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RASMUS KATTAI

The links between private sector indebtedness and banking sector vulnerability: An Estonian case study

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PUBLICATIONS AND CONFERENCE PROCEEDINGS

I Chapters in monographs

1. Kattai, R. (2004). Analysing the Suitability of the Currency Board Arrangement for Estonia's Accession to the EMU. Modelling the Economies of the Baltic Sea. Ed. Paas, T., Tafenau, E., Tartu University Press, pp. 167–205.

II Articles in international journals

1. Hughes-Hallett, A., Kattai, R., Lewis, J. (2011). How Reliable are Cyclically Adjusted Budget Balances in Real Time? Contemporary Economic Policy (forthcoming).
2. Kattai, R. (2010). Estonia's Potential Growth Before and After the Crisis. Baltic Journal of Economics, No. 2, pp. 61–76.
3. Kattai, R., Lewis, J. (2006). Hooverism, Hyperstabilisation or Halfway-House. Describing Fiscal Policy in Central and Eastern European EU Members. Baltic Journal of Economics, No. 2, pp. 38–47.
4. Kattai, R., Kangur, A., Liiv, T., Randveer, M. (2003). Automatic Fiscal Stabilisers in Estonia. Baltic Journal of Economics, No. 1, pp. 93–115.

III Other research articles

1. Kattai, R. (2010). Credit Risk Model for the Estonian Banking Sector. Working Papers of Eesti Pank, No. 1, 42 p.
2. Kattai, R. (2010). Potential Output and the Output Gap in Estonia—A Macro Model Based Evaluation. Working Papers of Eesti Pank, No. 3, 22 p.
3. Hughes-Hallett, A., Kattai, R., Lewis, J. (2009). Can We Rely on Real Time Figures for Cyclically Adjusted Budget Balances? Working Papers of Eesti Pank, No. 2, 29 p.
4. Paabut, A., Kattai, R. (2007). Kinnisvara väärtuse kasvu mõju eratarbimisele Eestis. Eesti Panga toimetised, No. 5, 42 lk.
5. Kattai, R. (2007). Constants do not stay constant because variables are varying. Working Papers of Eesti Pank, No. 1, 23 p.
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8. Kattai, R. (2005). EMMA—a Quarterly Model of the Estonian Economy. Eesti Pank Working Papers, No. 12, 79 p.
9. Kattai, R., Lewis, J. (2005). Hooverism, Hyperstabilisation or Halfway-House. Describing Fiscal Policy in Central and Eastern European EU Members. Working Papers of Eesti Pank, No. 5, 16 p.
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13. Kattai, R. (2004). Ülevaade valitsemissektori plokist Eesti majanduse makromudelis. Eesti Panga toimetised, No. 2, 21 lk.
14. Kattai, R., Randveer, M. (2003). Automaatsetefiskaalsete stabilisaatorite roll Eestis ja Euroopa Liidus. Kroon ja Majandus, No. 4, pp. 22–29.
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4. Kerem, K., Keres, K., Randveer, M., Kattai, R. (2004). Fiscal Policy as a Determinant of Consumption Expenditure: The Estonian Case. Papers of the

Congress of Political Economists (COPE), 14th Annual International Conference presented by Estonian participants, 12-19 July, 2003, Mexico City, Tallinn: Faculty of Economics and Business Administration at Tallinn University of Technology, pp. 142–164.

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2. Modelling Credit Risk of the Estonian Banking Sector. 2nd International Conference, Economies of Central and Eastern Europe: Convergence, Opportunities and Challenges, Tallinn, Estonia, June 2010.
3. Potentsiaalne SKP Eestis: vaade minevikku ja tulevikku. Sotsiaalmajanduslikud ruumsüsteemid ja territoriaalne haldus, Prof. Salme Nõmmiku sajandale sünniaastapäevale pühendatud konverents, Tartu, Eesti, Märts 2010.
4. Early Warning or Just Wise After the Event? Tge Problem of Using Cyclically Adjusted Budget Balances for Fiscal Surveillance in Real Time. The Baltic Central Banks' Research Workshop, Vilnius, Lithuania, May 2007.
5. Using the State Dependent Dynamic Homogeneity Restriction in Error Correction Models of Converging Economies. International Atlantic Economic Society's annual conference, Philadelphia, USA, October 2006.
6. Using the State Dependent Dynamic Homogeneity Restriction in Error Correction Models of Converging Economies. Research seminar of De Nederlandsche Bank, Amsterdam, Netherlands, September 2006.
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8. Matching Theory and Practice: The Importance of Dynamic Homogeneity Condition in Macro Econometric Models of Catching-Up Economies. Spring seminar of Estonian Economic Society, Pühajärve, Estonia, March 2006.
9. Estimating VECM of a Converging Economy: Applying Time Varying Dynamic Homogeneity Condition. The 5th International Conference on Operational Research: Simulation and Optimization in Business and Industry, Tallinn, Estonia, May 2006.
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of the European System of Central Banks' Working Group of Econometric Modelling, Vienna, Austria, September 2005.

11. Hooverism, Hyperstabilisation or Halfway-House. Describing Fiscal Policy in CEE EU Members. Joint Seminar of Tartu University and Helsinki University, Helsinki, Finland, May 2005.
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"Knowledge speaks, but wisdom listens."

Jimi Hendrix

INTRODUCTION

Background and motivation for the research

The recent global crisis has highlighted the relevance of modelling tools which would permit the vulnerability of the financial sector to be assessed. The crisis triggered a new wave of model-building that sought to provide a deeper understanding of how the performance of financial institutions and the real economy are interlinked. The models that suddenly became particularly important can be divided into three main branches: macro-financial models [1], early warning models [2] and stress test modes [3]. Although the three model types serve different purposes, they share one thing in common: they are built to show how severe macroeconomic movements triggered by certain shocks affect the performance of financial institutions and the sector as a whole. The process under consideration is complex and has numerous transmission channels, containing feedback effects and looping impulses from the real sector to the financial sector and *vice versa*.

Regardless of the modeling approach, the key components for evaluating the soundness of an individual financial institution or the stability of the whole sector are the underlying *vulnerabilities* and *shocks* that might hit the economy. Shocks are not harmful *per se*, but recessions and stress on a financial system are caused by *interactions* between shocks and vulnerabilities (Banerji, 2010). Detecting and quantifying shocks is a particularly challenging task. It is easier to measure them *ex post*, but their appearance is almost always sudden and unpredictable. Therefore it is even more important to study and understand the role of the vulnerabilities.

The list of vulnerabilities is very long. Earlier studies have focused on, for example, the roles of GDP and fixed capital formation (Borio and Lowe, 2002), foreign borrowing of banks (Sirtaine and Skamnelos, 2007), unemployment and inflation rates (Babihuga, 2007), foreign direct investments (Festić et al., 2010), private lending to GDP (Männasoo and Mayes, 2009), money aggregates M1 and M2 (Hadad et al., 2007), the exchange rate (Marcucci and Quagliariello, 2008), the oil price (Simons and Rowles, 2009) and employee compensation (Kalirai and Scheicher, 2002), but these are just a few of a much wider range of vulnerabilities. Examining the role of every single vulnerability is extremely important if we are to understand upon what financial soundness and stability depend. This is because

[1] For example Meh and Moran (2010) and Gerali et al. (2010).

[2] See Borio and Drehmann (2009), Davis and Karim (2008b), Barrell et al. (2010) and Davis and Karim (2008a) for alternative approaches.

[3] Cardarelli et al. (2010), Alexander and Sheedy (2008), Graeve et al. (2008) and Alexander and Baptista (2009) represent some of the post-crisis attempts.

all the vulnerabilities have a cascading effect when it comes to the deterioration of the economic environment.

The rapid expansion of credit in many countries before the global crisis broke has put debt related vulnerabilities in the spotlight. There is a growing body of literature on the indebtedness of the private sector and the severity of economic downturns. Although Giannone et al. (2010) interestingly find that output performance is better in countries with deeper financial markets, this stands out as an exception rather than the rule. The bulk of the literature relates higher private sector debt to poorer economic performance in crises. For example, Uusküla et al. (2005) find that greater indebtedness makes downturns longer and more pronounced. Lane and Milesi-Ferretti (2010) examine the effects of credit growth and show that high pre-crisis credit growth may be associated with a deeper recession. If it is accepted that there is a connection between the debt level and macroeconomic volatility, then the amplified response to shocks must have direct consequences on the resilience of financial institutions. This idea is supported by Männasoo and Mayes (2006) who show that banks fail because of the deteriorating state of the macroeconomy.

The body of literature that examines the links between private sector indebtedness and the vulnerability of the financial sector typically focuses on the episodes of banking crises. A majority of the studies use panel data estimation to draw conclusions based on that evidence. The shortcoming of panel data analysis is that it neglects the internal structure of the economy and therefore lacks the power to address some important issues, notably: what is the mechanism through which banks have become more vulnerable; and has the vulnerability increased equally to all kinds of shocks? Another important issue which has not been addressed by the previous studies is whether increased exposure to households has a different effect on the banks vulnerability than does increased exposure to companies?

The present thesis proposes to use a stress test framework which incorporates a structural macro model and the credit risk model for deeper understanding how the changed indebtedness of the private sector may affect vulnerability of the banks. Both models are built on Estonian data, which offer a good example in four ways. Firstly, the Estonian financial sector is highly bank-oriented, and the presence of the insurance and securities markets and of investment funds is almost negligible. Therefore a model of the banking sector alone covers almost all of the financial sector. Secondly, banks hold about 90% of their assets in loans, and so the risks for the banking sector and the whole financial sector are very much concentrated in credit risk. Consequently an assessment of financial sector vulnerability can be based solely on an evaluation of credit risk without sacrificing representativeness of total risk. Thirdly, Estonian banking sector is extremely concentrated. The four largest banks share about 91% of the credit market which makes it easier to build a credit risk model on micro data. Fourthly, Estonia experienced rapid financial deepening through credit expansion with the annualized credit growth rate reaching 62% for households credit and 48% for corporate credit in 2006 (Eesti Pank, 2006). The country offers data on the macro economy at the extremes of low and high levels of indebtedness within a time frame of only six years. Since 2004, that is since the start of the major expansion of credit, households and companies have increased their bank credit ratio from 20% to 55% and from 30% to 65% of GDP respectively. [4]

The rapid growth of indebtedness was largely a result of the structural changes in the banking market during the past ten years. [5] The banking sector has become mostly foreign-owned and many banks have become simply local branches. Foreign ownership has made it easier for the banks to get external funds to finance new loans in Estonia and that combined with the low interest rate environment boosted lending and tightened competition between the banks which were seeking ways to enlarge their market share. This process resulted in private sector indebtedness more than doubling between 2004–2009. Given these developments it is natural to ask whether the increase in private sector indebtedness has made households and companies more vulnerable to the various shocks that may hit the economy. If so, then banks have probably also become more vulnerable as their borrowers have become more fragile.

The aim and tasks of the research

The aim of the present thesis is to develop a modelling tool that would be appropriate for investigating banks' vulnerability conditional on the private sector indebtedness. The required tasks originate from the following considerations. Analysis of banking sector stability is most meaningful when individual banks are separated, so risk assessment should be carried out at the micro level. Financial sector data at this level of disaggregation is very detailed and it becomes highly inefficient, or even implausible, to merge this data with the comprehensive model of the macro economy into one stress-test model. The route taken in the present thesis is to create two separate models. The first task of the thesis is to set up and estimate a model for credit risk assessment. The second task is to set up and estimate a macro-econometric model to provide scenarios for the credit risk

[4] The total debt of companies also includes intra-group foreign loans and other foreign loans. With these liabilities corporate debt reached 90% in 2009 (Eesti Pank, 2009).

[5] Johnston and Sundararajan (1999) argue that restructuring the banking sector itself can lead to a change in the associated vulnerabilities. Their finding suggests that private sector indebtedness is expected to gain relevance after banks have decided to increase their credit exposure to households and companies.

model. The third task is to use both models for the assessment of the private sector indebtedness and to compare the results to the findings provided in the literature.

Research methodology and data

The credit risk model of the Estonian banks and the macromodel of the Estonian economy together form a stress test system, linking macroeconomic variables and the banks' balance sheets. The role of private sector indebtedness as a potential vulnerability for the banks is examined by scenario analysis. Scenario analysis is one of the possible usages of the stress test system besides sensitivity analysis, extreme value analysis and maximum loss analysis. Macro model is used to generate five hypothetical shock scenarios, showing how the economy copes with negative shock impulses. These scenarios are then repeated at different levels of private sector indebtedness to see, whether there are any changes in the response magnitudes. The simulation results, conditioned on different levels of private sector indebtedness, are then taken to the credit risk model and mapped to credit quality of the banks. The last step is supposed to indicate, whether vulnerability of the banks has changed with their increased exposure to the private sector.

The credit risk model built in the thesis belongs to the group of loan performance/balance sheet models, which regress loan quality indicators on the underlying state of the macroeconomy. The credit risk model makes use of the non-performing loans and loan loss provisions, and the model also extracts the non-observable default rates for the three credit sectors: consumer credit, mortgages and corporate credit. Separating the three distress measures and modelling them in a structured fashion sheds light on the multi-step process of loan loss generation, the feature that is ignored in the literature.

Financial data for the credit risk model originates from the Eesti Pank internal dataset and covers bank level data on credit exposures, non-performing loans and loan loss provisions. The dataset also disentangles three credit sectors: consumer credit, housing loans (mortgages) and corporate credit for every bank at a monthly frequency. Although this data exists for all the banks in the market, the credit risk model is built in a way that separates the four major banks and the rest of the sector. This is a sufficient level of disaggregation given the high concentration within the sector. Although the credit risk model is built on bank-level data, the confidentiality of the data means that nothing more than the aggregate series can be represented throughout the thesis. Macro-economic data is provided by the Estonian statistical office Statistics Estonia.

The macro model is built in the spirit of the traditional medium scale macro-econometric models, with some departures from the standard design. The novelty in the structure of the model lies in the explicit modelling of the banking sector and the bank credit channel. Credit to households and companies is divided into consumer credit, mortgages and corporate credit, so as to match the structure of the credit risk model and to keep the models mutually consistent. Credit equations bring financial frictions into the model in the form of the banks setting a maximum interest payment cost relative to the income of the obligor. The financial sector block helps to explain the earlier boom in the economy through significant capital inflows and credit expansion. The same mechanism can be exploited to match the downturn, which followed the boom.

The macro model is relatively big, consisting of approximately two hundred equations and identities. These equations and identities are used to characterise all the segments of the economy: households, companies, government, banks and main trading partners. The model economy is built to fit most important characteristics of Estonia, a country that has a small, very opened catching up economy with no active independent monetary policy.

As is typical of traditional macroeconometric models, most of the equations are built in the form of the error correction model. The merit of this approach is that it distinguishes between the long and the short run behaviours of the economic processes. This is especially crucial in the context of a catching up economy, which faces a number of structural shifts and instabilities.

The data used to build a macro model originates from various sources. The majority of the data are provided by the Estonian statistical office, and they include national accounts data, company statistics, price data and wages and salaries. The Estonian Institute of Economic Research provides data on confidence indicators, which are also used in the model as an input. Real estate prices originate from the Estonian Land Board database, while several time series are from the Eurostat database.

Research contribution

The present thesis contributes to the literature on financial stability by a specialised investigation of the role of private sector indebtedness in a customised stress test framework. In order to make that contribution the thesis develops several new features for modelling economic processes.

The first set of methodological advancements concern macro-econometric modelling. The macroeconometric model of the Estonian economy has several advancements and novelties compared to other models of the same class. The first and probably the most influential advancement is the addition of the financial sector to the model. Without a distinct bank lending channel it would be impossible to use the macro model to analyse the effects of financial deepening. The way the bank lending is introduced makes it possible to catch the financial deepening and also the the financial frictions which relate financial variables to the business cycle. This is crucial for the study of shock propagation mechanisms and the role of the banking sector in them.

Secondly, the thesis introduces the concept of time varying dynamic homogeneity restriction (TV-DHR). [6] This has been found to be an important feature for modelling catching-up economies. These economies exhibit a fall in the growth rates of economic variables as convergence brings them closer to the more advanced countries. TV-DHR becomes an essential part of the macro model in such cases in order to ensure consistent short and long run behaviour for behavioural equations. A violation of the dynamic homogeneity condition results in diverging projections for the dynamic part and the co-integration relationship of an error correction model.

Thirdly, the macro model includes a new type of fiscal rule to close the model. [7] The novel feature of the rule is that it has government adjustment on the expenditure side while targeting a certain budgetary position. The widespread alternative in similar macro models is a rule which makes government to adjust tax rates so that the fiscal target would be met. However, this is considered to be inappropriate because in reality there is no evidence that governments change tax rates in a cyclical fashion as the rule predicts.

The second set of advancements is related to credit risk modelling, and it contributes to the literature in two different ways. [8] Firstly, the credit risk model introduces a structural dynamic equation specification for non-performing loans which segregates the two subprocesses of generating the new non-performing loans and recovering the previously non-performing loans. The implied structure of the equation permits extraction of the missing data on the default rates, which becomes useful when there is no official data. It is shown that the information conveyed by the extracted default rates on the payment conditions of the banks' obligors payment is different from the information given by the non-performing loan rate, contrary to what is sometimes suggested in the literature. The difference emerges from the time varying recovery rate, which is dependent on the general macroeconomic environment.

Secondly, the model imposes structure on non-performing loans and loan loss provisions in order to give a consistent view of two distress measures. The richer structure of the credit risk model brings the model closer to the actual loan loss generation process. The data on non-performing loans and loan loss provisions are different in their natures. The first is more tightly linked to the underlying

[6] The concept is initially introduced by Kattai (2007).
[7] The rule is developed in Kattai (2004b).
[8] The model is based on Kattai (2010a).

macroeconomic conditions while the latter is to a large extent dependent on the decision taken by the banks as to how to account for the potential losses. This makes non-performing loans easier to model, although the main interest lies in the provisioned losses of the banks. However, it is more transparent to condition loan loss provisions on the non-performing loans because treating both of them together within the same framework gives a more comprehensive picture of the credit quality of the banks.

