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GDP at risk in a DSGE model: an application to banking sector stress testing

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Abstract

We suggest a complementary tool for financial stability analysis based on stochastic simulation of a dynamic stochastic general equilibrium model (DSGE) of the macro economy. The paper relates to financial stability research in which financial aggregates crucial to financial stability are modelled as functions of macroeconomic variables. In these models, stress tests for eg banking sector loan losses can be generated by considering adverse scenarios of macro variables. A DSGE model provides a systematic way of generating coherent macro scenarios which can be given a rigorous economic interpretation. The approach is illustrated using a DSGE model of the Finnish economy and a simple model of Finnish banking sector loan losses.

Pankkisektorin stressitestaus DSGE-mallin avulla

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Esa Jokivuolle – Juha Kilponen – Tero Kuusi
Rahapolitiikka- ja tutkimusosasto

Tiivistelmä

Tutkimuksessa esitetään rahoitusjärjestelmän vakausanalyysia täydentävä menetelmä, joka perustuu makrotalouden yleisen tasapainon mallin – ns. DSGE-mallin – stokastiseen simulointiin. Menetelmä liittyy rahoitusjärjestelmän vakautta koskevaan tutkimukseen, jossa vakauden kannalta keskeisiä rahoitusaggregaatteja mallinnetaan makromuuttujilla. Tällaisissa malleissa pankkisektorille voidaan tehdä stressitestejä ennustamalla luottotappioita makromuuttujien epäsuotuisissa tulemissa. Yleisen tasapainon makromallin etuna on se, että sillä voidaan tuottaa sisäisesti johdonmukaisia makroskenaarioita, joille voidaan antaa perusteellinen taloudellinen tulkinta. Menetelmää havainnollistetaan Suomen kansantaloutta varten kehitetyllä DSGE-mallilla ja pankkisektorin luottotappioiden mallilla.

Avainsanat: DSGE-mallit, rahoitusjärjestelmän vakaus, luottotappiot, stressitestit

JEL-luokittelu: E13, E37, G21, G28

Contents

1   Introduction

In recent years central banks and other financial supervisors have become increasingly occupied with analysing the stability of the financial system. Although there is yet no single commonly accepted definition of financial stability, we may say that financial stability prevails when the financial system; securities markets, financial institutions, and payment and settlement systems, can uninterruptedly service their fundamental functions in the economy. These functions include the allocation of savings to real investments via markets and institutions, the monitoring and disciplining of firms, and the provision of payment and trade settlement services.

Financial instability may result from financial distress of individual institutions such as large banks or a group of banks, from excessive volatility or severe mispricing in securities markets, or from operational failure of payment or settlement systems. Although financial stability analysis covers the entire financial system it may not be fruitful to separate it from the stability analysis of individual financial institutions, many of which alone can cause threats to the stability of the system. Therefore *macro prudential analysis* (aimed at system level) often uses, and should use, similar tools and models as *prudential analysis* (aimed at individual institutions). Many tools of financial stability analysis are common to, and often originate from, risk management departments of financial institutions. Today it is also part of financial supervision, via regulatory frameworks such as Basel II, to see that regulated institutions indeed use these tools to assess their own risks.

It is widely believed that at the core of financial stability lie the solvency of the banking sector and especially the solvency of large individual banks. Therefore a central part of financial stability analysis consists of models of banks' financial risks; trading risks, credit risks and balance sheet interest rate risks. For example, value-at-risk models of banks' various asset portfolios can be used to quantify potential losses that may endanger banks' solvency.[1] Efforts have also been taken to model jointly the risks of various institutions acting in the same market in order to incorporate possible contagion effects between institutions. Sorge and Virolainen (2006) provide a recent survey of many of the various approaches to assessing financial stability.

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[1] In a standard value-at-risk model a set of risk factors such as market prices of securities or latent market risk factors determines the values of instruments in the portfolio under consideration. The joint future probability distribution of this set of risk factors is generated through stochastic simulation. For each realisation of the factors, changes in the values of the instruments, and hence the change in the entire portfolio value (market or book value, depending on the model), is determined. Hence the joint probability distribution of the risk factors can be transformed into the probability distribution of the future portfolio value, of which a chosen percentile lying on the adverse tail of the distribution measures the 'value-at-risk' of the portfolio.

Credit risks still account for a major part of banks' financial risks; so much of financial stability analysis is concerned with credit risk. An important strand of credit risk portfolio models aims to incorporate macro economic variables as risk factors as adverse macro economic conditions appear to have underlain many banking crises.[2] Such models are favoured by supervisors and central banks as for them it is particularly important to understand how banks' credit losses are interlinked with macro developments. In Basel II, for example, banks are required to conduct stress tests in which their capital adequacy is assessed against potential losses in a 'mild recession' (Basel Committee, 2005). The models can be used to produce 'macro stress-tests' in that a potential adverse path of the macro variables is fed into the model of, say, bank loan losses to produce a stress scenario of these losses. Macro variables could be stochastically simulated to produce their joint probability distribution from which the stress scenario could then be chosen. Alternatively, the macro scenario could be chosen by using expert judgement. Several studies have modelled the relationship between macro economic variables and bank credit risk indicators (see eg Sorge and Virolainen, 2006), or imbedded the credit risk variables in a macro model (see eg Drehmann et al, 2004, Oung, 2004, Evjen et al, 2003, and Chirinko and Guill, 1991).

In this paper we extend the literature on macro stress-testing by making use of a dynamic stochastic general equilibrium model (DSGE) of macro economy. Such models have become standard in modern macroeconomics, and there are signs that they are also starting to attract economic forecasters, such as central banks.[3] It is therefore natural to consider their use also in systematic production of macro scenarios for the purpose of financial sector stability assessment. The attractiveness of a DSGE model in producing macro scenarios lies in the rigorous micro economic foundations it is based on. For a central bank it is also desirable to be able to use the same model for producing macro economic scenarios both for the purposes of monetary policy and financial stability analysis, in order to consolidate and facilitate the dialogue between the two fields of analysis.

