of the balance sheet variables included in the net interest income calculation are described in chapter 2.1.

For both the baseline and the stress scenario, lending and deposit interest rates and interest rates on other interest bearing assets are assumed to change in line with the lending rate predicted by the macro model. This can be justified by the predominance of floating rate lending in Norwegian banking, which may have enabled the banks to eliminate most maturity mismatches. As banks largely extend long-term loans at floating rates, they also prefer floating rates on long-term borrowing. When banks issue bonds at fixed rates, they convert their interest payments to floating money market rates by means of interest rate swap agreements. This means that higher money market rates make both short-term and long-term funding more expensive.

However, during financial turbulence, the spread between fixed swap rates and fixed rates on long term borrowing may increase substantially. When converting their interest payments to floating money market rates, the banks have to pay this spread above the floating money market rates. Thus, in the stress scenario, the additional spread paid above the money market rate for market funding is assumed to increase by 20 basis points in 2008 and again in 2009,

and then falling by 10 basis points in each of the years 2010 and 2011. Thus, the spread in 2011 is 20 basis points higher than the initial spread in 2007. The spread increases gradually, because it takes time before the whole balance of market funding has been refinanced.

We compare the calculated net interest income to projections of net interest income from a separate error correction model estimated on macro variables (the GDP level and the three month real yield on Treasuries)²¹. The comparison is done to make sure that the calculated net interest income is in line with the scenarios for the Norwegian economy. Thus, the projections from the error correction model are only used as a cross-check. The comparison unveils that the calculated net interest income represents a plausible development given the macro economic scenario. Thus, the projections of the input variables in the net interest income calculation are left unchanged.

Predictions of *other operating income* are a function of several predicted components. The bank model applies predictions of fee income from the separate error correction model estimated on macro variables. Dividends received on securities are in 2008 assumed to be the same amount as in 2007, then 20 per cent lower in 2009, 2010 and 2011. The net losses on securities are in 2008 set equal to the net losses from the first quarter of 2008. For the remaining prediction period zero gains/losses are assumed. The net gains on currency trade and derivatives are not assumed to be cyclically sensitive. Thus, the amounts of net gains on currency trade and derivatives are assumed to be the same as in 2007 during the whole prediction period. During the fourth quarter of 2007, DnB NOR had a 1.4 billion NOK gain on a property sale. As this is a one-time gain, other operating income falls by almost the same amount from 2007 to 2008. For the remaining period other operating income (i.e. exclusive of net interest and fee income) grows at the same rate as the inflation target, i.e. 2.5 per cent per year.

The banks' *labour costs* are assumed to be growing at the same rate as the labour costs (including both employment and salary changes) predicted by the macro model for both the baseline and the stress scenario. The year-on-year rise in *other operating costs* of Norwegian banks has only been around 0.5 per cent during the last five years. However, the potential for

²¹ $\Delta \ln \text{Net interest income}_t = -0.674 - 0.448 \ln \text{Net interest income}_{t-1} + 0.36 \ln \text{GDP}_{t-1} + 1.168 \text{Three month real yield}_t - 0.02 \Delta \text{Market share of foreign branches}_t + 0.035 \text{Second quarter} + 0.039 \text{Third quarter} + 0.004 \text{Fourth quarter}$

further cost reduction may be limited. Thus, non-labour operating costs are assumed to be growing at the same rate as the inflation target in both scenarios. Finally, the bank model builds on projections of *loan losses* from the macro model for both the baseline and the stress scenario. The distribution of loan losses from different industries is predicted by the enterprise sector model.

The banks are assumed to distribute dividends of 50 per cent when the profit after taxes is positive and 0 per cent when the profit after taxes is negative.