Both models, the credit risk and the macro-econometric model, introduce the interest rate re-pricing mechanism, which mimics how banks regularly revise lending rates. The mechanism is useful for accounting for the transmission of monetary policy decisions. It has the property of sustaining the monetary policy impacts, letting them transmit into the economy only gradually.

The synergy of the two models makes it possible to quantify how indebtedness of the private sector affects the vulnerability of the banking sector. It offers a deeper, structural understanding of how the vulnerability is affected, which is an important advance from panel-data-based evidence.

Structure of the thesis

The thesis consists of five chapters which build sequentially on top of each other (see Figure 1). The first chapter begins with a review of the literature on linkages between private sector indebtedness and the vulnerability of banks or banking system instability. This is followed by a detailed overview of the theoretical background and the empirical practices of stress testing, a framework which is used in the thesis to add an alternative view to those covered in the literature. As will be discussed, the field of possible stress test frameworks is very wide. The demands on the stress test system narrow down the initial number of frameworks, and this can then be further restricted by the availability of the data. The section ends with a discussion about which framework would be the most appropriate given the goal of the present thesis and the data limitations.

The second chapter describes the construction of the credit risk model. Firstly it provides a bird-eye view of the Estonian banking sector, highlighting its most characteristic features. It also shows a historical picture of the distress measures but does so only at the most aggregate level to preserve the confidentiality of the bank-level data. The main body of the section is devoted to setting up and estimating the credit risk model. Finally, sensitivity analysis is performed to assess the relative importance of the selected macro indicators on which the quality of the banks' credit depends.

The third chapter contains elements for setting up and estimating the macro-model for Estonia. The section starts off by giving a short overview of the most essential features and the main relationships of the different sectors of the economy, and this is followed by a presentation of the theoretical underpinnings of the core model. The rest of the section is divided into subsections, each of which presents an econometric estimation of the behavioural equations for a particular sector of the economy.

The fourth chapter firstly presents five shocks that may realistically hit the economy. Although the total number of shocks is low, they are chosen to cover heterogenous sources of origin, the domestic, foreign, real and financial sectors. The shocks are put into the macro model to produce fully consistent hypothetical scenarios where the real and financial variables interact in accordance with the historical structure of the economy. The scenarios generated are used to analyze the properties of the macro model and to understand how the shocks are propagated in the model economy. Then the same shocks are implemented by gradual shifting of the level of indebtedness in three credit sectors, one at a time. This experiment tests whether the sensitivity of macroeconomy to shocks differs at varying debt levels. The scenarios produced are then taken to the credit risk model which reveals whether the credit quality of the banks has become more responsive to the likely shocks.

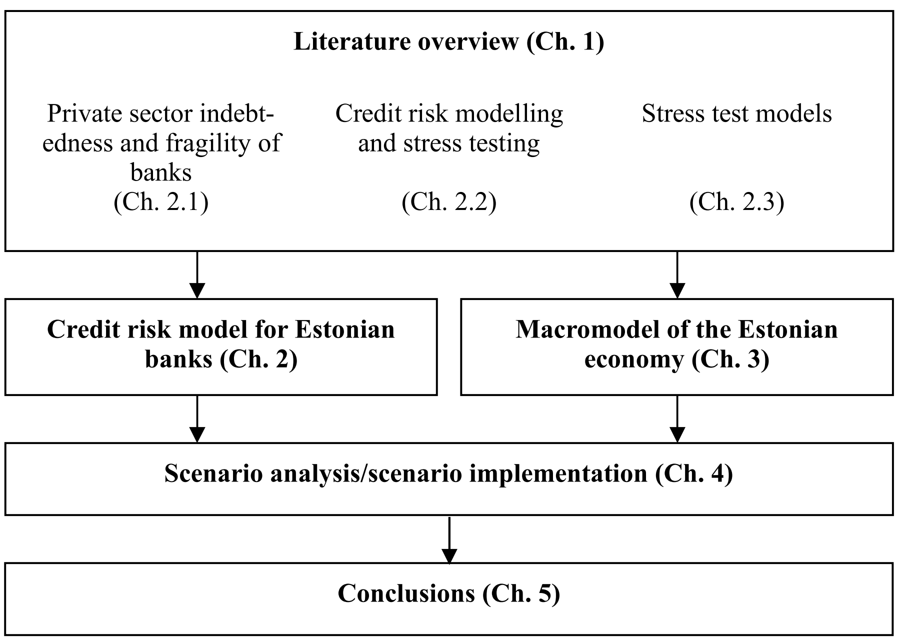

Figure 1: Structure of the thesis. Source: author.

Lastly, the fifth chapter summarises the main findings of the research. The findings suggest some policy recommendations which would help in maintaining a sound banking system. The concluding chapter also charts possible future work.

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1. EMPIRICAL AND THEORETICAL BACKGROUND FOR THE RESEARCH

"Essentially, all models are wrong, but some are useful." [9]

George E. P. Box

1.1. Literature on the links between private sector indebtedness and banking sector vulnerability

There are several theoretical explanations of how the level of private sector indebtedness, defined as bank credit to the non-bank private sector as a ratio of GDP, might affect the soundness of banks. The credit exposure of banks to the private sector opens them to credit risk, which is triggered by a worsening of the payment performance of borrowers (households and companies) in stressful times. This affects the banks as lenders through the deterioration of the assets on their balance sheets. A significant fall in the quality of its assets has serious consequences for a banks' profits and capitalisation, threatening the solvency of the institution. [10]

In principle a distinction can be drawn between the impacts of the level and growth of indebtedness, although of course they are interrelated. In the finance-growth nexus credit growth and financial deepening are expected to support economic growth. However, an overly rapid increase in credit may be a source of macroeconomic imbalances and banking sector distress (Duenwald et al., 2005). There are many papers showing that rapid private sector credit growth precedes bank distress or banking crisis, see for example Demirgüç-Kunt and Detragiache (1999), Kaminsky and Reinhart (1999), Duttagupta and Cashin (2010), Wong et al. (2010), Erdinç (2010) and Büyükkarabacak and Valev (2010). [11]

Credit growth may hurt the future payment performance of the borrowers and the profitability of the banks if the credit expansion fails to deliver the expected shift in income growth (Büyükkarabacak and Valev, 2010). If economic agents

[9] Box and Draper (1986).

[10] von Goetz (2009) finds that bank distress is mostly caused by the deterioration of the quality of the banks' assets.

[11] At the same time, although rapid credit growth has been one of the most robust leading indicators for bank distress, the majority of lending booms have not led to banking crises and the average estimated likelihood of a banking crisis following a lending boom is about 20 percent (Duenwald et al., 2005).

incorrectly perceive a temporary economic boom as a long term shift in potential output and thus their income, then there is a threat of the credit to GDP ratio exceeding the equilibrium level, violating its consistency with the underlying fundamentals. The private sector would suffer from relatively higher debt servicing costs as a proportion of income, making an individual borrower more likely to default in the occurrence of a negative shock. Consequently banks' assets become more sensitive to adverse shocks and credit risk rises. [12]

The previous argument implies that the financial deepening which follows the development of the fundamentals of an economy should not build up macroeconomic imbalances or increase credit risk. [13] However, bank distress is never caused by excessively rapid credit growth *per se*, but rather by the level of debt that has accumulated during the boom. Although a boom-generated increase in indebtedness may have a stronger influence on banks' vulnerability due to weakened lending standards (Duenwald et al., 2005), banks may become more open to credit risk even if financial deepening has been in line with macroeconomic fundamentals. In both cases higher indebtedness is associated with a relatively larger share of financial responsibilities in the borrower's budget. Assuming that borrowers have autonomous expenditures, a larger share of financial costs in the budget raises the likelihood of them not obeying their contractual agreement with the lender in the event of an unfavourable shock, *ceteris paribus*.

Under certain circumstances higher indebtedness may also be associated with increased soundness among banks. If a higher debt level indicates a more developed financial sector where borrowers have access to the counter-cyclical bank lending channel, it would be easier for the private sector to absorb unpleasant shocks. Therefore countries with higher debt levels might experience lower credit risk. Demirgüç-Kunt and Detragiache (1998) oppose this idea by saying that higher indebtedness, also meaning higher degree of financial liberalization [14], increase the opportunities for excessive risk taking by banks and therefore increase the instability of the financial sector.

Existing studies which investigate how private sector indebtedness is related

[12] On top of credit risk, rapid credit expansion could in principle also trigger current account imbalances (macro risk). If the credit growth is financed with foreign capital then foreign exchange exposure opens banks to currency risk. A country which relies on foreign capital may also suffer from sudden reversal of capital inflows. These risks are mutually reinforcing and create boom-bust cycles of credit and asset markets. (Erdinç, 2010)

[13] See Égert et al. (2006), Kiss et al. (2006) and Boissay et al. (2007) for estimation of the equilibrium debt. Cottarelli et al. (2005) for example demonstrate that it was relatively easy to detect excessive lending and misalignment with the fundamentals in Central and Eastern Europe and in the Balkans even in the beginning of the credit boom.

[14] For example Pill and Pradhan (1995) find that private sector indebtedness is the best indicator of financial liberalisation using a sample of Asian and African economies.

to the soundness of the financial system belong to the strand of banking/financial crisis literature. This strand of literature typically estimates a panel logit or a panel probit model on macro data where private sector indebtedness appears as one of the explanatory variables of distress events. [15] One of the seminal works in this vein is by Demirgüç-Kunt and Detragiache (1998) in which they estimate a multivariate logit model and show that countries with larger banking sector debt exposure to the private sector are more likely to experience banking crises. Their definition of a banking crisis, which has been adopted by many later studies, states that there is distress when at least one of the following conditions is satisfied: (a) the non-performing loan ratio exceeds 10%; (b) the cost of a rescue operation is at least 2% of GDP; (c) problems in the banking sector result in a large scale nationalisation of banks; and (d) there are excessive bank runs or frozen deposits or deposit guarantees are used. It is notable that the crisis definition includes somewhat incomparable elements. If non-performing loans pass 10% mark, it does not necessarily imply that well-capitalized banks have to default, whereas rescue or nationalisation indicate clear potential for default if there is no help from the government. This implies that the different crisis cases in the data-set may not all be equally severe.

Domaç et al. (2003) build a comparable model in which they use indebtedness and credit growth separately to describe distress as it was defined by Demirgüç-Kunt and Detragiache (1998). They find that high credit growth raises the likelihood of a banking crisis, especially in economies with a higher debt to GDP ratio. Klomp (2010) also separates indebtedness and credit growth and finds a statistically significant relationship between banking crises and the growth of credit but not between crises and the level of credit. However, he claims that although the estimated coefficient for indebtedness is not statistically significant on average, indebtedness is significant in individual crises.

Komulainen and Lukkarila (2003) and Büyükkarabacak and Valev (2010) get positive relationship between indebtedness and distress by estimating panel probit model and panel logit models respectively. Both papers borrow their crisis definition from Kaminsky and Reinhart (1999): a crisis occurs when (a) a bank run leads to the bank's closure, merge or takeover by the public sector or (b) there is no bank run but there is still closure, merge, takeover or large-scale government assistance. Männasoo and Mayes (2009) use data on 600 banks, which are defined as being in distress if at least one of the following conditions is met: the bank (a) is bankrupt, (b) is dissolved, (c) is in liquidation or (d) has negative net worth. Their estimation of a survival model interestingly shows that indebtedness is positively

[15] Indebtedness in more rarely used to explain financial crises than its growth since the latter is generally believed to be a better predictor of the crisis event.

related to distress but only in more advanced countries. Wong et al. (2010) and Čihák and Schaeck (2010) on the other hand detect no increased fragility of the banking sector that would be caused by an increased debt ratio.

Ali and Daly (2010) offer an alternative view of the issue. They use the indebtedness of the private sector to describe the average default rates of borrowers in the Australian and U.S. economies. Since the soundness of the banks is directly dependent on the performance of the borrowers, the positive relationship that they find also confirms that indebtedness increases credit risk for banks. Fidrmuc and Hainz (2010) get even deeper into the data and estimate panel logit and panel probit models on the micro data. Evidence from 700 individual loan contracts of the small and medium size enterprises (SMEs) in their dataset confirms that the probability of default for an individual borrower rises with higher indebtedness (see Table 1 for more details of the listed papers).

The study by Fidrmuc and Hainz (2010) is of great value because it concentrates only on the effect of corporate sector indebtedness. Büyükkarabacak and Valev (2010) state that differentiating between households and companies is crucial because of their different reasons for borrowing. Corporate credit raises capital accumulation, productivity and economic growth, whereas household credit smooths consumption in the short run and does not affect long run growth. It follows from the introductory part of this section that rapid growth in corporate credit is therefore less likely to deliver wrong expectations of future income, compared to a boom in the household lending, and hence it is potentially less important in raising credit risk as the debt stock builds up. Büyükkarabacak and Valev (2010) show that an increase in household indebtedness of one percentage point increases the probability of a banking crisis by almost twice as much as does the same increase in corporate sector indebtedness.

The majority of the studies discussed here emphasise the distress-inducing properties of the private sector indebtedness, but the modelling approaches used in them have some limitations and weaknesses, mainly related to the interpretability of the results. Firstly, the models do not provide any hard evidence of the mechanisms or channels through which banks' portfolios become more sensitive. The stress test framework that is used in the present thesis overcomes this problem by behavioural modelling of the household, corporate and banking sectors. The structural macro-econometric model is expected to capture the main transmission channels between the sectors.

Secondly, housing and corporate credit are treated equally in almost all of the earlier studies, except Büyükkarabacak and Valev (2010). These two types of credit are separated in the present thesis and this is then taken further, as household credit is divided into consumer and mortgage loans, which are very different in nature and are likely to have different impacts on credit risk and the sound-

Table 1: Studies which investigate the link between private sector indebtedness and banking sector distress

Paper	Distress definition	Model type	Coverage	Period	Effect
Demirgüç-Kunt and Detragiache (1998)	CDM[1]	Panel logit	30 countries	1980–1994	positive
Domaç et al. (2003)	CDM[1]	Panel logit	43 countries	1980–1997	positive
Klomp (2010)	CDM[1]	Panel logit	110 countries	1970–2007	positive/no
Wong et al. (2010)	CDM[1]	Panel probit	11 countries	1990–2007	no
Čihák and Schaeck (2010)	CDM[1]	Panel logit	100 countries	1994–2007	no
Komulainen and Lukkarila (2003)	CMTA[2]	Panel probit	31 countries	1980–2001	positive
Büyükkarabacak and Valev (2010)	CMTA[2]	Panel logit	38 counties	1990–2006	positive
Männasoo and Mayes (2009)	BDLN[3]	Panel cloglog	600 banks	1995–2004	positive/no
Ali and Daly (2010)	ADB[4]	Logit	2 countries	1995–2009	positive
Fidrmuc and Hainz (2010)	DoSME[5]	Panel logit/probit	700 loans	2000-2005	positive

[1] CDM—combined distress measure: the event classifies as distress if at least one of the following conditions is satisfied: (a) non-performing loan ratio exceeds 10%; (b) the cost of rescuing the banking sector is at least 2% of GDP; (c) banks are nationalised; (d) there are excessive bank runs or frozen deposits or deposit guarantees are used (originates from Demirgüç-Kunt and Detragiache (1998)). [2] CMTA—a bank is in distress if one of the following criteria is met: (a) closure, (b) merge, (c) takeover or (d) large-scale government assistance (definition originates from Kaminsky and Reinhart (1999), episodes originate from Reinhart and Rogoff (2008) and Laeven and Valencia (2008)). [3] BDLN—bank is in distress if one of the following criteria is met: it (a) is bankrupt, (b) is dissolved, (c) is in liquidation or (d) has negative net worth. [4] ADB—aggregate default of borrowers. [5] DoSME—small and medium size enterprises' default.

ness of banks. Mortgages are more likely to interact with real estate prices and generate booms, which have been shown to increase the probability of distress. Consumer credit, on the other hand, could be used to smooth cyclical implications and thereby is expected to have a smaller impact on probability of distress.

Thirdly, distress typically enters the estimated models in a bivariate form, where the crisis either takes place or it does not. The present thesis uses non-performing loans and loan loss provisions to measure distress in the banking sector. The merit of this is the continuos grading of the stress on the banks, which do not necessarily have to move into crisis as was presumed in the papers reviewed, but rather the quality of their assets may simply have become more sensitive to unfavourable shocks over the course of financial deepening.

1.2. Credit risk modelling and stress tests

Essentially the concept of stress testing is fairly simple: what is the expected portfolio performance given the current portfolio and specific scenario? (Breeden, 2008). According to the Bank for International Settlements (BIS) stress testing is a generic term to describe various techniques for exploring the potential vulnerability of financial institutions to exceptional but plausible events (Committee on the Global Financial System, 2001). In other words, the main interest lies in testing banks' portfolios under severe conditions to see whether individual institutions can cope with increased risks and bear the higher losses which could emerge without becoming insolvent.

The beginning of systematic stress testing dates back to the early 1990s, when banking supervisors and regulators sanctioned it as an important component of market risk monitoring (Blaschke et al., 2001). Stress tests are widely considered to play a central role in financial stability monitoring and in avoiding crises. There are serious consequences at stake, as research has shown that output losses resulting from a financial crisis are about 9% on average (Reinhart and Rogoff, 2009), which is substantially higher than the losses caused by non-bank crises (Haugh et al., 2009). World Economic Outlook (2009) reports a historical average loss of 10% but also emphasises substantial variations between countries, as the middle 50% of crisis episodes caused losses ranging between -26% and $+6\%$.