Our approach is to implement stochastic simulation of a DSGE model.[4] This is done by selecting a set of key exogenous variables of the model, running Monte Carlo simulation on their joint stochastic processes, and simultaneously solving for the new equilibrium of the DSGE model, which gives us paths of the endogenous variables of interest. The processes of the exogenous variables and their covariances are partly estimated and partly calibrated with the DSGE model such that the model produced moments of central macro variables match closely their empirical counterparts and stylized facts. The simulated paths of the

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[2] A pioneering model in incorporating macro factors into a credit risk measurement framework is Wilson (1997a, b).
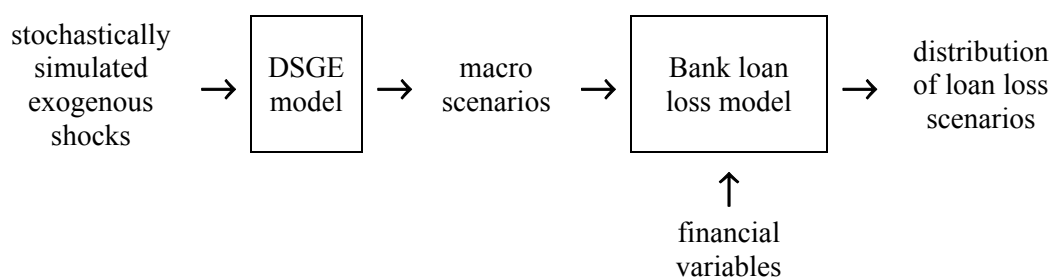
[3] See Kilponen–Ripatti (2006).

[4] The model used is the DSGE model of the Bank of Finland, called 'Aino'; see Kilponen, Kinnunen and Ripatti (2006).

variables that are explanatory variables in a chosen bank loan loss model are then used to generate loan loss scenarios and, ultimately, the entire probability distribution of loan losses.[5] We keep track of the simulated macro scenarios, not only of the variables needed in the loan loss model, so that we know what macro scenario caused a certain loan loss scenario. This way we are able to provide macro economic explanation to the loan loss scenario that lies, say, at the 99th percentile of the loan loss distribution. Figure 1.1 illustrates the stages of our procedure.

Figure 1.1   **Illustration of the approach to produce macro economic and loan loss scenarios**

stochastically simulated exogenous shocks → DSGE model → macro scenarios → Bank loan loss model → distribution of loan loss scenarios

↑
financial variables

We note that although we, as much of the literature, talk about stress tests we do not mean stress tests in which probabilistic risk assessment models are complemented with judgement based scenario analyses. Our approach produces the entire probability distribution of the variables of interest, and may hence be closer by nature to value-at-risk analysis than standard stress tests. While considering ad hoc stress scenarios has its own merits in financial stability analysis, the probabilistic approach followed in this paper might be better suited for monitoring financial stability developments over time. That is, by fixing the probability of the macro scenario considered for generating loan losses, we have more control over whether a change in loan losses from the previous stress testing point is really caused by a change in banks' exposure to macro shocks.

Finally, it should be emphasized that the DSGE model and the bank loan loss model are separate in that no feedback mechanisms are considered. An ultimate goal in this strand of research might be to incorporate the financial sector in a DSGE model.[6] This challenging task is, however, left for future research, and therefore the approach in this paper can perhaps best be seen as a pragmatic first step in organising the use of a DSGE model in financial stability analysis.

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[5] An auxiliary model of the Finnish banking sector loan losses is estimated in the spirit of Sorge and Virolainen (2006).

[6] Christiano, Motta and Rostagno (2007) derive and estimate a monetary DSGE model that includes financial markets. In their model, financial markets propagate shocks that originate from other than financial markets. Financial markets also act as source of shocks.

The rest of the paper is structured as follows. Section 2 briefly describes the DSGE model used, the choice of exogenous variables, and the model calibration. In section 3 the stochastic simulation of macro scenarios is implemented. These are then run through a simple bank loan loss model in section 4. The final section concludes.

2   The DSGE model and its calibration

The Bank of Finland's DSGE model, Aino, is described in more detail eg in Kilponen and Ripatti (2005) and Kilponen et al (2006). Here we provide just a brief account of its main features.

Aino model is cast in the overlapping generations framework and it consists of two types of consumers, workers and retirees, and five domestic firm types; producers of capital, intermediate and final goods, capital renting firm and exporting firm. Consumers make dynamically optimal consumption and labour supply decisions by maximizing utility over their life-cycle. There is imperfect competition in the labour market and the intermediate goods' market, but no imperfections stemming from financial markets or institutions. Both nominal and real rigidities have been introduced to smooth the model economy's responses to economic shocks. There is also a carefully modelled domestic public sector and an exogenous foreign sector.[7] The model is closed with fiscal policy rules and UIP condition, although in this exercise we replace the UIP condition with monetary policy rule, in order to generate endogenous fluctuations of the domestic nominal interest rate and capture the covariance of interest, inflation and output observed in the de-trended data.

In essence, Aino model is a single good model. This composite good is a CES-aggregate of individual goods produced by a continuum of identical domestic intermediate goods producers. The elasticity of substitution, ie the degree of competition between the individual goods may vary over time. The production process uses CES technology to combine capital services and labour. The composite good is then used as a factor of production of final goods. Model has three types of final goods since their relative prices have persistent trends. They are consumption goods, capital goods and exported goods. The final goods producers are called retailers. They combine the domestic intermediate goods with the foreign (imported) intermediate goods. Importing firms generate only import prices. Homogenous capital services are rented from capital goods producers (leasing firms). Physical capital stock itself is instantaneously transferable across firms. The markets for final goods and capital services are perfect. Intermediate

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[7] The rich public sector module was originally built for analysing specific fiscal policy related questions; for financial stability purposes it is considerably reduced.

goods firms and importing firms operate under imperfect competition and they use Calvo pricing with dynamic indexing.

Central to our approach is to identify the exogenous factors that are the fundamental sources of unpredictable fluctuations and shocks to endogenous economic developments such as GDP growth, domestic inflation and real interest rates. These economic developments in turn are likely factors influencing financial sector vulnerabilities such as bank loan losses. By shocking the key set of exogenous factors from their empirically estimated or calibrated joint probability distribution we are ultimately able to produce stochastic shocks to loan losses.

2.1   Calibration

There are a large number of exogenous shock variables in Aino but it is not necessary or feasible to include all of them in the version used in our simulations. It is important to focus on factors which have been identified as the most potential candidates in explaining business fluctuations; a question still very much debated in macro economic literature and naturally conditional on the economy in question.   For instance, capital-saving technological advances are important in explaining the 1990s phenomenon in Finland, whereby, despite rapid growth in output, investment recovery was, historically speaking, slow. According to our DSGE model, this was because considerably more output was extracted from the existing capital stock eg via the rearrangement of working hours.

We use a total of 15 exogenous shock variables in the simulation, each of which is specified as an AR(1) process with mutually uncorrelated error terms.[8] The list of the key exogenous shock variables that explain a major part of the variation in the model's key macroeconomic variables is given in Table 2.1, Panel B.

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[8] We intend to relax the independence restriction in future work.

Table 2.1 **Endogenous and exogenous variables**

Panel A: Moments of the key endogenous variables

Endogenous variable	AR(1)		REL.STD		CORR/Output		S.E.	
	Data	Model	Data	Model	Data	Model	Data	Model
Average labour productivity	0.528	0.826	0.777	0.450	0.583	0.507	0.010	0.006
Output	0.771	0.587	1.000	1.000	1.000	1.000	0.013	0.014
Consumption	0.883	0.504	0.535	0.670	0.142	0.844	0.008	0.009
Investment	0.886	0.849	2.744	2.467	0.723	0.387	0.036	0.034
Interest rate	0.868	0.631	0.481	0.294	0.686	0.598	0.006	0.004
Real wage	0.588	0.646	0.729	0.853	0.176	0.156	0.010	0.012
Employment	0.883	0.504	0.588	0.670	0.632	0.844	0.008	0.009
Inflation	0.712	0.880	1.474	1.071	0.353	0.048	0.019	0.015

Panel B: Processes of the key exogenous variables

Exogenous shock	AR(1)	S.E.
Labour aug.technical change	0.71	0.0039
Capital aug.technical change	0.81	0.0100
Dom. intermediate goods aug. tech in exports	0.79	0.0412
Price mark-up	0.95	0.0041
Imp. intermed. goods aug. tech in capital goods prod	0.9	0.0282
Dom. intermed. goods aug. tech in capital goods prod	0.78	0.0039
Imp. intermed. goods aug tech in cons.goods prod	0.76	0.0095
Competitors relative price	0.56	0.0345

Notes: All exogenous processes are assumed to be AR(1) with uncorrelated errors:
$$x_{i,t} = \alpha_i x_{i,t-1} + \varepsilon_{i,t}; \varepsilon_{i,t} \sim N(0,\sigma_i^2) \text{ and } corr(\varepsilon_{i,t}, \varepsilon_{j,t}) = 0$$

There are several approaches to determine the parameters of the exogenous variables' processes and deep parameters of the model. In general, we can divide them into following categories. The first contains parameter values that are calibrated and not estimated as such. The second set of parameters contains the parameters that affect the steady state of the model. These parameters are calibrated such as to reproduce some of the key sample averages of the data. The third set of parameters consists of parameters that are estimated. Some of these parameters have been directly estimated from the Finnish data using GMM and Co-integration techniques.[9] Another set of parameters have been estimated using a variant of the simulated-moments-method. In essence this means that we aim at matching the key moments of the set of the target variables. These target variables are indicated in Table 2.1, Panel A. In matching the key moments of the data, we apply the same filtering technique (HP-10 000-filter) to actual data and to simulated data. The actual data we match runs from 1995q1–2005q4. Filtering

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[9] A more formal numerical calibration exercise is work in progress.

technique is applied both to the actual data and to the simulated data since the model's responses to exogenous shocks are treated as deviations from the balanced growth path.

The model's empirical fit is illustrated in Table 2.1, panel A and in figures 2.1 and 2.2. Panel A in Table 2.1 shows the key moments and standard errors of the key macro variables, while Figures 1.1 and 2.3 draw the autocorrelation functions and cross-correlations of the key macroeconomic variables to output at different horizon. The model's ability to match the key business cycle moments is rather good, albeit it has some difficulties to match the cross-correlation between exports and output and in particular employment and output. The model also tends to underestimate the autocorrelation of employment, while investment volatility with respect to output is somewhat lower in the model when compared with the data. Otherwise, given a restricted number of exogenous stochastic shocks used in this paper, the model's fit can be regarded as reasonable.[10]

After the calibration and estimation a variance decomposition of the key macroeconomic variables such as GDP, private consumption, inflation, interest rate and employment was done (see Table 2.2). These 8 variables and their stochastic processes are the ones provided in Table 2.1, Panel B. For other parameter specifications used in the DSGE model see Kilponen–Kinnunen–Ripatti (2006). As can be seen from Table 2.2, a major part of the variation in key real and nominal macro variables is explained by the variation in labour augmenting technical change of the intermediate goods producing firm. The other important sources of variation are due to shocks to technology of the final goods producing firms.

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[10] In order to achieve a reasonable fit with the cross-correlations between interest rate, inflation and output growth, the interest rate is assumed to follow a type of Taylor rule. Given that Finland is a rather small economy participating in the euro system so that monetary policy can be largely considered exogenous, imposing the Taylor rule would be consistent with a view that shocks to the Finnish economy are sufficiently symmetric with the euro area shocks.