Interestingly Cerra and Saxena (2008) find that it is higher income countries that have faced greater output contractions and the consequences of such a crisis are milder in lower income countries. There is clear evidence that recessions are deeper and longer when they are associated with deep financial disruptions (Claessens et al., 2010b) or with credit crunches and house price busts (Claessens et al., 2009). The most recent evidence shows that the impact on macroeconomic variables can be traced for a decade (Reinhart and Reinhart, 2010). In this light the importance of regularly monitoring risks is evident. Thorough risk analysis may give early warning signals, indicating vulnerability in the financial sector, and encouraging the regulatory body to take precautionary action to prevent the crisis. [16]

A leading role in developing appropriate tools has been played by the IMF. In May 1999 the IMF, in co-operation with the World Bank, instituted the Financial Stability Assessment Program (FSAP) to promote soundness in the financial systems in member countries (Blaschke et al., 2001). The ultimate goal of the programme is to reduce the number of crises worldwide by investigating the weaknesses of each country's financial system and suggesting remedial policies (Kalirai and Scheicher, 2002). As a positive consequence, many authorities have introduced or developed further the practice of stress testing as a part of the FSAP (Foglia, 2009). Since risk modelling and stress testing have mainly been in the sphere of interest of central banks or financial supervisory agencies, most of the related literature originates from these institutions.

The BIS divides stress tests into sensitivity tests and scenario analysis. [17] The sensitivity test is a univariate approach for assessing the impact of one risk factor (vulnerability) on the financial data. Analysing one shock in isolation has advantages and disadvantages. The strengths of the sensitivity analysis are that (a) it conveys important information on the performance of the model itself and (b) it outlines the most important factors that drive clients into insolvency. The most crucial drawback of the approach is that it ignores the simultaneity or interdependence of risk factors.

Scenario analysis is a more complicated way of exploring the risks. It provides an integrated view of economic fundamentals and financial data, as risk factors are projected to evolve in a consistent manner. Due to its multivariate nature, scenario analysis is generally believed to be more realistic than sensitivity tests, since in reality all the risk factors interact (van den End et al., 2006). Literature on this subject distinguishes between two types of scenario: historical and hypothetical. Historical scenarios draw their financial data from macro episodes that have already occurred, whereas hypothetical analysis tries to see what would happen in circumstances that have never occurred before (Hadad et al., 2007). Hypothetical scenarios are more flexible because they are not restricted in their formulation of potential events (Blaschke et al., 2001). It may be difficult to justify a hypotheti-

[16] Early warning is an important function of the monitoring and stress testing procedure. Frydl (1999) shows that the level of loss that materialises depends on the speed with which regulatory bodies resolve the crisis. The speed of action depends heavily on how quickly the authorities are warned about possible problems and the proportion of losses that can still be avoided.

[17] The definitions and meanings of stress test, scenario analysis and sensitivity analysis vary in the literature. Here and onwards the definitions of the BIS are preferred.

cal scenario without any historical comparison, but they are realistic in the sense that new shocks may have nothing in common with what has been experienced in the past. Hypothetical scenario analysis becomes the only option when structural breaks in the financial system, such as deregulation, consolidation or a change of currency, have annulled the information content of past episodes (Quagliariello, 2009). [18]

Quite often two additional techniques for stress testing are defined in the literature. Committee on the Global Financial System (2000) disentangles extreme value theory and maximum loss approach, also known as worst case scenario analysis. Extreme value theory, as its name suggests, deals with extreme events in financial markets. Rather than looking at the distribution of all returns, it concentrates on the distribution of extreme returns, which are considered to be independent over a long time period (Longin, 1999). The maximum loss approach finds the combination of market moves that would cause the greatest loss to the portfolio (Committee on the Global Financial System, 2000).

Occasionally contagion analysis is defined as the fifth type of stress test. This approach quantifies the transmission of the failure of one financial institution to others and its possible impact on the whole financial system. Moretti et al. (2008) give an overview of the different types of stress test used in the IMF's FSAP and show that contagion analysis has become more common over the years. The increased popularity of the method stems from the tightened linkages between financial institutions within each country and across borders. Alessandri et al. (2009) refer to an unpublished study by Gai and Kapadia (*mimeo*, Bank of England) which finds that the effect of the greater connectivity of financial networks is twofold. Firstly, it enhances risk sharing and therefore lowers the likelihood of crises actually happening, but secondly, if a crisis does occur, its impact would be more severe. This effect is reinforced by financial innovations and general macroeconomic stability (Gai et al., 2008).

Typically scenario analysis requires two or three kinds of model for assessing credit risk. In the first stage of scenario analysis a model which links the stressed variable(s) to the key macroeconomic variables, a macroeconomic model, is used to produce scenarios. These models quite often exclude the financial sector. In this case satellite models can be used to map the macro environment to the key financial variables. Satellite models can be built using data from individual banks

[18] Matz (2007) summarises that sometimes the term "scenario" is used to indicate the deterministic path of the underlying macro variables, while "stress test" is considered to indicate their probabilistic paths (and therefore also the values for the balance sheet items). In other cases "stress test" refers to a univariate and "scenario" to a multivariate analysis. According to the third set of definitions the term "sensitivity test" is used to distinguish univariate analysis from the multivariate analysis labelled as "stress test".

or from the aggregate data. The inclusion of the financial sector within one single model is preferred as it will consider the feedback from the financial sector to the real economy.

In the second stage the credit risk model links stress measures, such as non-performing loans, actual or provisioned loan losses to the set of explanatory variables, which may include several macro economic variables, and also client-specific data if the model is built on micro data. In the final stage losses are compared with the banks' buffers. The sequence of use of the models is depicted in Figure 2.

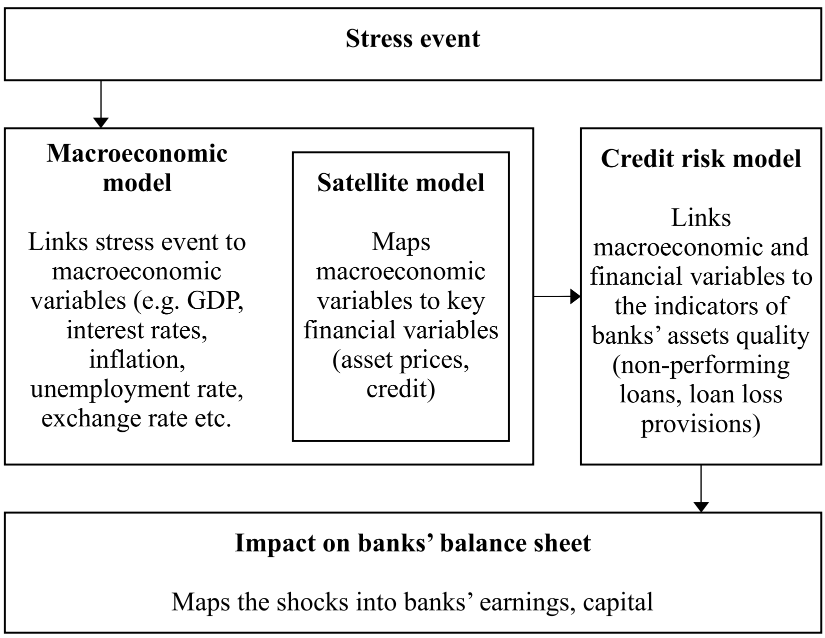


Figure 2: Models in the scenario analysis. Source: Foglia (2009), author's modifications.

There is a vast wealth of literature on which kind of macroeconomic models to use. [19] Foglia (2009) provides a comprehensive overview of the practices of central banks and supervisory authorities. The most common model types used to translate a scenario into the macro environment are a structural econometric model, a VAR model or pure statistical methods. Most of the thirteen institutions

[19]See for example Basel Committee on Banking Supervision (2009) and Committee on the Global Financial System (2001).

covered by Foglia (2009) used macroeconomic models developed for monetary policy analysis and forecasting.

Macro-econometric models are generally regarded as best for implementing stress scenarios, because one objective of the stress test is to understand the impact of the changes in the macro environment on the financial system (Jones et al., 2004). According to Quagliariello (2009) structural macroeconomic models are superior for creating scenarios because they are already built for forecasting and are designed to show how shocks materialise. The strength of the approach is a coherent, internally consistent prediction of the macro variables, responding to the shocks added to the model. A concern that may arise is whether the macro-econometric model responds adequately to the shocks imposed, given its structure and its coverage of the variables and the linkages between them. [20] Missing links would underestimate the severity of a scenario and the threats to the financial system. In a similar vein Foglia (2009) raises the issue that linear macro models fail to produce a consistent relationship between the variables, which may become nonlinear at times of stress.

In practice, vector autoregressive models (VARs) or vector error correction models (VECMs) are used if a macro economic model is not available or suitable for generating the desired scenarios (Foglia, 2009). VARs and VECMs are widely used alternatives, appreciated for their flexibility and relatively low building costs. The drawback of these models is that they are to a large extent statistical, which means that outcomes are difficult or sometimes even impossible to interpret. Despite the problems of explaining the outcome, they still provide coherent shock scenarios. However, it is widely recognised that creating a scenario is the most difficult and controversial aspect of stress testing, whatever modeling technique is used (see for example Blaschke et al. (2001)).

There are also various techniques for modelling credit risk. The selection of the most suitable model depends on the availability of the data and on the type of the stress test to be done, whether it is to be carried out using top-down or bottom-up principles. Authors are more consistent in defining the top-down approach, which means modelling aggregated financial data. The meaning of the bottom-up method varys somewhat in the literature. According to Čihák (2007) the bottom-up approach only refers to the level of disaggregation, as it separates individual portfolios and the analysis can be done in one centre, such as the central bank or a supervisory agency. Hadad et al. (2007) also emphasise the separate roles of supervisors and financial institutions in the bottom-up approach, where the supervisory agency defines the shock to be analysed and collects the impact evaluations

[20] For example, standard macro-econometric models are not particularly good at mimicking oil price shocks, unless they are specially designed to do so. The comparison of the Euro Area central banks' models by Fagan and Morgan (2005) proves that shortcoming.

carried out by individual institutions, and then aggregates them. Therefore the bottom-up approach is sometimes also called an aggregate test, in which a central co-ordinator has an important role (Committee on the Global Financial System, 2000).

Sorge and Virolainen (2006) make a further distinction within the group of top-down models by splitting them into balance sheet models and value-at-risk models (VaR). Balance sheet models explore the links between financial institutions' accounting items such as non-performing loans, loan loss provisions or write-offs, and the business cycle. These models are relatively simple and typically linear, using the most relevant macro variables, such as GDP, inflation, and interest rates, to account for variations in the accounting items. Sorge and Virolainen (2006) emphasise intuitiveness, low computational burden and broader characterisation as advantages of the balance-sheet models. On the other hand there are also several drawbacks, including linear relationships that may be too simplistic, parameter instability, and the lack of feedback effects, and it is also true that loan loss provisions and non-performing loans could be too noisy as indicators of credit risk. Breeden (2008) adds that such an approach would work if the quality and the volume of new loans were constant or at least random, and independently and identically distributed. In reality, however, this hardly ever holds true.

VaR models also use multiple macro economic variables to gauge their effects on financial institutions' portfolios but the emphasis is on probabilistic outcome. The vulnerability of the financial system is captured by a probability distribution of losses based on a suitable macro scenario. This method avoids the possible shortcomings of the balance sheet models but has other concerns, as value-at-risk measures are not additive across portfolios, and so most models in this strain focus on aggregate portfolios (Sorge and Virolainen, 2006). The shortcoming may become quite restrictive at times of high risk because it does not permit analysis of an individual institution's performance nor the possible contagion effects. Arguably, VaR models have dominated in questions of financial risk, such as credit risk management since they were first launched in the early 1990's (Aragonés et al., 2008).

Čihák (2007) provides yet another categorisation of models, distinguishing between loan performance models and default rate models. The first class of models is similar to what was earlier described as balance sheet models, using non-performing loans, loan loss provisions or default frequencies as distress measures, as determined by macroeconomic conditions. These models are not necessarily related to the top-down approach and vary greatly in their level of aggregation—some focus on aggregate data while others work at industry level, but banks can also be separated out if the data is available. The second class of models is built on client-specific micro data, which are explained by macro economic conditions. Macro data can enter the default rate model directly, or another satellite model could be used first to draw a link between the macro data and an individual borrower's performance characteristics such as future income. Foglia (2009) argues that default rate models, the methods that use financial data to forecast bankruptcies, may detect possible problems in loan portfolios sooner than models based on loan classification data such as non-performing loans or loan loss provisions. However, these models require large datasets that are available only to selected institutions/researchers.

In practice the models for performing stress tests vary greatly and the choice of modelling framework is often predetermined by the availability of the data. Individual financial institutions, market participants, are closer to the data needed for the models and are better able to analyse their own credit risk than is a supervisory body, and therefore the choice of tools is larger for an individual institution than for a supervisory agency or a central bank. Nevertheless, it is important for a supervisory body or a central bank to have a tool for evaluating potential problems that may occur in severe economic conditions. The focus in this case is not only on individual banks but on the banking system as a whole (Basel Committee on Banking Supervision, 2000a), and on top of this the Basel Committee on Banking Supervision (2000b) sees the role of a supervisory agency as requiring that banks have an effective system in place to identify, monitor and control this risk.

An alternative route to take in setting up the stress test system is to bind the macro model and the credit risk model into one aggregate model. For example Hogarth et al. (2005) estimate a VAR model which includes write-offs in the vector of endogenous variables. Pesaran et al. (2006) construct a global VAR (GVAR) model with credit loss contingent on the macroeconomy, while Alves (2005) employs a cointegrated VAR (CVAR) framework for capturing the risk interactions. The merit of these models is that they have only one concentrated tool, which also permits the feedback loops. The disadvantage is that they have limited the number of variables in favour of higher degrees of freedom, which may result in a lack in the structure.

Regardless of the modelling technique or stress test approach, results must be interpreted with caution. Bunn et al. (2005) state that "... no single model is ever likely to capture fully the diverse channels through which shocks may affect the financial system. Stress testing models will, therefore, remain a complement to rather than a substitute for, broader macroprudential analysis of potential threats to financial stability." Any model built on economic data is a simplification of reality and unable to take into account all the complex structures and sources of shocks as they occur in the real world.

1.3. Model selection for the stress test framework

This chapter elaborates on the issue of selecting the models for the stress test to best suit the aim of this particular research. As shown in the previous section, this involves choosing the appropriate macro modelling framework and a suitable credit risk modeling framework. The selection of both models is driven by two main criteria: data availability and the model's suitability for running certain types of stress tests to achieve the goal of the research, which in turn requires scenario analysis to be performed conditional on the level of indebtedness of the private sector. Both models must be tailored for this task.

Data availability is certainly more restrictive in the case of the credit risk model. For Estonian banks the available data covers each individual bank's time series of non-performing loans, loan loss provisions and its exposures of mortgages, consumer and corporate credit. Unfortunately there is no access to default rates or default probabilities. This shortcoming narrows the selection of applicable modelling frameworks. The possible range of models is the loan performance/balance sheet models, which regress loan quality indicators on the underlying state of the macro economy. Lehmann and Manz (2006) and Jiménez and Mencía (2007) represent typical routes of modelling with this sort of data using panel data estimations to link loan loss provisions to the macro environment.

The credit risk model built in the present thesis departs from the other models and offers a more structured view of the loan loss generation process than the alternatives would. It deliberately separates the different stages of how banks provision the expected losses in order to capture the rich inner dynamics of the whole process. The credit risk model disentangles non-performing loans and loan loss provisions. The distinction is largely motivated by the fact that non-performing loans exhibit a tighter link with the underlying macro indicators, whereas loan loss provisions are subject to bank-specific provisioning schemes and are harder to predict. The method solves this problem by modelling provisions proportional to the non-performing loans, conditional on the time varying loss given default rate.

The range of applicable macro modelling frameworks that can be used for generating scenarios is relatively wide. This is partly because there are multiple theoretical grounds but also because there are fewer data restrictions. The broad classes of models considered in the literature are vector autoregressive models (VAR), vector error correction models (VECM), structural vector autoregressive models (SVAR), dynamic aggregative estimated models (DAE), real business cycle models (RBC), general equilibrium models (GE) and dynamic stochastic general equilibrium models (DSGE).

Bårdsen et al. (2006) provide a comprehensive overview of the different model classes in the context of financial stability analysis. They compare models by looking at the features necessary for a particular task. The features they consider are contagion, default, missing financial markets, heterogeneous economic agents, macroeconomic conditions, structural micro-foundations, empirical tractability, suitability for testing and the inclusion of money, banks, liquidity and default risk. They conclude that no single model can be expected to be detailed enough to capture all the risk factors. Building a model with all the features would be extremely complicated, probably impossible and highly inefficient. As a solution, they suggest using a suite of models instead.

A pragmatic summary of the findings of Bårdsen et al. (2006) is that the macro model has to be detailed enough to capture the most relevant features of the economy. When a scenario is implemented in the macro model, then it must allow for the most relevant transmission mechanisms to operate in order to get an adequate reflection of the economy. However, it may be argued that the range of relevant features and channels varies depending on the particular scenario and variable(s) shocked as no single model is designed to be suitable for all purposes.

At first glance the model classes that are most promising for the current task are DSGE and the structural macroeconometric model, which is closest to DAE. These models comply with the need to assess and understand the interactions between the financial sector and the real economy. The other alternatives are considered either to be unable to replicate the actual data sufficiently well or to provide no information on the causes of the behaviour of the model-economy. This stems from the trade-off between data coherency and the theory coherency, a conflict which has been discussed by Pagan (2003) (see Figure 3).

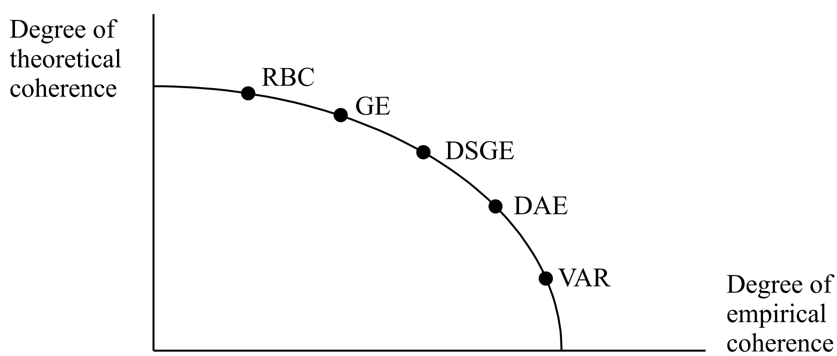


Figure 3: Pagan Diagram. Source: Pagan (2003) and Bårdsen et al. (2006).