Figure 2.1 **Autocorrelation functions of key variables from simulated and actual data**
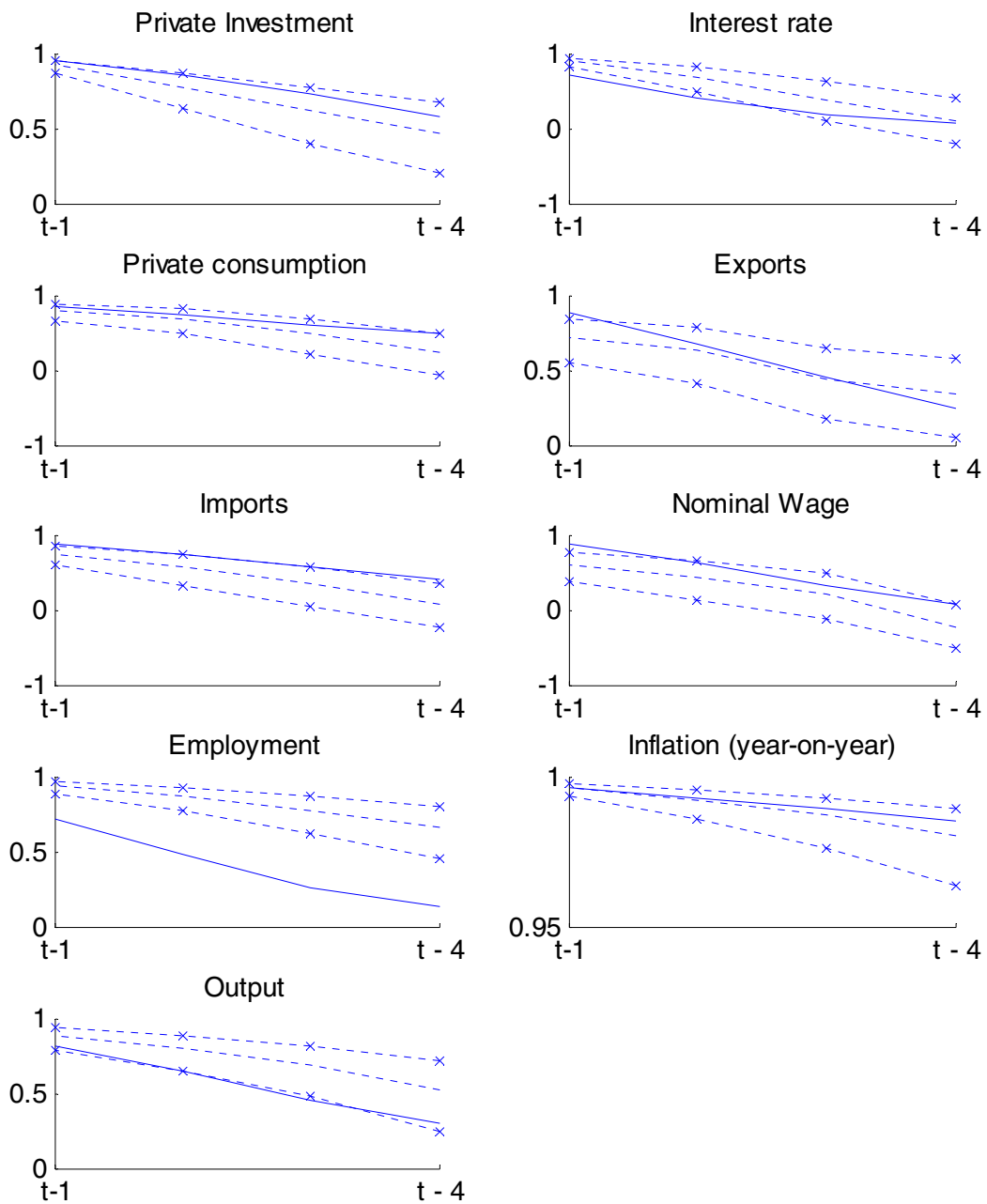
Notes: Solid lines represent the autocorrelation functions of the model and dashed lines represent the autocorrelation functions of the data. Dashed lines with stars indicate the 95% confidence intervals.

Figure 2.2 **Correlations between key macroeconomic variables and output at different horizon in the data and in the model**
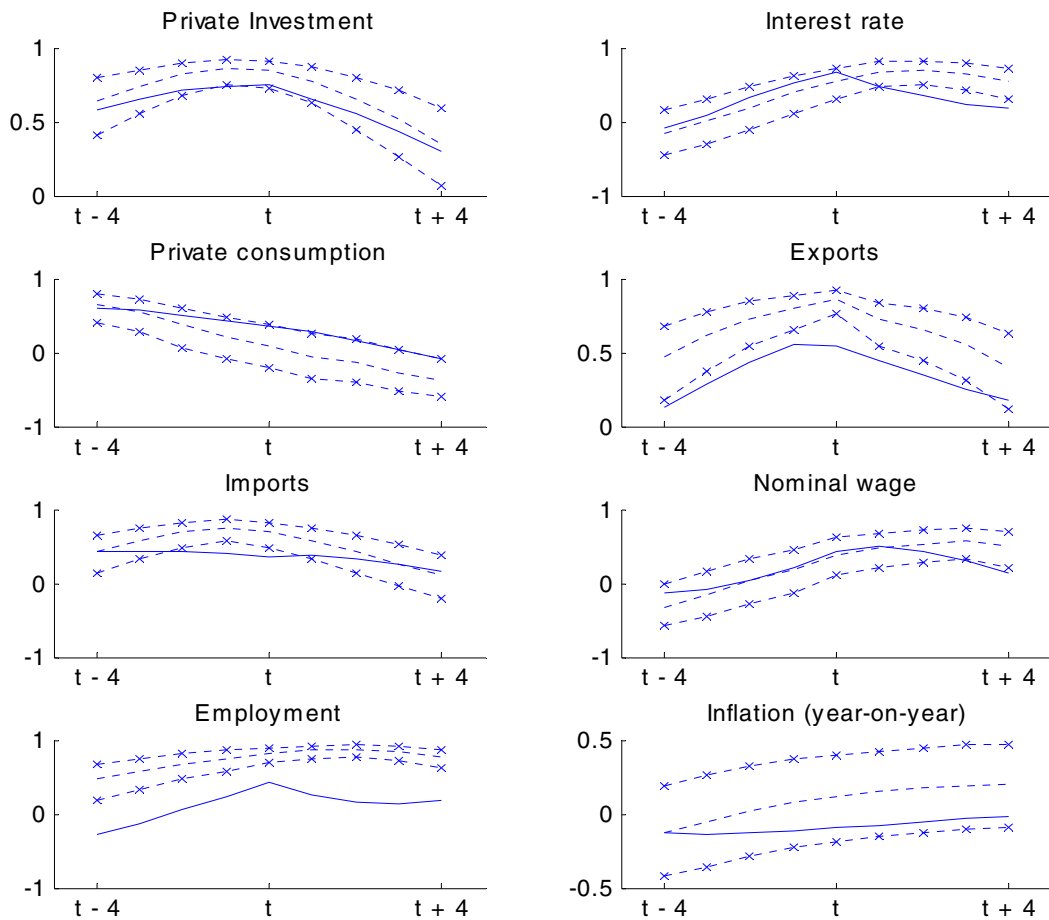
Notes: Solid lines represent the correlation of respective variables and the output of the model and dashed lines represent the same correlation observed in the data. Dashed lines with stars indicate the 95% confidence intervals.

Figure 2.3   **Simulated probability distribution of the average**
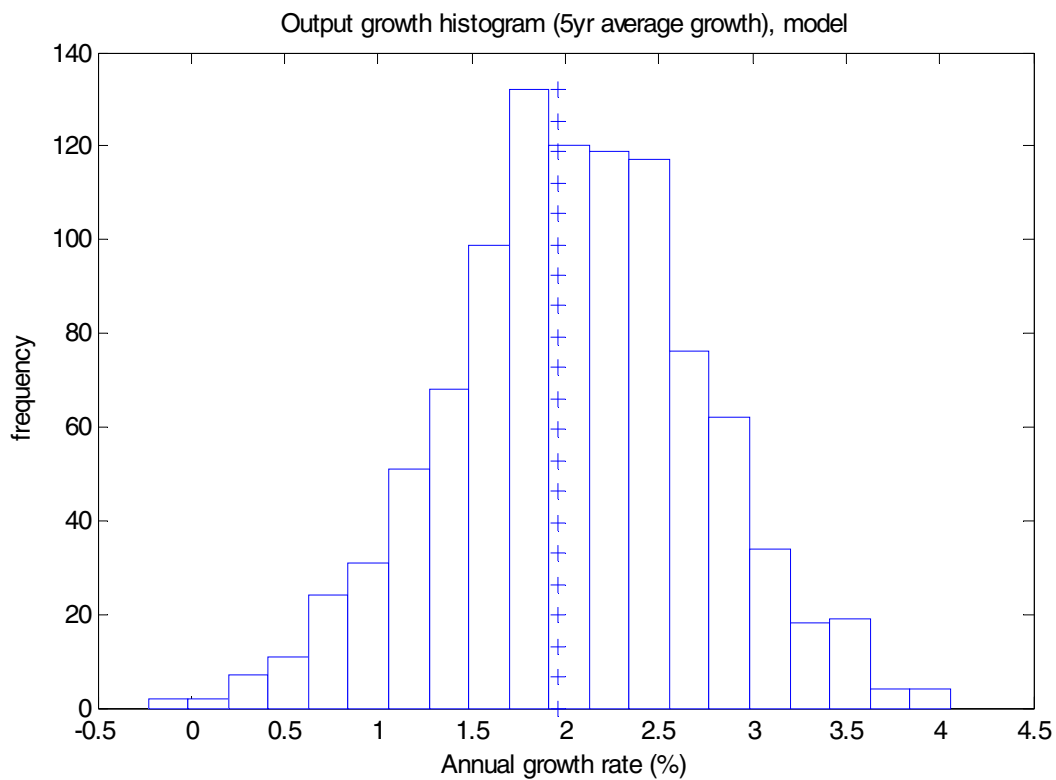   **annual GDP growth rate over a five year horizon**

Output growth histogram (5yr average growth), model

Table 2.2   **Variance decomposition of key macro variables**
                               in the model

Exogenous shock	Labour productivity	Output	Consumption	Investment	Interest rate	Real wage	Employment rate	Inflation
Labour aug.technical change	83.4	81.5	73.0	13.2	9.9	80.2	58.6	28.0
Capital aug.technical change	1.2	0.8	0.3	1.0	0.2	1.1	0.3	4.8
Dom. intermediate goods aug. tech in exports	0.5	1.1	0.1	0.7	18.7	0.5	1.6	9.5
Price mark-up	2.0	2.4	1.8	13.3	0.5	5.2	8.8	2.2
Imp. intermed. goods aug. tech in capital goods prod	1.2	1.4	0.8	29.0	0.6	1.1	1.5	3.2
Dom. intermed. goods aug. tech in capital goods prod	0.5	1.1	0.1	0.7	18.7	0.5	1.6	9.5
Imp. intermed. goods aug tech in cons.goods prod	1.2	1.4	0.8	29.0	0.6	1.1	1.5	3.2
Competitors relative price	2.8	2.3	15.6	3.5	3.7	2.9	13.0	2.9

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3   Simulating macro scenarios

When exogenous shocks hit economy in the DSGE model, GDP growth and other variables deviate from their balanced growth path (long-run steady state) but, in the case of temporary shocks, start reverting back to the steady state. As the DSGE model is forward-looking, responses to shocks take place immediately.

Stochastic simulation of the DSGE model proceeds as follows. Let t denote the starting period of the simulation. It is assumed that at time t all exogenous variables are at their steady state level. At period t+1 realisation of the error terms of the exogenous variables are randomly generated from their probability distributions and the time t+1 value of the exogenous variables are calculated from their respective equilibrium equations (see Table 2.1). The DSGE model is then solved for the new equilibrium. In period t+2, random errors for the exogenous variables are again generated and the new equilibrium is computed, and so on. The simulation is extended over a five-year period; ie to t+20 as the DSGE model is calibrated to quarterly data. The resulting stochastic paths of the model's endogenous variables represent the equilibrium responses of the economy to the set of unexpected shocks occurring at date t+j. For the illustrative purposes of the current paper 1000 such paths were simulated. In each period and for each simulation we keep track of the realisations of the endogenous variables which are needed both for the bank loan loss model (see section 4) and for describing economic developments more broadly in scenarios of interest.

In practice, the DSGE model is solved using an algorithm which is freely available in a package called Dynare.[11] Dynare also provides the stochastic simulation procedure. However, in the solution algorithm the model is linearized around the steady state. This may not be desirable for the purposes of prudential financial stability analysis which focuses on extreme outcomes because the linearization may smooth the outcomes. Non-linear solutions, though available in principle, would however be computationally much more time consuming and are left for future refinements of our approach.