The choice between the traditional structural macroeconometric (DAE) and DSGE models depends on their relative advantage in including the financial sector with its frictions. Most of the work in this field has been done in the framework of the DSGE models. Seminal works of DSGE literature, on which later works relied for a long time, most commonly Christiano et al. (2005) and Smets and Wouters (2003), neglect financial frictions. Contemporary DSGE literature has realised that both aggregate demand and also supply are determined by credit market frictions. At the current moment there are two competitive solutions for tackling this issue. The first and most commonly used strand on financial frictions is the *financial accelerator* (Bernanke et al. (1999), Iacoviello (2005)). The financial accelerator mechanism works through the banks modifying the risk premium on top of the risk free lending rate. An increase in the leverage of companies increases their risk of default and banks respond by raising the risk premium. The opposite happens when the leverage falls. Pro-cyclical movements in the risk premium amplify responses to shocks and make the economic cycle more volatile.

The second strand of the financial frictions literature deals with *collateral constraints* (Kiyotaki and Moore (1997)). In these models bank lending is limited by the value of the collateral. The mechanism which links the financial and real sectors is quite similar to the financial accelerator. The difference is that banks do not react by changing the risk premium but by cutting lending when the value of the collateral falls or increasing lending when collateral value rises. These models emphasise the role of real estate prices in determining the amplitude of the economic cycle.

The main advantage of the DSGE models compared to the traditional macroeconometric models is that they are based on micro foundations, and this gives them a more solid theoretical grounding. [21] But there are also two major methodological weaknesses in these models: they are linearised and use de-trended data. [22] Linearisation allows the model-outcome to be interpreted only in terms of deviations from the steady state, which have to be extracted from the data. Typically the de-trending methods are very simple, either linear trends or univariate filters. The problem which may arise from independent de-trending of the series is that the cyclical information across the series may not be consistent. The use of de-trended data rules the class of DSGE models out for the current research, as the

[21] However, DSGE models have received a fair amount of criticism as well. Gordon (2009) claims that current DSGE models contain too much micro and not enough macro. His critique of the DSGE paradigm also accuses these models of not being rich enough in their components, trying to explain business cycle fluctuations through a self-imposed corset of technology shocks, consumer preferences and monetary policy reactions.

[22] Linearisation has been used in some newer macro-econometric models as well, see for example Bårdsen and Nymoen (2009).

model must be able to catch financial deepening and allow for trended data within the model. [23]

There are few traditional macro-econometric models known which include financial sector. For example Ortega et al. (2007) model households' financial wealth, which they find to be significant in explaining the behaviour of the household sector. Jeanfils and Burggraeve (2005) introduce the financial sector by letting households have negative net asset positions but do not specify borrowing explicitly. The current research enriches the traditional macro-econometric model with the financial sector and explicit lending to companies and households. The model is built to replicate financial deepening as it happened in Estonia and also includes financial frictions to account for the pro-cyclical, cycle-amplifying impact of the bank lending.

There are several macro models already developed for Estonia, for example macroeconometric models by Meriküll (2003), Basdevant and Kaasik (2002) and Sepp and Randveer (2002); and DSGE models by Gelain and Kulikov (2009) and Colantoni (2007). But these models do not embed financial sector explicitly or else they do it too simplistically, in addition to which, most of them are outdated. There are also VAR models developed to analyse specific issues on the macro level, such as the transmission mechanisms of foreign developments into the Estonian economy (Danilov, 2003) and shock absorption capacity (Lättemäe, 2003), which could also be considered for scenario generation, but these are also outdated models and not rich enough in their structure for the current purpose. None of these models would be suitable for analysing the role of indebtedness in determining the vulnerability of banks.

The macro model builds on Kattai (2005), which has very limited coverage of the financial variables. The model developed in the present thesis includes bank lending to households and companies, and household access to consumer and mortgage loans. The credit-wothiness of the clients depends on the debt servicing costs. Increase in the periodical interest payments as a proportion of income is treated as a source of risk by the banks and they respond by issuing fewer loans. The main principle of the friction is similar to the collateral constraint, but instead of comparing the loan to asset value (stocks), the friction is built into the flows.

Another friction is embedded in the sluggishly adjusting interest rates. The model makes a distinction between the interest rates on newly issued loans and the interest rates on stocks, which are re-priced at the frequency of the base interest rate changes. Therefore any movement in the base interest rate transmits into the average stock interest rate and into the debt servicing costs with a lag, postponing the full transmission of an interest rate shock. Borrowers are also modelled to

[23] This is also a problem when the model operates on growth rates instead of deviations, like for example Adolfson et al. (2007) and Smets and Wouters (2007).

make a distinction between the base interest rate and the risk premium charged by the banks. The argument for that lies in the fact that the base interest rate is time varying but risk premium is fixed for the whole duration of the loan contract and therefore the two have different implications for borrowing decisions. The model estimation proves that credit turnover responds differently to changes in the interest rate depending on whether it is caused by a change in the base interest or in the risk premium.

The macro model does not cover all the necessary characteristics outlined by Bårdsen et al. (2006) but still meets some important criteria. Firstly, it is used for forecasting and policy analysis on a regular basis, meaning it has proved its robustness in practice. Secondly, the model also incorporates a wide range of financial variables, and so the predicted macro variables are already conditioned on financial developments and the scenarios generated are consistent in this respect. Thirdly, default probabilities are not included in the forecast model but they are directly linked in the credit risk model, which is sufficient when the model is not specifically used for investigating the implications of a bank failure. There are also some aspects that are not relevant in Estonia, for example due to the high ratio of foreign ownership, the interbank market in Estonia is so thin that there is no need to have heterogeneous agents. [24] In connection with this, contagion is also not of high importance (at the local level).

Figure 4 organises all the issues related to performing stress tests, which were discussed earlier, into one general sequence of decisions. It depicts the steps for stress testing credit portfolios, although the same procedure holds true for other types of risks too, namely for market risk (interest rate and exchange rate risks) and for liquidity risk.

The thesis follows the two parallel routes shown in Figure 4. Firstly a sensitivity analysis will be performed in section 2.3. using the ”bottom up” principle. Analysis is done to reveal the impact of each key macroeconomic variable on the banks' aggregate portfolio. Thereafter the macro-econometric model is used to implement scenario analysis in section 4. The macro-econometric model is firstly used to simulate economic development at different debt levels. These scenarios form the basis for the second round, where each baseline scenario is paired with different shock scenarios. Comparing the baseline and the shock scenarios at different environments of indebtedness in the private sector shows whether the debt level matters for the reactions in the real economy. These scenarios are then taken to the credit risk model to assess their implications for the quality of credit on the same grounds.

[24]Bårdsen et al. (2006) justify the need for heterogeneous agents with the argument that if all the banks were identical, there would be no incentive for them to trade with each other.

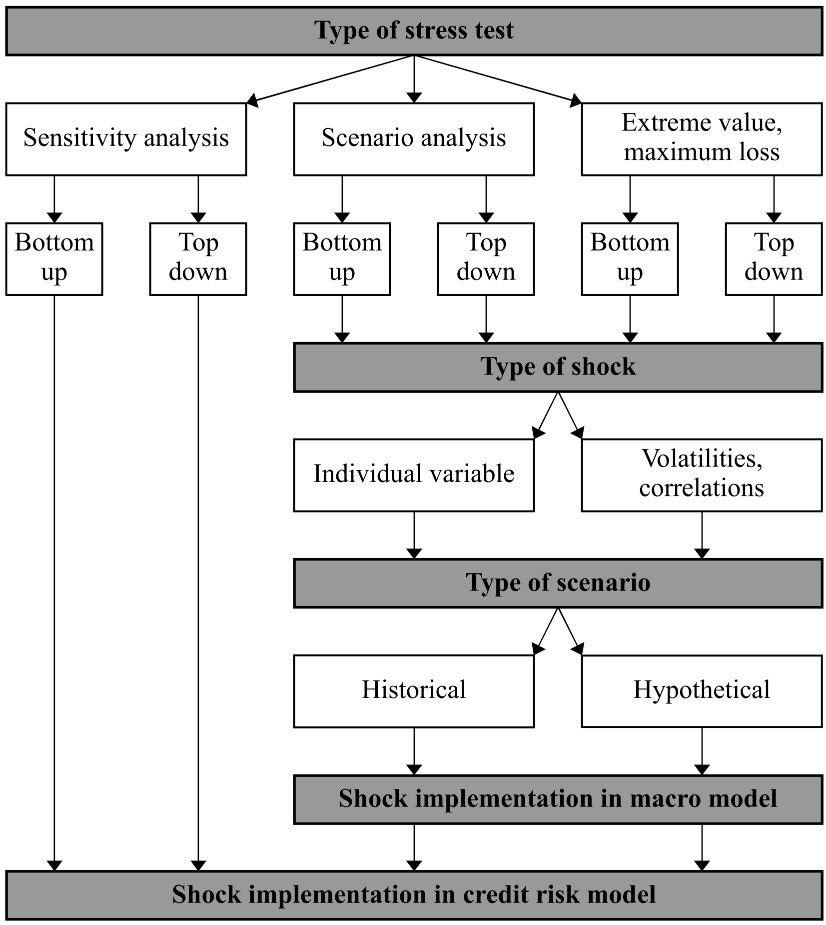


Figure 4: Decision making sequence of stress testing. Source: author.

2. CREDIT RISK MODEL FOR THE ESTONIAN BANKING SECTOR

2.1. Overview of the Estonian banking sector

The Estonian financial sector is dominated by the banking sector, while the presence of the securities and insurance market and of investment funds is growing but still relatively small. Currently the Estonian banking sector contains 20 banks, most of which are foreign owned. [25] Of the foreign banks 13 are branches and therefore, by law, are not subject to the rules and regulations of the host country (Gylfason et al., 2010). This is an important point, because that the local supervisory body has less control over the market participants and probably has more need for international cooperation. The difference in legal presence can be of substantive importance, especially in the event of a crisis (Tschoegl, 2005).

Banks operating in Estonia mostly specialise in lending. In mid 2010, most of the banks' assets, around 89% on average, were held in loans to clients. Of the aggregate loans portfolio, 39% were loans to households, 36% were loans to the corporate sector and the other 25% were mostly loans to other financial institutions (Finantsinspektsioon, 2010). The structure of Estonian banks' assets clearly suggests that the main source of possible income loss and the main threat to profitability can be found in credit exposure. The interest income of the banks has generally been found to be less sensitive to adverse macroeconomic shocks than the other income items are. [26]

The outstanding stock of loans to the private sector has been growing remarkably rapidly. Until 2003 the private sector's debt ratio to GDP remained stably below 30%, but in 2004 credit expansion started, peaking in 2006 when average annual growth of credit exceeded 60%. The year following the start of the global financial crisis also saw the turning point in the local credit market. By 2009 the average annual credit growth had dropped to zero but the preceding credit boom had lifted the private sector's debt to GDP ratio above 100%. [27] This means that the indebtedness of the private sector had tripled in only six years (see Figure 5).

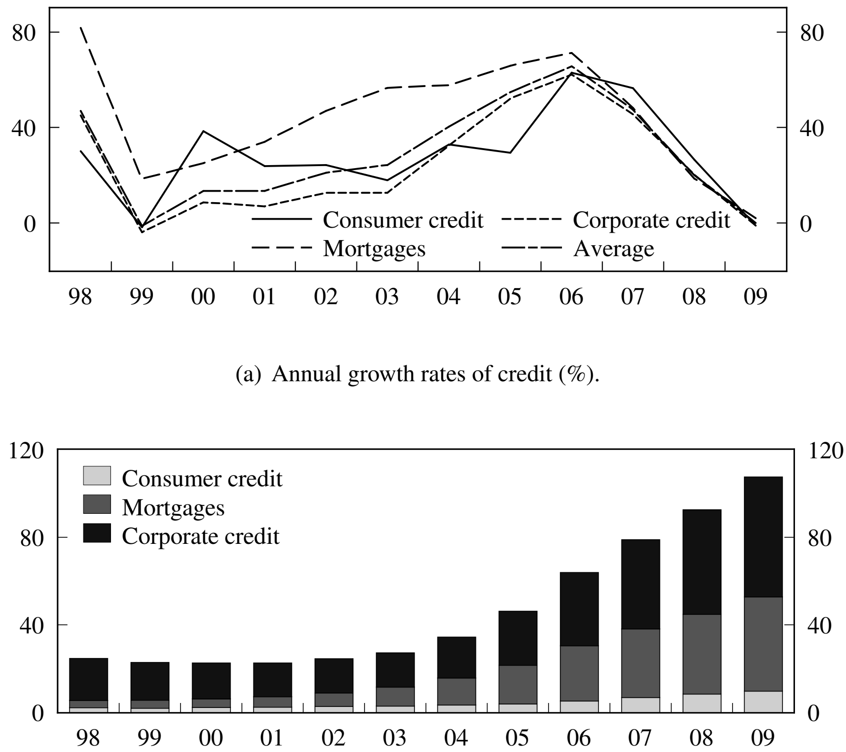
Such high growth rates became possible largely because of the foreign ownership of the banks which opened up sources of financing for bank lending. An-

[25] The number of banks was considerably larger after independence was first regained but it has shrunk rapidly. There were more than 40 banks operating in Estonia in 1992 (OECD, 2000), but more than 20 of those had disappeared by 1993 because they had either gone bankrupt or been taken over by other banks after they had failed to satisfy the minimum capital adequacy ratio (Zirnask, 2002). The number of banks dropped to 21 in 1993 EBRD (2002).

[26] See the analysis by Coffinet et al. (2009).

[27] The increase in the ratio in 2009 was due to the decline in GDP.

other significant factor was the high proportion of foreign-currency-indexed loans, which reached 80% and was the highest in CEE11 (Backé et al., 2007). Lending in foreign currency, mainly in euros, has enabled the banks to set very low interest rates on their products. At the same time, borrowers were willing to bear the currency risk. The currency risk has been perceived as being low because of the currency board arrangement which fixed the kroon to euro exchange rate and also because of the expected Euro Area membership.



(a) Annual growth rates of credit (%).

(b) Credit to GDP ratio (%).

Figure 5: Indicators of financial deepening. Source: Bank of Estonia.

The Estonian banking sector is extremely highly concentrated. The big four (Swedbank, SEB, Danske Bank and Nordea) hold 91% of the credit market, with the remaining 9% split between the 16 smaller banks. Among the big four, the largest is Swedbank, which has issued 46% of the total loans to households and approximately 37% of the loans to companies. The second largest bank on the market is SEB, which holds 26% of the loans to households and 21% of the loans to companies. Nordea and Danske Bank, the third and fourth in size, hold 20% and 11% of total corporate debt respectively and 12% of the loans to households each.

Banks' exposures have been under stress twice since 1997. The impacts of the Asian and Russian crises strongly affected the local economy and the banks' clients, lifting non-performing loans (NPLs) close to 5% of the total exposure with an exceptional peak in August 1999, when the ratio temporarily rose to 6.4%. The loan loss provisions (LLPs) were around 5% at the time (see Figure 6).

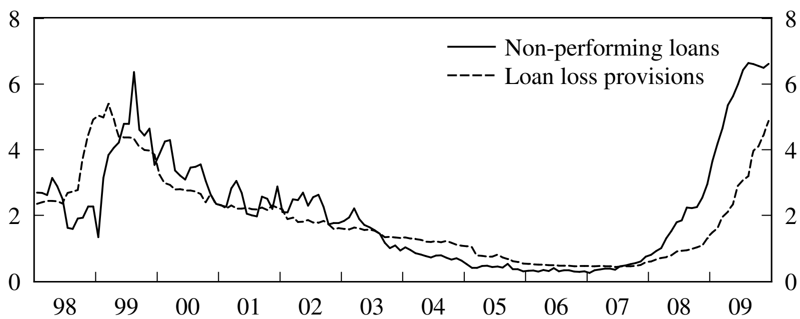


Figure 6: Banking sector average non-performing loans and loan loss provisions (% of total exposure). Source: Bank of Estonia.

The data shows that non-performing loans and loan loss provisions fell only slowly after the event. The slow improvement in the indicators was a consequence of the fact that banks were not making write-offs very hastily but tried instead to restructure the existing contracts and make them performing again. An exception was the rapid cut in provisions at the end of 1999 and in the beginning of 2000, when several banks' went bankrupt and exited the market.

The most recent crisis transmitted into distress measures fairly quickly. Within two years, 2007–2009, the non-performing loans ratio rose from 0.6% to 6.5% and provisioned losses rose from 0.5% to 5%. Comparing the two episodes reveals that the more sudden stop in economic activity during the later crisis was also reflected in the larger proportion of non-performing loans. Loan loss provisions, on the other hand, have risen proportionally less. Most likely this reflects better management of risks by the banks, which can be attributed to the acquisition of local banks by foreign investors Lättemäe (2007). But also banks' legal status may be important because local branches do not have responsibility to provision their loan losses.

2.2. Structure of the credit risk model

The model sets its focus on credit risk, which is defined as the failure of a bank borrower to meet its contractual obligations as they have been agreed (Basel Committee on Banking Supervision, 2000b). It is built to give an insight into the ways that economic conditions affect the ability of banks' clients to service their obligations, how this is reflected in the healthiness of banks' portfolios and how loan losses emerge. Figure 7 depicts graphically the actual process of loan loss generation. All the clients have certain probability of default and in each period there are obligors who become unable to fulfil their contractual agreement with the bank. The reasons for this may be loss of a job, a cut in wage or a fall in other income, a rise in interest rates or similar causes, which are characterised by certain macro variables for the group of obligors at the aggregate level. These macro variables explain the proportion of new dysfunctional contracts in the overall exposure of the banks, the default rate. Once the contract has become dysfunctional, it shows up as a *new* non-performing loan and builds up the already existing stock of NPLs from the previous periods. At the same time banks have a responsibility to provision the expected loan loss that arises from the new NPLs, using the outstanding unpaid loan and the collateral values as the basis.

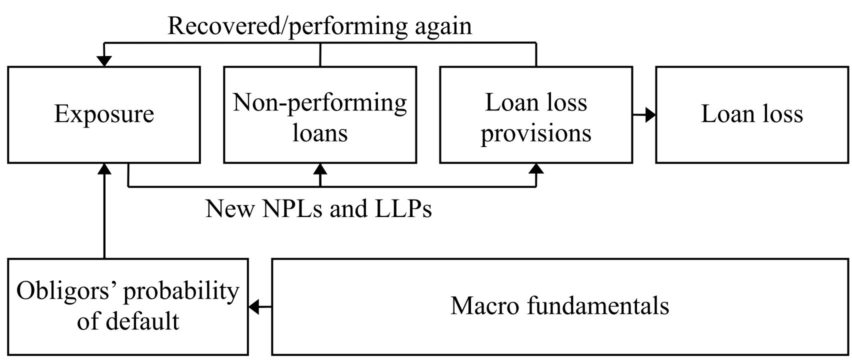


Figure 7: Loan loss generating process. Source: author.

In each period there is also a certain percentage of previously non-performing loans which become performing again. The reasons for this may be a restructuring of the loan, a reversal of the income, a new job, or similar causes. Once that happens, the loan value is discarded from the stock of NPLs and from the stock of LLPs. These flows indicate that NPLs and LLPs evolve dynamically in relation to how many clients stop servicing their contracts because they face economic difficulties and how many contracts become performing again. It is a general rule that banks do not write the loan off the balance sheet while it is still likely that the NPL may become performing again. When that event is declared to be unlikely, banks make a write-off and the loan disappears from the bank's exposure, and also from the NPLs and LLPs.

The credit risk model is built to replicate the processes described above. It disentangles the most common measures of distress, non-performing loans and loan loss provisions, with the second as a function of the first. This is done in order to gain a more comprehensive overview of the health of the banks' portfolios. Concentrating on only one of these measures, as often done in the literature (Jakubik and Scmieder, 2008), would give only partial information, whereas in reality these aspects are interlinked. As stated before, having both of them together within the same model is also motivated by the fact that in practice it is easier to correlate NPLs with the underlying economic conditions, but here the main interest is actually in the potential losses of the banks, the LLPs.

The model does not include banks' capital buffers or profits. This means that the provisioned losses from credit exposures have to be compared against banks' capital reserves externally, outside the credit risk model, in order to establish which set of circumstances may run a bank into insolvency. However, testing these circumstances is not relevant for fulfilling the goal of the thesis. It is enough to show which macro indicators affect the healthiness of banks' portfolios, and their relative importance in explaining variation in NPLs and LLPs. The macro model, which is then used to generate alternative scenarios, can give an answer to the question of whether those macro variables have become more responsive to negative shocks, meaning that the banks have become more vulnerable too.

The credit risk model is built for the whole banking sector in Estonia. Four major banks—Danske Bank (d), Nordea (a), SEB (s) and Swedbank (w) enter the model individually, while the the others are grouped together (o). This division is optimal because of the high concentration of the sector, where the share of the four largest banks' is about 91%. Each bank's credit portfolio is divided into three sectors. These are mortgage (h), corporate (f) and consumer credit (c). [28]

The stock of non-performing loans, N, is modeled for sector $m \in \{c, f, h\}$ of each bank, $b \in \{d, a, o, s, w\}$. Equation 1 generalises the dynamic process that generates the outstanding stock of non-performing loans. The first component on the right hand side of the equation stands for the *new* non-performing loans, which are drawn from a bank's exposure, $E^{b,m}$, at a default rate Π^m:

[28] Foglia (2009) emphasises that central banks or supervision authorities should concentrate on bank level performance rather than on an aggregate system-wide portfolio. Aggregate data may conceal substantial variation at portfolio or bank level, leaving the potential for failure of individual institutions undiscovered.

$$N_t^{b,m} = \left(\eta^{b,m} + \psi^{b,m}\Pi_{t-k}^m\right) E_{t-k}^{b,m} + \left(1 - \rho_t^{b,m}\right) N_{t-1}^{b,m} - M_{t-1}^{b,m} + \zeta_t^{b,m}. \quad (1)$$

Π^m stems from individual obligors' probabilities of default and stands for the average materialised default rate of all the clients in a group m. In the standard way of presentation, the loss indicator of an individual obligor j is generated by:

$$\tilde{l}_j = E_j \lambda_j l_j, \quad l_j = \mathbf{1}_{D_j}, \quad \mathbb{P}(D_j) = DP_j, \quad (2)$$

where E_j denotes exposure at default to client j, λ_j is the associated loss given default and D_j stands for the event where the obligor defaults within a certain period, the probability of which is $\mathbb{P}(D_j)$ (Bluhm et al. (2003)). From this, the non-performing loan indicator would simply be $\tilde{n}_j = E_j l_j$ with $l_j = \mathbf{1}_{D_j}$ and $\mathbb{P}(D_j) = DP_j$. The total expected amount of new non-performing loans in bank's aggregate portfolio is $\tilde{n} = \sum_j E_j l_j$ with $l_j = \mathbf{1}_{D_j}$ and $\mathbb{P}(D_j) = DP_j$, which allows the observed new NPLs to be written in the form $n = \Pi E$, where $E = \sum_j E_j$ and $\Pi = E^{-1}\tilde{n}$. Π therefore is the proportion of the outstanding stock of loans in a bank's portfolio that actually turn non-performing in a certain period. Each sector m has the average default rate Π^m but equation 1 contains parameters η and ψ to test for heterogeneity between the clients of the same sector across the banks.

The second component stands for the "healed" or "cured" contracts, loans that were non-performing in the previous period but have become performing again. This may be because the client has restructured or refinanced the loan, sold the collateral and paid back the loan or become solvent again. [29] Recovery rate ρ ($0 \leq \rho_t^{b,m} \leq 1 \forall t$) corresponds to the proportion of the "recovered" loans in the transition matrix and the parameter is time dependent to reflect cyclical deviations in the rate. [30]

The second component in equation 1 is used to replicate the decrease in the number of observed non-performing loans ($\Delta N_t < 0$). New non-performing loans, $(\eta^{b,m} + \psi^{b,m}\,\Pi_{t-k}^m)E_{t-k}^{b,m}$, are always non-negative because $\Pi \geq 0$, $E \geq 0$, $\eta \approx 0$ and $\psi \geq 0$. In principle, the fall in the non-performing loans could be due to loans being written-off, M, as a consequence of the principle that a non-performing loan is removed from the balance sheet once the bank writes it off. But

[29] One point related to the restructuring of a loan is that technically it becomes performing and will not show up as a non-performing loan any more, but the quality of the bank's portfolio may fall as a result.

[30] There is a lot of evidence that transition matrices and hence ρ are time varying, depending on the cyclical position of the economy (Bangia et al., 2002) or on the characteristics of an individual loan (Calem and LaCour-Little, 2004). See also Jones (2005) for a detailed overview of deriving transition matrices using proportion data.

equation 1 is shaped to be able to explain improvements in banks' portfolios even without write-offs, when $M = 0$. This is especially plausible in the economic recovery phase, when banks' clients are more likely to become solvent again.

Foglia (2009) calls a non-performing loan a "retrospective indicator" of asset quality, which should be controlled using lagged values of the probability of default. This is represented by k in equation 1. The value of k is dependent on the definition of a non-performing loan, how long the loan has to be past due before it is considered non-performing. Here loans that are 60 days past due are treated as non-performing, which means that in fact the clients became insolvent two months ago and N_t is actually generated by Π at $t-2$ from E_{t-2}.

Dividing both sides of equation 1 by exposure, E_{t-2}, transforms the left hand side of it into a non-performing loan ratio (assuming that N_t was in fact already non-performing two periods before, which is the lag of the denominator). The equation to be empirically estimated becomes:

$$\frac{N_t^{b,m}}{E_{t-2}^{b,m}} = \eta^{b,m} + \psi^{b,m}\Pi_{t-2}^{m} + \left(1-\rho_t^{b,m}\right)\frac{N_{t-1}^{b,m}}{E_{t-2}^{b,m}} + \omega_t^{b,m}. \tag{3}$$

Equation 3 disentangles the default rate and the NPL ratio although Blaschke et al. (2001) show that the NPL ratio itself can be treated as a default frequency measure. They say that this is true if the assumption of the normal distribution of individual exposures holds and there is no time variance in the recovery rate. As equation 3 includes a time dependent recovery rate, the concepts of the NPL ratio and the default rate are kept different. Later it is shown that the default rates exhibit slightly different dynamics from those of the NPL ratios.

Write-offs, M, do not appear in equation 3 because loans have been written off only exceptionally in Estonia. With almost zero variation it has no explanatory power and is therefore left out of the equation. Any reduction in N can only be attributed to the "recycling" of the loan, supporting the dynamic set-up of the equation. Error term ω has the property of $\omega^{b,m} \sim N(0, \sigma_{\omega^{b,m}})$ and relates to ζ by $\omega_t^{b,m} = \zeta_t^{b,m}/E_{t-2}^{b,m}$.

Since there are no official data available for default rates, they have been stripped out from the related data. This is done by estimating equation 3 sector-wise, by aggregating the data for one sector from all the banks. The default rate of a sector m, Π^m, is proxied by a set of macro indicators, X, and the corresponding set of parameters, β^m:

$$\frac{N_t^{m}}{E_{t-2}^{m}} = \frac{e^{f(\beta^m,X)}}{1+e^{f(\beta^m,X)}} + (1-\rho_t^{m})\frac{N_{t-1}^{m}}{E_{t-2}^{m}} + \xi_t, \tag{4}$$

where N^m and E^m equal $\sum_b N^{b,m}$ and $\sum_b E^{b,m}$ respectively. Equation 4 regresses the NPLs directly on macro fundamentals, and the combination of them generates the default rate series because $e^{f(\beta^m,X)}/(1+e^{f(\beta^m,X)}) = \Pi^m$ as imposed by the initial equation 1. Note that parameters η and ψ do not appear in the equation since it extracts the *average default rate* within the sector across the banks. [31] Logistic form is used to keep the default rate always greater than zero. Another reason for using the logistic form is to add non-linearity to the system. This is in line with the finding that the financial system is hit more severely on occasions when shocks are large and the relevant macro variables are further away from their fundamentals (Foglia, 2009).

The list of macro variables or vulnerabilities used in different studies is quite long. The core list includes such variables as GDP growth, real and nominal interest rates, inflation and indebtedness. Hadad et al. (2007) also use money aggregates M1 and M2 and the stock price index and Marcucci and Quagliariello (2008) include exchange rate and output gap data. The oil price was found to be a significant risk factor in a study by Simons and Rowles (2009), while Kalirai and Scheicher (2002) extend the list by including consumption spending, employee compensation and new car registrations.

Howard (2009) argues that the choice of variables should be based on stress scenarios and the types of risk that will be analysed with the model. And so the macro indicators used in the function of default rates are those which also appear in the macro model—unemployment, real output growth, nominal interest rates and inflation, the last two are used to calculate the real interest rate on stock. These coincide with the conventional list of variables used in similar models, and they also meet the key requirement of economic plausibility, stressed by Foglia (2009), which states that all predictive variables must have clear meaning and an interpretable relationship with the dependent variable.

In the credit risk model cyclical pressures are captured by the unemployment rate and economic growth. [32] The output gap has been left out of consideration, although Marcucci and Quagliariello (2008) find it to be the most powerful cyclical indicator. Problems may arise with the predictability of the output gap at stressful times, when potential output may, for various reasons, shift downwards. These permanent or temporary structural shifts can only be detected *ex post* and remain questionable *ex ante*, making them a major source of error. The economic

[31] A small exception is allowed in equation 3 when it is used to extract the default rate of the consumption credit sector. The performance of the NPL ratio of the “other banks” differs greatly from the average for the sector and for that reason other banks’ nonperforming loans are not included in the sector totals—for $\sum_b N_t^{b,c}$ and $\sum_b E_t^{b,c}$ the set of banks is smaller, $b \in \{d, a, s, w\}$.

[32] The correlation between unemployment and economic growth is not statistically significant, leaving aside multicollinearity issues.

growth rate is therefore considered to be a more reliable indicator of the economic cycle.

Both cyclical indicators are normalised to have zero mean and unit variation. [33] The normalised unemployment rate, $\tilde{u}_t$, is given by $(u_t - \overline{u})/\sigma(u)$ and normalised output growth, $\tilde{y}_t$, is given by $(y_t - \overline{y})/\sigma(y)$, where $(\bar{.})$ denotes mean value and $\sigma(.)$ denotes the standard deviation of a variable. Unemployment is expected to have a greater impact on households' average default rate, as it implies a sudden stop in the stream of income and leads to households being unable to service their obligations. Output growth is expected to reflect the performance of companies more closely by illuminating the ease with which they can sell their products and get revenues to service their debts. On the other hand, output growth is a close proxy for households income as well, as it is highly correlated with disposable income.

Real interest rates have a clear impact on borrowers' ability to service debt. The real interest rate on the stock of loans, r^s, is defined as the difference between nominal interest rates on stock, i^s, and the weighted inflation rate: $r_t^s = i_t^s - [\tau_m \pi_t + (1 - \tau_m)\mathbb{E}\{\pi\}]$. Parameter τ $(0 \leq \tau \leq 1)$ shows how much weight the borrowers put on the current inflation rate, while $1 - \tau$ shows the importance of inflation expectations $\mathbb{E}\{\pi\}$, which are proxied by the historical mean, $\overline{\pi}$. For the default rate function the real interest rate is normalised to have zero mean and unit variance: $\tilde{r}_t^{s,m} = (r_t^{s,m} - \overline{r}^{s,m})/\sigma(r^{s,m})$. [34]

Default rates are also considered to be functions of the debt to output ratio (indebtedness) in the sector, $e_t^m = E_t^m / Y_t P_t$, where Y is real GDP and P is the price level. The debt ratio is also normalised for the sake of comparison with the other regressors $\tilde{e}_t^m = (e_t^m - \overline{e}^m)/\sigma(e^m)$. Indebtedness is added to the equation in order to account for the increase in monthly obligations of principal and interest payments compared to earnings, this makes a client more likely to stop servicing a loan if an unfavourable shock hits, *ceteris paribus*. Combining all the indicators, the function to extract the average default rates of mortgage and consumption credit clients and of companies becomes:

$$f(\beta^m, X) = -\beta_0^m + \beta_1^m \tilde{u}_{t-2-l} - \beta_2^m \tilde{y}_{t-2-o} + \beta_3^m \tilde{r}_{t-2-j}^{s,m} + \beta_4^m \tilde{e}_{t-2}^m, \tag{5}$$

where l, o and j denote the time lags which are required for the unemployment rate, output growth and real interest rate to affect the default rate. The choice of

[33] The frequency of the originally quarterly GDP growth and unemployment rate data is increased by matching the quadratic average.

[34] In principle a more complex construction for the interest rate could be found. According to Evans et al. (2000) the relevance of the interest rate decreases with high economic growth rates. This could be modelled by using an interaction term.

lags is based on the statistical significance of the estimated parameters. Longer time lags would imply the existence of greater savings or other resources which can be used to service the debt during the period when earnings have fallen or the price of credit has increased. [35]

Equation 4 is estimated using general method of moments (GMM). The results are presented in Table 2. Unemployment appears to be a relevant factor for all the clients, although the interpretation is different for households and companies. For households unemployment directly means cuts in earnings whereas for companies unemployment is the consequence of their own behaviour in adjusting to the changes in the economic environment.

Table 2: Estimation results: default rates

Param.	Descrption	Mortgage	Consumption	Companies
$\hat{\beta}_0$	intercept	6.19***	5.51***	6.03***
$\hat{\beta}_1$	unemployment rate	0.17***	0.10***	0.22***
$\hat{\beta}_2$	economic growth	0.23***	0.09***	0.21***
$\hat{\beta}_3$	real interest rate	1.57***	0.24***	1.55***
$\hat{\beta}_4$	indebtedness	0.40***	0.25***	0.29***
$\hat{\tau}$	inflation weight	0.05***	0.00	0.04*
l	lag of unempl. rate	2	0	1
o	lag of economic growth	4	2	1
j	lag of interest rate	0	0	0
R^2		0.75	0.67	0.79

Notes: estimation method GMM, estimation period: 2004M1 – 2010M3 ($NOB = 75$). *** and * denote statistical significance at the levels of 1% and 10% respectively.

Economic growth also appears statistically significant in all three equations. It has a relatively greater impact on the payment performance of companies and mortgage clients, but it also remains an important factor for consumption credit clients. In all three equations unemployment rate and output growth exhibit similar coefficient values, which means that change in either of them by one standard deviation should roughly have the same effect on the default rates.

The interest rate matters most for the mortgage sector and for companies, con-

[35]The model deliberately excludes measures for currency risk. Most of the debt is denominated in foreign currency, which potentially creates vulnerability to currency risk among indebted households and corporations Rosenberg et al. (2005). Nevertheless, currency board arrangement (CBA) has been assumed to be perfectly credible and the risk vanishes on the first of January 2011 with the adoption of the Euro.

sumer credit holders seem to be less sensitive to it. This can be explained by the relatively smaller size of individual loans and the relatively high interest rate levels. These mean that any change in the interest rate has a relatively smaller impact on clients' ability to service their loans. The weight of the contemporaneous inflation rate is zero or close to zero for all the sectors, suggesting that companies and households rely on the expected inflation rate when calculating the real interest rate. Lags support an instant response to the stock interest rate changes by the default rates. The interest rates on stocks, on the other hand, adjust only slowly when the base interest rate changes because it takes some time to re-price all the loan contracts (explained later).

Indebtedness is relevant in all three sectors, and is at almost the same level. This finding contributes to the goal of the research as the increased debt level has raised the obligors' default frequency *ceteris paribus*. Indebtedness is a very sluggish variable and does not feature much uncertainty in the context of risk assessment. However the logistic form of the default rate function has another important implication, that the increased indebtedness also amplifies the response of the default rates to the shocks in the other input variables.