To organise the simulated scenarios we rank them according to the cumulative development of the GDP growth over the given time horizon (five years in our case). By the same token we can form confidence intervals or the probability distribution of the GDP growth. Figure 2.3 depicts the simulated distribution of the annual GDP growth rate as an average over the five year horizon. The midpoint of the distribution is around 2% growth rate while the worst outcomes exhibit an average five-year growth rate of less than 0.5%. Over a five-year period this represents quite a poor economic development but, nevertheless, does not appear to match a development like the one experienced in Finland in the early

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[11] See http://www.cepremap.cnrs.fr/dynare/.

1990's. This indicates that given the shock processes and the model's current structure and parameter calibration, the current model may not yet be able to generate such stress scenarios which have in actuality been experienced in history.

Having kept track of the entire set of variables of interest in each scenario we may then proceed to ask what happened in the economy in the scenario that produced, say, the worst GDP development out of the 1000 simulations; ie in the scenario that corresponds to the 99.9th percentile of the GDP growth probability distribution over the horizon. Figure 3.1 displays the paths of the various variables of interest in this scenario. Panel a draws the realisation of the main shocks corresponding to 99.9th percentile scenario. Notice that this is just one example of the shock combination that has generated the paths of the model's endogenous variable's corresponding to 99.9th percentile of the GDP growth probability distribution. Of course, there can be a multitude of shock combinations that can generate as bad outcomes in terms of GDP growth. In this example, series of relatively large and persistent negative realisations of labour and capital augmenting technical change of intermediate goods producer firms cause rapid deceleration in output growth during the first periods of simulation. These shocks are combined with somewhat less important but still sizable negative shocks to the production technology of the final good firms. These negative shocks to final goods producing firms can be interpreted also as a 'taste' shocks that cause a final good firms to substitute, say, domestic intermediate goods with imported intermediate goods, driving the demand of domestic intermediate goods down further. Associated with a negative realisation of capital and labour augmenting technical change, there is an eventual increase in inflation, driven by the increase of firms real marginal costs. Initial decrease in inflation is due to the initial positive technology shock realisations, which feed into inflation slowly due to assumed nominal rigidities in price setting of the firms. Furthermore, there is an initial decrease in nominal interest rate, which reflects a large drop in output. Eventual increase in inflation that is due to persistent negative technology shocks contributes also to increase in nominal interest rate towards end of the simulation period. Finally, in this particular scenario, negative shocks to word demand of exports drive down exports and thus also demand for domestic intermediate goods and GDP. Roughly speaking this scenario could feature the events around 1990s recession in Finland, although clearly in smaller scale.
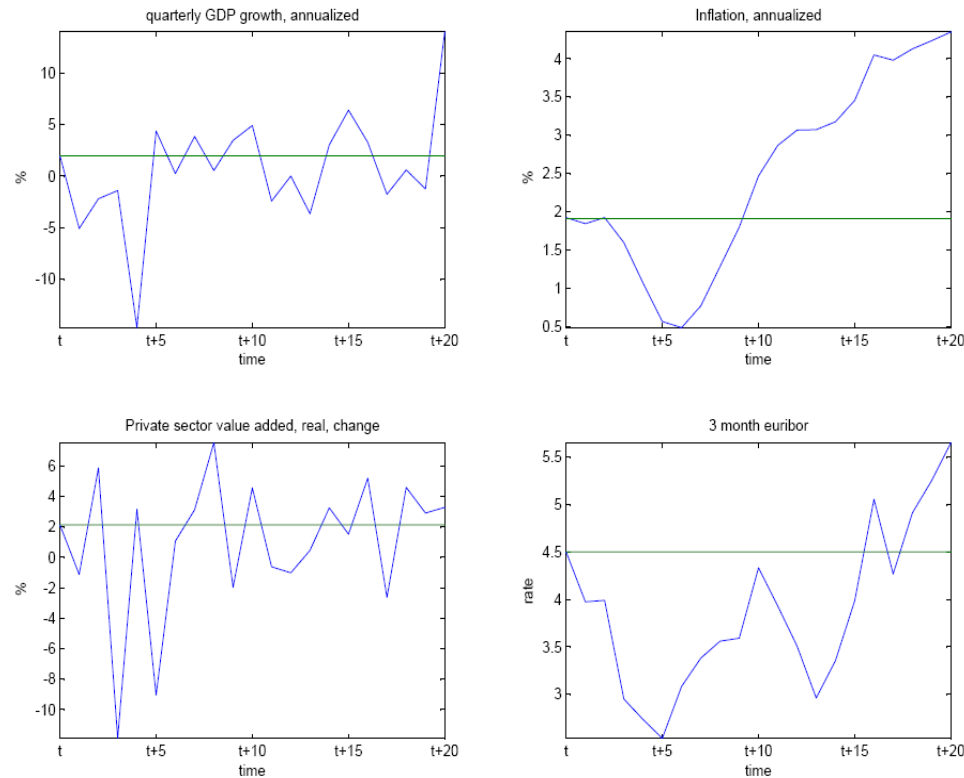
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Figure 3.1   **Developments of the various variables in the macro
                              scenario corresponding to the 99.9th worst
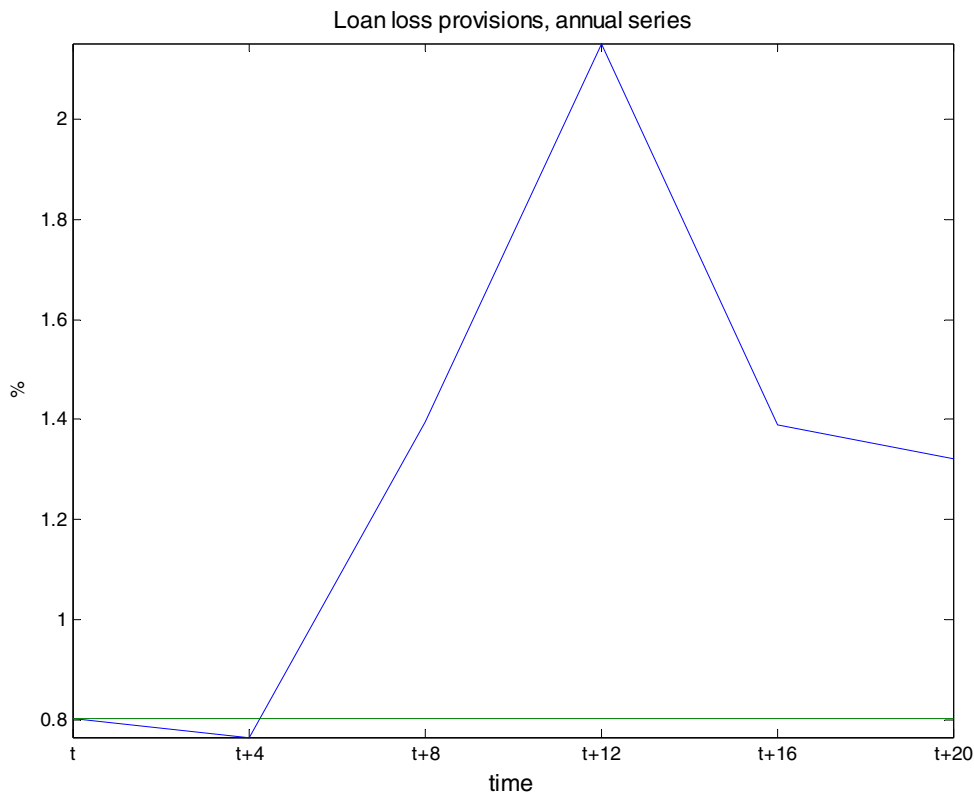   percentile of the GDP growth distribution**