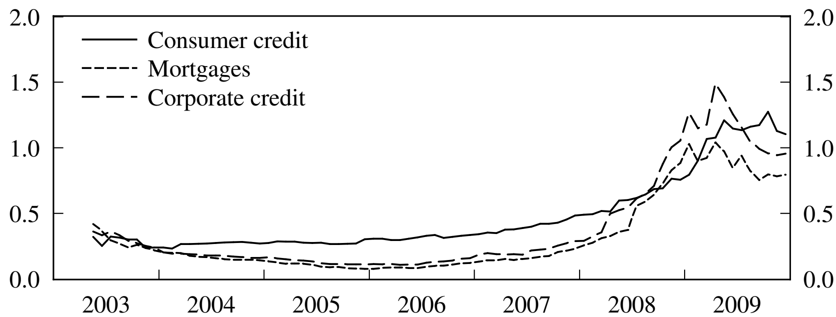
The selection of lags shows that it takes longer for mortgage clients to be affected by unfavorable economic conditions. Consumption credit clients and companies react more quickly in this respect. The reason may be the different commitment of clients to servicing their debt. It is plausible that mortgage clients are more cautious about servicing their obligations when conditions become unfavourable as they risk losing their property while the consequences of not servicing consumer credit are less harmful.

The number of observations used to estimate the equations (nob = 75) is relatively high because monthly data is used instead of quarterly as is most usual. However, the relationship between the NPL ratio and the selected macro indicators may be influenced by the lack of a full cycle in the data, as discussed by Simons and Rowles (2009). The common sample used in the estimation only starts in January 2004 and therefore the macro indicators only capture three quarters of the last cycle. [36] Balance sheet data, on the other hand, covers all the possible states of the credit market, from the low initial indebtedness of households and companies, through rapid credit growth hand in hand with the asset price boom, and finally up to the collapse of the demand for credit. Considering that indebtedness prior to 2004 was very low, the properties of the model could not be improved by extending the sample backwards anyway. Having the data from the period of the credit demand collapse as well somewhat answers the criticism brought up in the Basel Committee on Banking Supervision (2009) that models built on the data

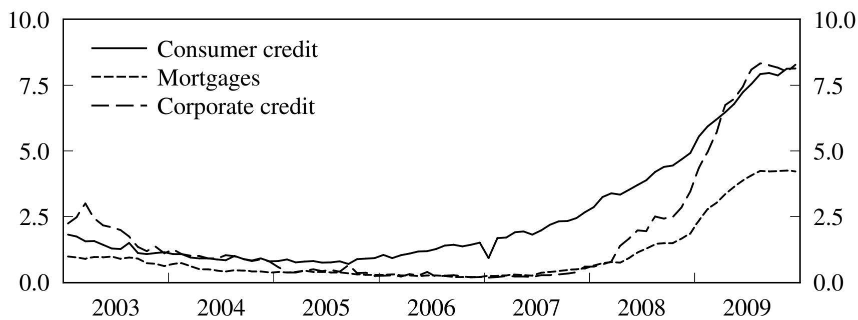
[36] The data is available for earlier periods as well but the sample is cut by the lagged instruments.

of a stable period were not able to pick up severe shocks of the type that recently occurred, and hence they underestimated the vulnerability within the financial system.

Figure 8 compares the extracted default rates and NPL ratios. All the default rates peak in early 2009 and start to fall afterwards, but the NPL ratios do not reflect any improvement in the clients' payment performance. The difference is explained by the time varying recovery rate. At stressful times the proportion of the healed loans lowers and the stock of NPLs may stay unchanged even if the default rates have already started to decline.



(a) Default rates.



(b) Non-performing loan rates.

Figure 8: Sectoral break-down of default rates and non-performing loan rates. Source: Bank of Estonia.

The different dynamics of the default rates and NPL ratios suggest that the latter are not a very good proxy for the obligors' credit servicing discipline. NPL ratios are not able to pick up the turning points in the payment performance and do not signal improved perspectives for lowered credit risk. It is also possible to conclude that neglecting the time varying recovery rate or the structural presentation of the NPL generation process in general, and regressing NPL rates directly on the underlying vulnerabilities could result in having incorrectly specified model. The mis-specification is a consequence of different dynamics in the new NPLs and the healed contracts. Regressing the outstanding stock of the NPLs, on the same set of vulnerabilities may result in non-stable parameters which are trying to catch two processes at the same time.

In the following step the NPL equations are estimated for individual banks and sectors, employing the structure presented in equation 3 and making use of the extracted default rate series. A summary of the results is presented in Table 3, but individual equations are not shown for reasons of data confidentiality. The table shows that the results for η equal zero in almost all equations. The positive η value in one case was caused because the NPL ratio was high even when the average default rate in the sector was very low.

Table 3: Summary of estimation results: non-performing loans

				p^*			
	Min.	Max.	Mean†	$[0, 0.01)$	$[0.01, 0.05)$	$[0.05, 0.1)$	$[0.1, \infty)$
				mortgages			
$\hat{\eta}$	0.00	0.00	0.00	3	1	1	0
$\hat{\psi}$	0.73	2.58	0.95	5	0	0	0
R^2	0.52	0.81	0.62	–	–	–	–
				consumption credit			
$\hat{\eta}$	-0.00	0.05	0.01	4	0	0	1
$\hat{\psi}$	0.52	2.67	1.21	4	0	0	1
R^2	0.36	0.58	0.49	–	–	–	–
				corporate credit			
$\hat{\eta}$	-0.00	0.00	0.00	2	0	0	3
$\hat{\psi}$	0.14	1.17	0.89	4	0	1	0
R^2	0.43	0.75	0.56	–	–	–	–

Notes: Estimation period: 2003 M5 – 2010 M3 ($NOB = 83$). † unweighted mean of the estimated coefficients. * number of estimated coefficients falling in the specified range of statistical significance.

Parameter ψ illustrates quite extensive variations in the client base of the banks, ranging between 0.14 and 2.67. If $\psi < 1$ then the clients are less vulnerable to changes in the macro environment compared to the sector average and if $\psi > 1$ the opposite is true.

While it is common in the literature to focus on either non-performing loans or loan loss provisions as a measure of distress (Jakubik and Scmieder, 2008), the model here combines the two into one system. The equation for loan loss provisions, consistent with equation 1, regresses potential losses on the outstanding stock of non-performing loans in proportion to the loss given default rate:

$$L_t^{b,p} = \lambda^{b,p} e^{-\kappa^{b,p}\tilde{z}_{t-q}} N_t^{b,p} - M_{t-1}^{b,p} + \phi^{b,p} + \nu_t^{b,p}. \tag{6}$$

Equation 6 is a simplification of the actual provisioning process. It tries to find the average level of provisioned losses rather than the exact number period by period because provisioning decisions are discretionary and cannot be explained by a simple model without knowledge of a bank's policy on making provisions. The expression of the loss given default, $\lambda e^{-\kappa\tilde{z}_t}$, is time variant, and dependent on the asset prices, proxied by the normalised real estate price indicator, $\tilde{z}$. $\tilde{z}$ is obtained by normalising the ratio of real estate prices, Z, and their own 18-month moving average value: $\tilde{z}_t = (Z_t/A_t - \overline{Z/A})/\sigma(Z/A)$, where $A_t = \sum_{g=0}^{v} Z_{t-g}v^{-1}$ and $v = 18$. λ is a constant parameter to be estimated and it represents the loss given default (LGD) when real estate prices grow at the trend rate ($\tilde{z} = 0$). [37] The inclusion of the asset prices enables the rise in the LGD caused by the decrease in the value of collateral and the reverse effect to be mimicked. Parameter κ shows the importance of real estate prices in every equation.

Variable M stands for written-off loans as in equation 1. Having M in both equations keeps them consistent in that after a loan has been written off, it no longer appears either in the pool of non-performing loans nor in loan loss provisions. Nevertheless, M is excluded from the estimated equations because its variation is close to zero, as stated before. Parameter ϕ is the bank specific intercept. It mostly stands for the periods when banks face a very low level of non-performing loans but still maintain buffers for loan losses that might occur.

Superscript p is equivalent to m, which was used to identify sectors before. The only difference is that in addition to the sectors already defined, p also includes general provisions, $L^{b,g}$, $p \in \{c, f, g, h\}$. General provisions are drawn from the overall stock of non-performing loans, defined as $N_t^{b,g} = \sum_{m\in\{c,h,f\}} N_t^{b,m}$. The estimation results for the loan loss provisions equations are presented in Table 4.

Estimates of κ indicate the relevance of real estate prices in determining the loss ratio for the banks, as it appears statistically significant in all equations. Estimated λ values show that LGD has been 0.14 on average across banks and sectors (unweighted statistics). Given that general provisions are also drawn from the

[37] Alternatively λ could also be derived from the loan-to-value ratio and the age of the loan instead of econometric estimating, as is done by Coleman et al. (2005). This method cannot be used here, because it requires micro data from a credit register, which does not exist for Estonian banks.

same pool of non-performing loans as specific provisions, the effective loss ratio for a bank is higher than the average of the estimated λ values. The effective LGD for the bank b is given by $\sum_m [(\lambda^{b,m} + \lambda^{b,g}) N_t^{b,m}] N_t^{b^{-1}}$, where $N_t^b = \sum_m N_t^{b,m}$. When real estate prices were at their peak in 2007, the average LGD was 0.07 across the banks and sectors, then the fall in real estate prices pushed the average LGD up to 0.40.

Table 4: Summary of estimation results: loan loss provisions

				p^*			
	Min.	Max.	Mean†	$[0, 0.01)$	$[0.01, 0.05)$	$[0.05, 0.1)$	$[0.1, \infty)$
				mortgage			
$\hat{\lambda}$	0.04	0.18	0.08	4	0	0	0
$\hat{\kappa}$	0.49	1.35	1.01	4	0	0	0
$\hat{\phi} \times 10^{-2}$	0.49	0.49	0.49	1	0	0	0
R^2	0.94	0.98	0.95	–	–	–	–
				consumption credit			
$\hat{\lambda}$	0.02	0.40	0.20	4	0	0	0
$\hat{\kappa}$	0.13	0.44	0.34	4	0	0	0
$\hat{\phi} \times 10^{-2}$	0.58	0.58	0.58	1	0	0	0
R^2	0.92	0.99	0.95	–	–	–	–
				corporate credit			
$\hat{\lambda}$	0.00	0.37	0.15	5	0	0	0
$\hat{\kappa}$	0.41	4.20	1.58	5	0	0	0
$\hat{\phi} \times 10^{-2}$	3.49	3.49	3.49	1	0	0	0
R^2	0.94	0.98	0.96	–	–	–	–
				general provisions			
$\hat{\lambda}$	0.04	0.20	0.12	3	0	0	0
$\hat{\kappa}$	0.45	0.53	0.50	3	0	0	0
$\hat{\phi} \times 10^{-2}$	0.84	1.57	1.21	2	0	0	0
R^2	0.94	0.96	0.95	–	–	–	–

Notes: Estimation period: 2004M1 – 2010M3 ($NOB = 75$). † unweighted mean of the estimated coefficients. * number of estimated coefficients falling in the specified range of statistical significance.

The complete credit risk model consists of 144 equations and identities, all of which are listed in Appendix 1. In addition to equations 3 and 6, the model also includes equations for the recovery rates and identities for adding together non-performing loans and loan loss provisions across banks and sectors. In calculating the NPL and LLP ratios out of the sample it is assumed that the growth of each bank's exposure in each of the three sectors equals the average predicted credit growth in the same sector. Credit growth projections are exogenous to the system and they are produced by the macro model. The macro model keeps these paths consistent with overall macro-economic development including the unemployment rate, GDP growth, interest rates and inflation.

2.3. Sensitivity analysis

Sensitivity analysis is performed to assess each macro factor's individual effect on credit quality. Each macro indicator's impact can be explored in isolation to assess its pure effect or it can be looked at in combination with others. All the macro indicators are shocked permanently by increasing/decreasing their values from their baselines by two standard deviations and by one percentage point/100 base points. The signs of shocks are defined so that they would increase the measures of distress. [38]

The advantage of defining shocks in standard deviations is that it gives better comparability for the resulting reactions. The alternative, defining shock size in percentage points, makes it intuitively easier to understand the magnitude of reactions. All deviations are presented in percentage points and are measured three years after the occurrence of a shock. This is a sufficient time horizon to let all of the impact to pass through, as macro variables do not affect default rates instantly but with a considerable time lag; furthermore, interest rates on the stock of loans only adjust to changes in the policy rate sluggishly.

Due to the non-linearity of the default rate function, reactions to the shocks depend on the initial baseline values of macro variables, as shocks hit the financial system harder the further off the macro variables are from their means. In this exercise all macro variables appearing as rates (inflation, GDP growth, unemployment rate, interest rates) are initially set to equal their historical average values. All the level variables (HICP, GDP, credit) are extrapolated using the most recent level data and the historical mean growth rates.

Interest rate changes are mimicked by shocking the 6-month Euribor, which is the base interest rate of the euro-denominated loans and therefore relevant from the policy perspective. The share of euro-denominated loans is very high, about 87%. The pricing of new loans is done by setting a risk premium, ϑ, on top of the Euribor rate, i^{ea}: $i_t^m = i_t^{ea} + \vartheta_t^m$. Given this pricing mechanism, Euribor changes are reflected in i^m instantly.

Most of the existing contracts are repriced twice a year, meaning a complete

[38] Shocking by two standard deviations is suggested by the IMF (2002). The probability of a two standard deviation shock is approximately two percent if a normal distribution is assumed. Some studies propose even larger shocks in order to simulate structural breaks in economic relationships and shocks that might never have occurred before but are plausible (Chuhan, 2005).

pass through of Euribor into the interest rate on stock takes about six months. Equation 7 models the movement of the interest rates on stock, $i^{s,m}$, which in principle is the weighted average of repricing the existing loans and the interest rate of new loans, i^m: [39]

$$i_t^{s,m} = \mu^m + \chi_t^m[i_{t-1}^{s,m} + \gamma(i_t^{ea} - i_{t-6}^{ea})] + (1 - \chi_t^m)i_t^m. \tag{7}$$

Parameter γ in equation 7 reflects the proportion of contracts revised each month. If all the contracts were in euros and repriced after every six months, γ would be 1/6. A parameter value less than that shows that not all the contracts are related to the euro. γ can also be less than 1/6 because contracts have interest rates fixed for a longer period. These reasons explain why the estimation of equation 7 shows γ to be 0.12/0.13 (see Table 5).

Table 5: Estimation results: interest rates on stock

	Mortgages	Consumption	Corporate
$\hat{\mu}$	-0.00	-0.00^{***}	-0.00^{***}
$\hat{\gamma}$	0.13^{***}	0.13^{***}	0.12^{***}
$\hat{\theta} \times 10^{-1}$	-0.35^{***}	-0.25^{***}	-0.26^{***}
$\hat{\alpha} \times 10^{-2}$	0.34^{***}	0.13^{***}	0.12
R^2	0.99	0.91	0.99

Notes: Estimation period: April 2003 – June 2009 ($NOB = 75$). ***, ** and * denote statistical significance at levels of 1%, 5% and 10% respectively.

Weighting parameter, χ_t^m, is time variant and it depends on credit growth, $\Delta ln(E_t^m)$: $\chi_t^m = [1 + e^{\theta^m + \alpha^m \Delta ln(E_t^m)}]^{-1}$. At times of faster credit growth the share of the interest rate from new loans increases and it falls in times of slower credit growth. Logistic form keeps the share between zero and one, in the sample χ ranges between 0.8 and 0.95 in all sectors.

A rise in the Euribor rate has a considerable impact on measures of distress. The responses of the average default rate and the NPL and LLP ratios to the historical variances of macro indicators highlight the importance of the interest rate as the main factor determining the ability of banks' credit clients to service their obligations, *ceteris paribus* (see Table 6). The effects of the unemployment rate and economic growth on the LLP ratio equal one of the interest rates. When comparing the two, an increase in the unemployment rate of $1pp$ is about twice as harmful as a fall in output growth of the same magnitude. The difference in their

[39]The re-pricing function developed here is closer to the actual data generating process than is the sluggish adjustment of the lending rate á la Calvo as used for example by Hülsewig et al. (2006).

variance shows that output fluctuations are still potentially 1.5 times more damaging, in terms of the LLP ratio. The inflation rate has only a modest influence on the quality of credit. This is in line with the estimation results of equation 4, which showed that short term fluctuations in inflation are not significant in the calculation of the real interest rate but the long term average inflation rate is.

Table 6: Sensitivity test results

variable (shock size)	Default rate	NPL ratio	LLP ratio
Shock in standard deviations			
Unemployment rate ($+2\sigma(u)$)	0.114	0.983	0.266
Economic growth ($-2\sigma(y)$)	0.259	1.498	0.387
Inflation ($-2\sigma(\pi)$)	0.038	0.120	0.029
Euribor ($+2\sigma(i^*)$)	0.758	2.456	0.693
Combined effect	3.733	34.299	10.219
Shock in percentage/basis points			
Unemployment rate ($+1pp$)	0.017	0.113	0.029
Economic growth ($-1pp$)	0.011	0.054	0.014
Inflation ($-1pp$)	0.005	0.016	0.004
Euribor ($+100bp$)	0.253	0.820	0.230
Combined effect	0.350	1.353	0.381

Notes: deviations are presented in pp's, standard deviations of the macro variables are $\sigma(u) = 2.83$, $\sigma(y) = 7.89$, $\sigma(\pi) = 3.55$, $\sigma(i^*) = 1.08$.

One implication emerging from the sensitivity test is that responses to each individual shock do not add up together to the combined effect caused when all the shocks hit the economy at the same time. The non-linear default rate equation therefore also implies that each determinant is potentially more vulnerable to changes the further off the *other* macro indicators are from their respective means. This sort of interdependence has clear economic logic as, for example, unfavourable or contractionary interest rate shocks are regarded as more damaging when the economic growth rate is lower, and the opposite also holds true. This implies that in order to produce correct distress scenarios, the reactions of the macro variables must be mutually consistent. To ensure that, shock simulations will be carried out with the macro model, which mimics the structure and main features of the Estonian economy.

A critique likely to emerge towards the credit risk model would be that it is not able to pick up all the risk factors. In particular the model does not contain any information on lending standards, which may deteriorate during lending booms.

Claessens et al. (2010a) show that credit booms tend to lower lending standards and open banks to more risks in the future. This is supported by Jiménez and Saurina (2005), who in addition also emphasise that the effect is quite lagged. This phenomenon is potentially significant in explaining credit quality but is omitted by the model because of the lack of related data. The model accounts for the quantitative risk factors only.

3. MACROECONOMETRIC MODEL FOR THE ESTONIAN ECONOMY

3.1. Non-technical overview of the macro model

In principle any macro model serves the same purpose of providing an understanding of how the real economy works by simplifying the complex structures and mechanisms of the economic environment. Given this, the macro model of Estonia is designed to emulate the most relevant features of the Estonian economy. These features are a small, very open and flexible catching up economy with no active independent monetary policy.

The high level of openness makes economic performance highly dependent on trade partners' economic conjuncture, which impact export volumes, as exports are a crucial source of earnings to pay for the imported goods that have no domestic substitutes, as is typical in a very small economy. High levels of openness also mean that the country is exposed to foreign events and sensitive to shocks which originate from the trade partners' economies. The status of a catching-up economy with higher demand for capital goods has meant a negative trade balance and current account deficit for most of the periods during the past twenty years.

The ongoing convergence of income and price levels is yet another significant process, the impact of which is traceable in most of the economic indicators. The *per capita* income level is still below the EU average, but it has risen remarkably fast due to relatively higher productivity growth and capital deepening, which has been caused by several factors such as free mobility of financial capital and the resulting substantial FDI inflows, credit market reorganisation and credit easing. Higher productivity growth has also led to a higher rate of inflation than the EU average because high productivity growth has put pressure on wage and production price inflation, leading to consumption price inflation. Consequently the relative price level has been increasing in close relation to the convergence of income levels. Part of the excess inflation has also been imported because the small size of the economy makes the Estonian trade sector a price taker in international goods markets.

One of the key elements of the Estonian economy has been the use of the currency board arrangement (CBA) as an exchange rate regime. Monetary policy signals under the CBA are exogenous, since there can be no active monetary policy, meaning there are no active monetary policy instruments. Monetary transmission in its authentic sense under a currency board means the transmission of the policy signals generated by the external monetary authority. Estonian kroon has been tied to the euro, which means that these have been euro area monetary policy decisions that have affected local financial conditions. The model treats a currency board as a completely credible fixed exchange rate regime, without a specific feature describing devaluation expectations, in combination with no monetary policy instruments. [40] Being the eurozone member since the 1st of January 2011 requires no change in modelling the exchange rate regime, monetary policy transmission mechanisms and channels remain the same as they were under the CBA.

Macroeconomic time series are given in Estonian kroons to comply with the official data available at the time when the model was estimated. Using prices in kroons is only an accounting issue, denoting everything in euros would just require multiplication of the kroon-denominated series by the official exchange rate. Since the exchange rate has been fixed for the whole period of the model estimation, effectively there is no difference which currency is used.

There are five institutional sectors in the model which embed information on the phenomena listed above: households, government, non-financial companies, financial companies (banks) and the rest of the world. Figure 9 plots these main building blocks of the model and outlines the basic relationships between them.

The household sector is fundamental to the economy as it owns financial capital, which is rented to companies, and it also provides the labour input for production. Households get capital and labour revenues in return, which, taken together with the transfers received from the government minus taxes paid, form households' disposable income. Disposable income is used to finance purchases of either domestically produced or foreign goods (either consumption or investment goods or services), but households can also borrow from the banks. Households can borrow against their income, but credit servicing costs are not allowed to exceed a certain proportion of their income.

The government acts in a model as a redistributive body by collecting taxes and making transfers to households. In addition to this the government sector also spends a fraction of the revenues it collects on buying goods from domestic and foreign companies. The model allows this economic behaviour to be mim-

[40] Political and institutional considerations that in fact distinguish the CBA from the completely credible regime are omitted. In principle there is a possibility that the nominal exchange rate changes even under a CBA (see, for example, game-theoretical model in Batiz and Sy (2000)).

icked under several fiscal policies, so that when automatic fiscal stabilisers are allowed to operate fully then the general government generates surpluses during the upswing of the economy and deficits during the downswing, dampening the volatility of the economic cycle. Alternatively the public sector can be set to run a balanced fiscal strategy where its revenues and expenditures are equal in each period, or a third option is to use a combination of the two extremes in various proportions (described later).

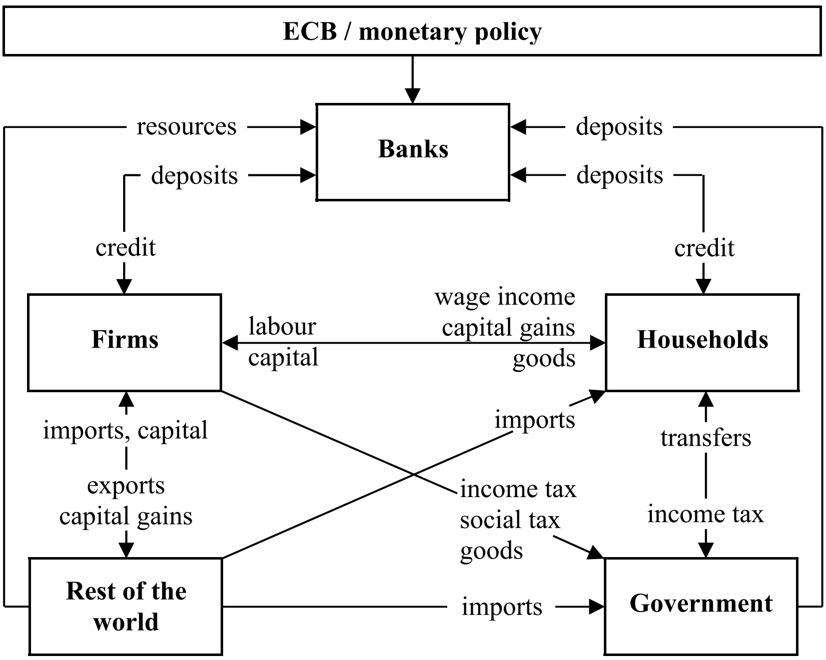


Figure 9: Flows between institutional sectors. Source: author.

Companies accumulate fixed capital and hire labour to produce goods, which are sold in the domestic market or exported. They can engage foreign financial capital or borrow from the banks if local financial capital is not sufficient to finance their purchases of investment goods, either imported or domestically produced. Borrowing of companies is constrained, banks cut lending when debt servicing cost increases in proportion to companies' earnings.

Banks operate as financial intermediaries using not only domestic deposits but also foreign resources to lend money to the private sector. Major banks are either subsidiaries or branches of foreign banks, so domestic resources from deposits are not limiting as the banks have easy access to international capital markets. For this reason, banking sector is modelled mostly as being driven by demand and less as dictated by supply.

The main accounting identities of the sectors, which guarantee the consistency of the model economy, are presented in a condensed and simplified form in Table 7. The total nominal expenditure in the economy consists of household consumption, $C^h P_{C^h}$, household investment $I^h P_{I^h}$, government consumption, $C^g P_{C^g}$, government investment, $I^g P_{I^g}$, corporate investment, $I^f P_{I^f}$ and trade partners' expenditure on exports, XP_X, where C^h, I^h, C^g, I^g, I^f, and X are household consumption, household investment, government consumption, government investment, corporate investment and exports in real terms and P_{C^h}, P_{I^h}, P_{C^g}, P_{I^g}, P_{I^f} and P_X are their deflators (see the full list of acronyms and their description in Appendix 2). The total nominal expenditure equals the receipts of domestic companies, YP, and the export revenues of the rest of the world, MP_M, where Y is real GDP, P is GDP deflator, M denotes real exports and P_M stands for its deflator. The volume of imported goods, MP_M, equals $\varsigma_{C^h} C^h P_{C^h} + \varsigma_{I^h} I^h P_{I^h} + \varsigma_{C^g} C^g P_{C^g} + \varsigma_{I^g} I^g P_{I^g} + \varsigma_{I^f} I^f P_{I^f} + \varsigma_X X P_X$, where ς denotes the import share of each expenditure item.

Companies receive revenues for the goods sold domestically and on foreign markets: $(1-\varsigma_{C^h}) C^h P_{C^h} + (1-\varsigma_{I^h}) I^h P_{I^h} + (1-\varsigma_{C^g}) C^g P_{C^g} + (1-\varsigma_{I^g}) I^g P_{I^g} + (1-\varsigma_{I^f}) I^f P_{I^f} + (1-\varsigma_X) X P_X$. Earned revenues equal companies' total expenditure, consisting of compensation to labour, consumption of fixed capital, gross operating surplus and mixed income, and taxes paid to government. Households receive whL for their labour input, where w is the hourly wage, h is the number of hours worked by a worker and L is the number of workers. Capital depreciation equals $\delta_K K P_{I^f}$, where δ_K is the depreciation rate of physical production capital stock K. Gross operating surplus and mixed income Q is partially retained within the companies to finance investments (Q^f) and the rest is paid to households: $Q^h = Q - Q^f$. The tax burden of companies, T^f, includes social security tax and taxes on production and imports.

Households' nominal disposable income contains net wage earnings, government transfers and operating surplus, and also interest receipts on deposits, $i^{s,d} D^h$, minus interest payments on accumulated debt, $i^{s,h} E^h$: $Y^h P_{C^h} = whL - T^h + G + Q^h + i^{s,d} D^h - i^{s,h} E^h$. Households save what is left of their disposable income after consumption $C^h P_{C^h}$: $S^h = Y^h P_{C^h} - C^h P_{C^h}$.

Taxes paid by companies and households, $T^f + T^h$, form the total revenues of the public sector. The government uses the revenues collected to make transfers to households, G, and spends the rest of them on goods: $(1-\varsigma_{C^g}) C^g P_{C^g}$ comes from the local producers and $\varsigma_{C^g} C^g P_{C^g}$ is imported. Government savings are determined by the budget balance as revenues collected minus payouts: $B = T^h + T^f - C^g P_{I^g} - G$.

Table 7: The main accounting relationships

		Households	Government	Corporations	Banks	RoW
Total consumption	E:	$C^h P_{C^h} + I^h P_{I^h}$	$C^g P_{C^g} + I^g P_{I^g}$	$I^f P_{I^f}$		XP_X
	R:			YP		MP_M
Compensations	E:			$whL + \delta_K K P_{I^f} + Q + T^f$		
	R:	$whL + Q^h$	T^f	$Q^f + \delta_K K P_{I^f}$		
Taxes & transfers	E:	T^h	$G + C^g P_{C^g}$			
	R:	G	T^h	$(1 - m^g) C^g P_M$		$m^g C^g P_M$
Savings	E:	$Y^h P_{C^h} - C^h P_{C^h}$	B	$S - S^h - S^g$		
	R:	S^h	S^g	S^f		
Financial services	E:	$i^{s,h} E^h$		$i^{s,f} E^f$	$i^{s,d}(D^h + D^f + D^F)$	
	R:	$i^{s,d} D^h$		$i^{s,d} D^f$	$i^{s,h} E^h + i^{s,f} E^f$	$i^{s,d} D^{**}$
Net foreign income	E:					R^{FI}
	R:			R^{FI}		
Net foreign transfers	E:					R^{FT}
	R:			R^{FT}		
Foreign trade	E:					XP_X
	R:					MP_M

Notes: RoW—rest of the world, E—expenditures, R—receipts. Expenditure components of GDP are presented in real terms and deflated with their respective deflators. All other variables are expressed in nominal terms.

The total savings in the economy equal the current account balance plus the investments of all sectors: $S = R^{FI} + R^{FT} + XP_X - MP_M + IP_I$, where R^{FI} is net foreign income and R^{FT} is net foreign transfers. Corporate savings are backed out as a residual from $S^f = S - S^h - S^g$. Negative savings are covered by lending D^F from abroad using banks as financial intermediaries. For their bank-intermediated financial services, households and companies pay interest $i^{s,h}$ and $i^{s,f}$ on E^h and E^f respectively. Banks earn on the interest rate spread $i^{s,h}E^h + i^{s,f}E^f - i^{s,d}(D^h + D^f + D^F)$, where $i^{s,d}$ denotes the effective interest rate that banks pay for their resources in the form of deposits from households and companies (D^h and D^f) and interbank (foreign) lending, D^F.

3.2. Theoretical set-up of the core model

3.2.1. The demand side of the economy

Here, a generic demand function is derived. Its construction is similar to that used by Boissay and Villetelle (2005), (Sideris and Zonzilos, 2005), Willman and Estrada (2002) and McGuire and Ryan (2000). The reason for deriving the general demand function is to bind relative prices and demand for goods, as this is necessary later for setting up the representative company's profit maximisation problem.

The consumption basket includes all types of goods, with domestic and foreign goods, public goods and investment goods. Demand for these goods is derived from a utility maximisation problem, where the exact form of the consumer utility function $U(C)$ is left unspecified. The representative household consumes a basket of differentiated goods c_j with constant elasticity of substitution (CES), indicated as C:

$$C = \left(\int_0^1 c_j^{\frac{\varepsilon-1}{\varepsilon}} dj \right)^{\frac{\varepsilon}{\varepsilon-1}}, \tag{8}$$

where ε (satisfying the condition $\varepsilon > 1$) is the elasticity of demand of good c_j to its relative price P/P_j. P denotes the price of the generic good and P_j stands for the price of the product c_j. Consumers maximise their utility along the following iso-elastic demand curves:

$$c_j = C \left(\frac{P}{P_j} \right)^{\varepsilon}. \tag{9}$$

There are N consumers in the economy consuming goods produced by companies. In the equilibrium, the production of good c_j (given as Y_j) must equal the demand for it (c_j^*). Given this, the equilibrium for each good c_j is dependent on relative prices:

$$Y_j = c_j^* N = C^* N \left(\frac{P}{P_j}\right)^{\varepsilon}, \tag{10}$$

where $P = \left(\int_0^1 P_j^{1-\varepsilon} dj\right)^{1-\varepsilon}$. Similarly, as is the case for one specific good c_i, the aggregate demand in the equilibrium has to equal the aggregate supply, so that $Y = C^* N$. The latter constitutes market equilibrium for goods in the open economy because C includes all types of goods, including foreign goods. Substituting $C^* N = Y$ into equation 10 and rearranging the terms yields the relationship for the representative company's profit maximisation problem, which relates the price of production of the *j*-th corporation to the general price level, relative to the volume of production and the price elasticity of demand: $P_j = P(Y/Y_j)^{1/\varepsilon}$.

3.2.2. Supply side of the economy

The supply of goods which determines the behaviour of the model economy in the long run is derived from the representative company's optimisation problem. Companies operate on a monopolistically competitive market, which implies that they have a certain power to fix the price of their goods above the cost of production and earn profits. [41]

The market consists of j monopolistically competing corporations ($j \in [0, 1]$). Each of them produces a differentiated product Y_j using a Cobb-Douglas production function with constant returns to scale and Harrod-neutral (labour augmenting) technological progress. The representative company maximises its profit (Π):

$$\begin{aligned} max_{P_j,Y_j,H_j,K_j} \Pi(Y_j) \quad &= \quad P_j(1-z)Y_j - w(1+q)H_j - P_K K_j && (11) \\ s.t. \quad & \\ & Y_j = K_j^{\alpha} H_j^{1-\alpha} A^{1-\alpha}, && (12) \\ & P_j = P\left(\frac{Y}{Y_j}\right)^{\frac{1}{\varepsilon}}. && (13) \end{aligned}$$

In these z denotes an indirect tax rate. Multiplying P_j, the gross price of produced good Y_j by $(1 - z)$ gives the production price at factor costs, which

[41] Issues regarding the supply side of the model economy such as potential output are covered in more detail in Kattai (2010b).

is the price that the company gets for selling its products. Thus, the expression $P_j(1-z)Y_j$ corresponds to the earnings of a corporation. Production possibilities are determined by the production function (equation 12), where parameter α indicates the income share of capital and A denotes the level of technology. The crucial decision for a company is the level of labour and capital inputs to use. An increase in these inputs raises output, but also increases costs. As the Cobb-Douglas function meets the Inada conditions, where the marginal products of the production inputs are positive, but diminishing, there exists a certain combination of inputs that maximises profits. [42]

Labour costs are expressed as $w(1+q)H_j$, where w is the given nominal hourly wage—the corporation cannot influence the market wage rate—H_j is the total number of hours worked by the labour hired by the j-th company and q stands for the tax rate levied on labour. Here the profit maximisation problem of a corporation is augmented by labour taxation, which essentially is social security payments and an additional component of labour cost.

The total payment for using capital is $P_K K_j$, where P_K is the given nominal user cost of capital, which is the same for all market participants, and K_j is the capital stock rented by the company j. The nominal user cost of capital is defined as:

$$P_K = P(1-z)(r+\delta_K+\rho), \tag{14}$$

where r is the real interest rate, δ_K is the physical depreciation rate of the accumulated capital stock and ρ is risk premium that corporations have to pay. The real interest rate is defined as $r = i - \pi_I$, where i denotes the nominal lending rate and π_I is the investment deflator inflation.