a) exogenous shocks
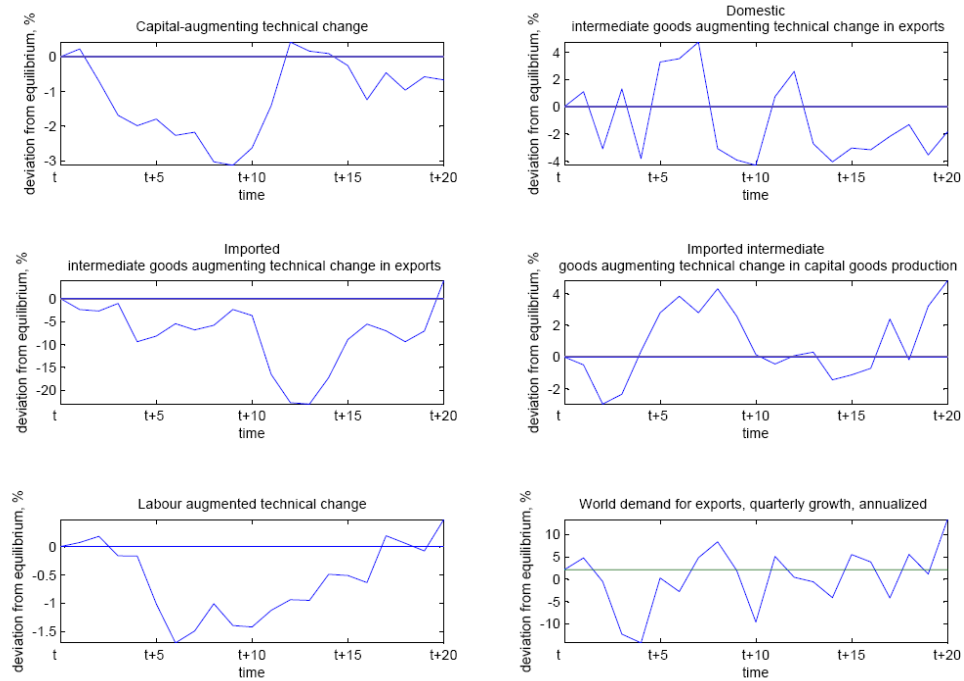
b) endogenous variables

c) Loan loss provisions

Loan loss provisions, annual series

4 Macro scenarios and bank loan losses

Simulation of macro scenarios and generation of the probability distribution of GDP growth, carried out in section 3, are interesting in their own right and potentially useful as complements to macroeconomic forecasting. However, the main motivation for this paper is in how the DSGE simulation can be used in financial stability analysis. To illustrate this, our simulation procedure includes a model for bank loan losses, which is based on certain endogenous macro variables of the DSGE model. The recent Finnish history provides an interesting case, previously studied eg by Sorge and Virolainen (2006) and Pesola (2001), as it is marked by huge bank loan losses in connection with the banking crisis in the early 90's.

We estimate the following model for Finnish banks' loan loss provisions using annual data over the period 1986–2005.

$$LLR_t = a_0 + a_1*LLR_{t-1} + a_2*RIRD_t + a_3*GDPGAP_{t-1} \qquad (3.1)$$

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where LLR is the ratio of loan losses to outstanding loans. The exogenous explanatory variables are chosen in the spirit of the DSGE model: RIRD is the deviation of real interest rate from its long term level and GDPGAP is the output gap, lagged by one year.

Table 3 gives the estimation results. All variables are quite significant and obtain the expected signs. Partly due to the presence of the lagged dependent variable the explanatory power is also very high. When real interest rate is above its long term level loan losses tend to be higher. The output gap in turn has a negative effect on loan losses; in economic booms loan losses are low. A caveat in this type of a linear model is that negative loan losses are also possible. This could be a problem especially in the scenario and stress testing type of analysis conducted in this paper. Hence further development the loan loss model may be needed in the future.

Table 4.1   **Banking sector loan loss model in the period 1986–2005**

Dependent variable: LLR$_t$	coeff.	robust st. err.	t-stat	p-value
constant	0,324	0,124	2,61	0,017
LLR$_{t-1}$	0,596	0,080	7,470	0,000
RIRD$_t$	0,068	0,024	2,780	0,012
GDPGAP$_{t-1}$	-0,195	0,069	-2,840	0,010
No. of obs.				
R-squared	0,908			
Durbin-Watson	1,320			

Figure 4.1 depicts the distribution of annual loan loss provisions as an average over the five year horizon, obtained by running the loan loss model in each macro scenario path simulated in section 3. In contrast with stylized facts of skewed loan loss distributions (see also Sorge and Virolainen, 2006), this distribution is quite normal. Moreover, it is not very dispersed, with worst case five-year average loan loss provisions reaching about 1.5% of total loans. Again, this appears to fall short of the Finnish banks' loan loss experience of the early 90's. Normality of the loan loss distribution is due to the linear specification of the loan loss model and the

linearization of the DSGE model. Obtaining a more realistic shape for the loan loss distribution is an issue we plan to revisit in future work.[12]

Figure 4.1 **Distribution of the average yearly bank loan loss provisions, as apercentage of total loans, over the five year horizon**

Loan loss provisions, yearly average

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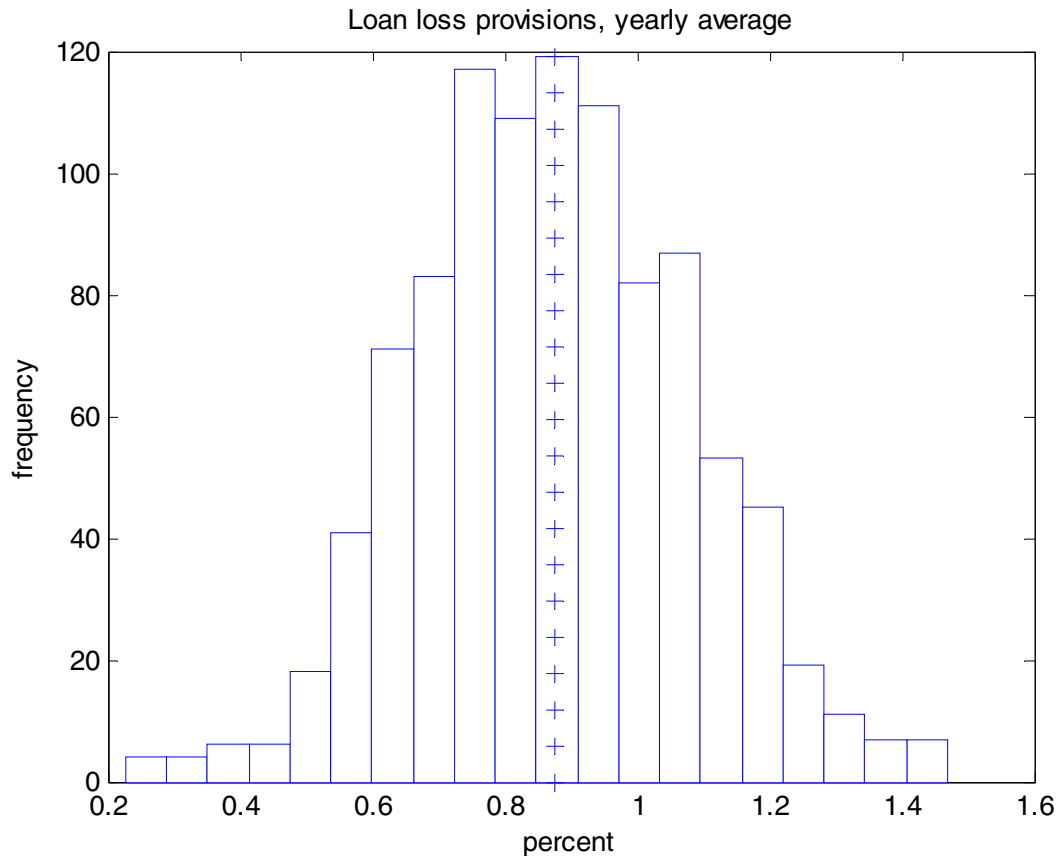
[12] One way forward could be to consider in the loan loss equation the type of cross-terms used by Pesola (2001), in which GDP and interest rate shocks are multiplied by the ratio of aggregate indebtedness of the private sector. This aims to capture the effect that the impact of a GDP or an interest rate shock on loan losses could be reinforced if the level of prevailing indebtedness is sufficiently high. Moreover, the aggregate indebtedness would have to be modelled simultaneously, probably as a function of the GDP growth, in order to track its path for the purpose of the simulated multi-period loan loss scenarios.

5   Conclusions

In this paper we have suggested an alternative way to do macro stress tests for financial stability analysis; namely, the use of a macro economic dynamic stochastic general equilibrium model to generate macro economic stress scenarios. This has been done via stochastic simulation of the DSGE model in order to produce the entire probability distribution of, say, GDP growth over a chosen horizon, and at the same time tracking the developments in other macro variables of interest. The macro scenarios have then been run through a separate banking sector loan loss model to produce the probability distribution of aggregate loan losses. A particular stress scenario corresponding to a certain tail percentile of the GDP growth distribution, and the corresponding loan loss scenario, has also been taken under more careful scrutiny. By this we wish to accentuate the analogy between our approach and value-at-risk analysis. Thereby one aim of the paper is to advocate a macro stress testing procedure which also provides for consistent comparison of risk assessments over time; this is achieved by monitoring changes in the loss at a given tail percentile of the loss distribution.

Our approach has been practical by nature and does not necessarily involve new conceptual insights compared to prior literate on macro stress testing (see the survey of Sorge and Virolainen, 2006, and the categorisations provided therein). Nonetheless, we believe it is useful to complement the arsenal of macro stress testing methods by making use of modern macro economic equilibrium models which are increasingly attracting the attention of institutional forecasters. For a central bank using a DSGE model in its economic analysis and forecasting it is particularly natural to utilise it also in financial stability analysis; hence bringing the two central areas of central bank analysis closer together and facilitating their mutual communication.

A number of issues remain in making the approach a better practical tool. For instance, the solution procedure of the DSGE model is linearized around the steady state. As a result, adverse macro scenarios may become artificially smoothed, which is not desirable from the perspective of (macro) prudential analysis.

Secondly, the macro scenarios in the present approach may be less severe than they should be because there are no feedback effects from the financial sector to the real sector. Introducing financial accelerator type propagation (see for instance Bernanke, Gertler and Gilchirst, 1999) mechanisms into otherwise standard DSGE models would possibly be a way ahead. While filling this challenging gap is deliberately left for future research, we believe our approach offers, nevertheless, a useful first step to combining modern general equilibrium macro models with financial stability analysis.

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