The price of good Y_j depends on the generic price (see equation 13). Substituting P_j from equation 11 with equation 13 and rearranging terms, gives the following maximisation problem:

$$max_{Y_j,H_j,K_j}\Pi(Y_j) \quad = \quad P(1-z)Y^{\frac{1}{\varepsilon}}Y_i^{\frac{\varepsilon-1}{\varepsilon}} - w(1+q)H_j - P_K K_j \tag{15}$$

$$s.t.$$

$$Y_j = K_j^{\alpha}H_j^{1-\alpha}A^{1-\alpha}. \tag{16}$$

Differentiating function 15 with respect to K_j and assuming that the system is in a symmetrical equilibrium ($K_j = K_\iota = K$, $Y_j = Y_\iota = Y \ \forall \ j, \iota$) the overall desired capital stock in the economy becomes:

[42] Originally shown by Inada (1964).

$$K = \frac{1}{\eta}\alpha Y \frac{P(1-z)}{P_K}, \tag{17}$$

where parameter η stands for the mark up, which is defined as $\varepsilon/(\varepsilon - 1)$.

The aggregate demand of hours is also derived from the representative decision-making process of a company. Taking each company's inverted production function and assuming symmetric equilibrium again ($H_j = H_\iota = H$, $K_j = K_\iota = K$, $Y_j = Y_\iota = Y \; \forall \, j, \, \iota$), the demand for total hours worked in the economy is:

$$H = Y^{\frac{1}{1-\alpha}} K^{\frac{-\alpha}{1-\alpha}} A^{-1}. \tag{18}$$

The real wage rate is derived from the first order condition, which equates the marginal labour cost to its marginal product revenue. Differentiating the profit maximisation function (equation 15) with respect to H_j and assuming symmetrical equilibrium ($P_j = P_\iota = P$, $Y_j = Y_\iota = Y \; \forall \, j, \, \iota$) gives for the real hourly wage:

$$\frac{w}{P} = \frac{(1-\alpha)(1-z)}{\eta(1+q)} \frac{Y}{H}. \tag{19}$$

The value of mark up is greater than one by definition because the companies are assumed to be profitable. Equation 19 implies that due to the monopolistic competition causes the real wage paid to the owners of labour to be η times smaller than the marginal productivity of labour. Despite the spread in levels, the growth in the real wage follows the growth in labour productivity.

The key price in the model is the price of production, which in the later work is used to model the domestic component of consumption prices. The equilibrium level of this has been defined as marginal labour cost (unit labour cost—*ULC*) multiplied by mark up:

$$P = \eta \frac{Hw(1+q)}{Y(1-z)(1-\alpha)}. \tag{20}$$

The previous set of equations (17, 18, 19 and 20) is the one that shapes the model's long run growth path. The convergence to a balanced growth path is determined by the parameters of these equations, the calibrated values of which are: $\alpha = 0.4$, $\eta = 1.165$ and $\varepsilon = 9.7$, given that $\bar{z} = 0.115$, $\bar{\rho} = 0.04$, $\delta = 0.01227$ and $q = 0.33$. [43]

[43] Bergheim (2008) claims that it is impossible to test the parameters of the aggregate production function by estimating it as the model would always have a perfect fit due to its construction, which is based on the national income identity.

3.3. The estimated model

3.3.1. Data and estimation method

The data used to construct the model originate from four sources: Estonian national accounts data is provided by the Estonian Statistical Office, Estonian financial statistics by Eesti Pank, confidence indicators by the Estonian Institute of Economic Research, real estate prices by the Estonian Land Board and foreign sector data by the Eurostat database. The model operates using quarterly data, which are available for most of the series. Interpolation and the author's own construction are used otherwise.

All time series in the model are seasonally adjusted. The method used for seasonal adjustment is Tramo/Seats (Time Series Regression with ARIMA Noise, Missing Observations and Outliers/Signal Extraction in ARIMA Time Series). Tramo/Seats is based on the ARIMA model with estimated parameters. One reason why Tramo/Seats is used is that the alternative tools (most common are X12 and X11) work by smoothing the time series (the non-parametric method), which may generate an end-point problem. Biased estimates for the adjusted data in the end of the sample would create problems in the model's forecast and scenario generation properties. Tramo/Seats is also a useful tool when dealing with time series that include missing data. It successfully identifies outliers and eliminates their impact on the adjusted time series, which is not possible with moving-average methods, where the adjusted series is affected by the extreme values.

For aggregate time series that consist of the sum of two or more components, indirect seasonal adjustment is always used. This means that a seasonally adjusted aggregate equals the sum of its seasonally adjusted components. The reason for using indirect adjustment is that each component may have a different seasonal pattern and this fact is ignored when the adjustment technique is applied to aggregate values. Another argument for not adjusting the aggregate and its components separately is the non-additivity problem where the sum of the adjusted components does not add up to the directly adjusted aggregate.

Since 2008 Statistics Estonia has constructed real GDP data by chain linking. One of the implications of the new methodology is non-additivity—real subcomponents of GDP do not add up to the chain linked headline real GDP. This means that the model has to replicate chain linking for all the GDP components, for GDP sub-aggregates like net exports and domestic demand, and for GDP itself. The model solving code calls a programmed routine to perform this task. The annual overlap method which used is described in detail by Bloem et al. (2001).

All the behavioural equations of the model are presented in the form of an error correction model (ECM), constructed using a two-step Engle-Granger technique. The parameters in behavioural equations are estimated using OLS. More elaborate estimation techniques are not used because they do not improve parameter properties in small samples. Cointegration equations are estimated with the standard OLS but dynamic equations are estimated with the trend-weighted OLS to put more weight on the later observations. The maximum time period used for the estimations is 1996 first quarter to 2009 third or fourth quarter, but a shorter time period is often used because of either data availability or data quality.

One of the known weaknesses of macro-econometric models is their exposure to the Lucas critique since the equations do not include ”deep structural parameters” that would be resilient to policy changes. There are papers that confirm the relevance of the Lucas critique [44] but in general there is no particularly strong empirical support for it. Ericsson and Irons (2001) review numerous theoretical and empirical articles and conclude that there is no evidence of the empirical applicability of the Lucas critique, as much of the evidence cited in the literature comes from model mis-specification. [45] Even if the critique is taken seriously, the estimated model of the Estonian macro economy cannot be attacked on the grounds of the Lucas critique because the monetary regime and fiscal policy have been unchanged over the whole estimation period. Although joining the eurozone classifies as a change in the monetary regime, the new regime is not in effect different from the preceding currency board arrangement. [46]

Two supply side equations, the real wage and GDP deflator equations, are restricted in order for the dynamic homogeneity condition to hold. The reason for applying a dynamic homogeneity restriction (DHR) is to ensure that the dynamic and the long run equilibria match. Although Botas and Marques (2002) show that no difference exists between the static and the dynamic long run equilibrium and thus from the theoretical point of view there is no need to impose restrictions, DHR is a standard feature and it is widely used. The DHR applied differs from the standard representation in that it is time varying. As shown in Kattai (2007), time-dependency of the DHR is essential when modelling a converging economy with steady decline in growth rates (see Appendix 3 for details). Supply side equations without DHR would contradict the convergence content of the data by assuming no decrease in price inflation nor in economic growth and the long run simulation properties would be flawed.

[44] See for example Blanchard (1984), Whiteman (1984), Alogoskoufis and Smith (1991).

[45] Bårdsen et al. (2003) for example show that improper modelling of expectations in simultaneous dynamic equations could cause the model’s parameters to change. A correct model specification would offset the Lucas critique.

[46] If Estonia had any other currency regime in place before joining the eurozone then explicit modelling of the regime switch would have been required. Cúrdia and Finocchiaro (2010) estimate a DSGE model for the Swedish economy and find that changes in the monetary regime must be acknowledged in order to avoid spurious results.

3.3.2. Financial sector

The financial sector consists of banks, which operate as financial intermediaries, lending to households and to corporations by signing nominal contracts. Banks build up their resources (liabilities) by collecting deposits, borrowing on the interbank market or from their parent institutions. Banks maximise their profit, which is the difference between interest receipts and resource costs. Banks credit exposure (assets) is split between consumption credit, E^c, mortgage loans, E^h, and corporate credit, E^f. At any given time a certain fraction of clients fail to fulfil their obligations to service their debts and these debts stand out as non-performing loans, N, so the interest is actually earned on $E^m - N^m$, $m \in \{c, h, f\}$. On the cost side banks pay an effective interest rate $i^{s,d}$ on the engaged resources engaged from deposits by households and companies, D^h and D^f, and from foreign funds D^F:

$$\begin{aligned} \Pi_t^b &= i_t^{s,c}(E_t^c - N_t^c) + i_t^{s,h}(E_t^h - N_t^h) + i_t^{s,f}(E_t^f - N_t^f) \\ &- i_t^{s,d}(D_t^h + D_t^f + D_t^F). \end{aligned} \tag{21}$$

A high ratio of non-performing loans to overall exposure during stressful times may cause banks to suffer substantial losses and may potentially lead to bankruptcy. However, bank failure is a micro phenomenon and not assessable at aggregate levels, and supervisory authorities or central banks are concerned about the performance of individual banks, which is more informative. For this reason the macro model is not designed to perform banking sector stress tests but it allows different macro scenarios to be produced which can be used as an input by the credit risk model, returning stress test results at the single bank level. The drawback is that the macro model would not be able to quantify the effects of the banking sector failure to the real economy. But given that it has no real value at the aggregate level, the aim of the macro model is to produce macro scenarios conditional on the general financing conditions.

Banks set the price of lending by asking a risk premium, ϑ, on top of the base interest rate , i^{ea}. The base rate used in the model is the Euro Area interbank rate (six month Euribor), which is the base rate for the vast majority of the existing loan contracts and new ones. Banks differentiate two components of the risk premium. The first component is the "inflation risk premium" [47] , which is the steady trend-like decline in the premium associated with the stabilisation of inflation, denoted by Ψ. Low inflation rates are also accompanied by lower volatility, which lowers risks and hence the risk premium (Padoan, 2001).

[47] The terminology originates from Armitage (2005).

The other component is related to specific, probabilistic events, such as a sudden contraction in the economy, which may occur following various shocks. If these shocks occur, banks raise the risk premium by $\psi^m, m \in \{c, f, h\}$, which is conditioned on the debt to assets ratio, Υ^m, of borrowers. A higher debt to assets ratio is associated with higher riskiness and therefore the risk premium demanded is also higher, *ceteris paribus*. Households' assets are their deposits, while the assets of companies are their deposits and accumulated physical production capital. The event that triggers banks to increase the premium suddenly is annual real GDP growth falling below zero: $\Delta_4 ln(Y_t) < 0$. The particular trigger is used with the motivation that banks see higher risks only if the economy contracts, which means fall in income and revenues of their clients. Any positive growth is treated as non-risky macro environment. [48] All the lending rates i^m, are represented in the form of:

$$i_t^m \;=\; i_t^{ea} + \vartheta_t^m, \quad \vartheta_t^m = \Psi_t^m + \psi^m(\Upsilon_t^m)\mathbf{1}_{\{\Delta_4 ln(Y_t)<0\}}. \tag{22}$$

Interest paid on deposits follows quite similar rule. The risk premium ϑ^d offered to depositors, either households or companies, on top of the interbank rate depends on the moving average inflation rate, $\xi(\pi)$, and on the additional premium when the real economy contracts and resources become more scarce:

$$i_t^d \;=\; i_t^{ea} + \vartheta_t^d, \quad \vartheta_t^d = \xi(\pi_t) + \psi^d\mathbf{1}_{\{\Delta_4 ln(Y_t)<0\}}. \tag{23}$$

Households are entitled to take two different types of loans, mortgage loans and consumption credit. Newly issued mortgage and consumer loans are denoted by $E^{T,h}$ and $E^{T,c}$. The outstanding stocks of both types of loan build up through the accumulation processes $E_t^h = (1 - \delta_{t-1}^h)E_{t-1}^h + E_t^{T,h}$ and $E_t^c = (1 - \delta_{t-1}^c)E_{t-1}^c + E_t^{T,c}$. Parameters δ^h and δ^c are the fractions of mortgages and consumer credit that households have to pay back each period. Effectively $\delta_{t-1}^h E_{t-1}^h$ and $\delta_{t-1}^c E_{t-1}^c$ are the principal payments. Both parameters have been close to constant values historically, but they are treated as time-variant to account for the slight changes in the past.

Households' demand for mortgages is modelled as proportional to the sector's demand for investment, which functions as a scale variable. This stems from the fact that some of the new mortgages are used to finance investments in housing

[48] The data confirm that banks do not increase the premium gradually in these circumstances but very rapidly like a regime shift.

and the remaining part is used to buy real estate on the secondary market. [49] The other factor driving the demand for mortgages is the risk premium, defined as the spread between the interest rate of the newly issued mortgage loans, i^h, and the base interest rate, i^{ea}: $\vartheta_t^h = i_t^h - i_t^{ea}$. Using the risk premium in the equation instead of taking the total interest on the new loans is motivated by the fact that borrowers make their lending decision based on the premium they have to pay on top of the base interest rate. A higher premium would lift the discounted interest payments even if the base interest rate is low since the premium is fixed for the whole contract period.

Households are constrained from borrowing excessively as an increase in the ratio of the credit servicing cost to households' disposable income reduces the issuance of new loans. The relative debt servicing cost is given by $i_{t-1}^{s,h} E_{t-1}^h (Y_{t-1}^h P_{C^h,t-1})^{-1}$, where Y^h is households' real disposable income and P_{C^h} is the private consumption deflator. Interest on the stock of mortgages, $i^{s,h}$, evolves recursively through the re-pricing of existing contracts and the signing of new ones at the new rates. [50] The stock interest rate follows the process $i_t^{s,h} = \chi_t^h (i_{t-1}^{s,h} + \phi^h \Delta_3 i_t^{ea}) + (1 - \chi_t^h) i_t^h$, where the weight parameter χ^h equals $(1 + e^{-0.781 - 2.302 E_t^{T,h} E_t^{h^{-1}}})^{-1}$. χ^h increases when relatively fewer new loans are issued and falls when there are relatively more. This also implies that sudden interest rate shocks transmit into the stock rates only gradually and hence the impact on credit holders' interest payment is not immediate (historically χ^h has ranged between 0.7 and 0.77). Changing weights have an interesting feature in terms of how monetary policy shocks are transmitted into the financial variables and into debt servicing costs. Since expansionary monetary policy increases credit turnover and lowers χ^h, the effect on both sets of variables is faster than that of the transmission of the contractionary shock. The estimated equilibrium level of mortgage credit turnover is given in equation 24a, t-statistics of the estimated coefficients are presented below the coefficient values (see Appendix 4 for more estimation details):

[49] It is assumed in the model that the proportions are stable. Investment activity is also supposed to pick up cyclical pressures and market disturbances, as household investments depend on real estate prices and possible price-bubbles as shown later. This is necessary for the correct estimation of the role of the interest rate in the credit demand as according to Rabin (2004), mis-specification of the initial disturbances of the credit market leads to an invalid relationship between the interest rate and the associated financial variable.

[50] The re-pricing scheme is the same as in the credit risk model. The two differ in terms of the data frequency.

$$ln(E_t^{T,h^*}) = \underset{2.707}{1.059} + ln(I_t^h P_{I^h,t}) - \underset{-13.968}{0.655}\, ln(\vartheta_t^h) \qquad (24a)$$
$$+\underset{10.692}{0.265} ln(Y_{t-1}^h P_{C^h,t-1}(i_{t-1}^{s,h} E_{t-1}^h)^{-1}),$$

$$\Delta ln(E_t^{T,h}) = -\underset{-0.924}{0.014} - \underset{-3.428}{0.506} ln(E_{t-1}^{T,h} E_{t-1}^{T,h^{*-1}}) - \underset{-2.390}{66.554}\Delta(\vartheta_t^h) \qquad (24b)$$
$$+\underset{5.105}{0.793}\Delta ln(I_t^h P_{I^h,t}) + \underset{2.092}{0.212}\Delta ln(E_{t-1}^{T,h}).$$

The dynamic equation reveals a very rapid correction to the intermediate target as the estimated coefficient for the error correction mechanism is -0.506. Households' housing investments are equally important, and an increase in investment of one percent raises mortgage turnover by almost 0.8 percent in the same period, with error correction covering the remaining 0.2, since in the long run the elasticity of mortgages with respect to housing investment is one. The rest of the variation in mortgage turnover is explained by the interest rate spread and inertia in lending.

Households' demand for consumer credit is built on the same principles as demand for mortgages (see equation 25a). The main difference is in the scaling of the consumer credit to consumption instead of investments in the long run. According to the parameter estimates of the long-run relationship, the sensitivity of consumer credit to the interest rate spread is almost the same as that of mortgages. The borrowing constraint is, on the other hand, looser (0.097¡0.265). This may reflect the fact that consumption loans have shorter maturities and that the average size of an individual loan is considerably smaller, meaning the already existing stock of consumer credit and interest payments are less binding. Monetary policy shocks are also transmitted into the stock interest rate more slowly, making consumer credit less responsive. The interest rate on stock is $i_t^{s,c} = \chi_t^c(i_{t-1}^{s,c} + \phi^c \Delta_3 i_t^{ea}) + (1 - \chi_t^c) i_t^h$, where the weight parameter $\chi^c = (1 + e^{-0.865 - 6.042 E_t^{T,c} E_t^{c^{-1}}})^{-1}$. χ^c has been between 0.82 and 0.94 historically and therefore the adjustment of $i^{s,c}$ is more sluggish than $i^{s,h}$.

$$ln(E_t^{T,c^*}) = -\underset{1.835}{2.546} + ln(C_t^h P_{C^h,t}) - \underset{-6.216}{0.643} ln(\vartheta_t^c) \qquad (25a)$$
$$+\underset{1.453}{0.097} ln(Y_{t-1}^h P_{C^h,t-1}(i_{t-1}^{s,c} E_{t-1}^c)^{-1}),$$

$$\Delta ln(E_t^{T,c}) = -\underset{-0.957}{0.007} - \underset{-4.827}{0.694} ln(E_{t-1}^{T,c} E_{t-1}^{T,c^{*-1}}) - \underset{-2.430}{8.678}\Delta(\vartheta_t^c) \qquad (25b)$$
$$+\underset{2.021}{0.595}\Delta ln(C_t^h P_{C^h,t}) + \underset{1.899}{0.250}\Delta ln(E_{t-1}^{T,c}).$$

The behaviour of consumer credit in the short run is very similar to the behaviour of mortgages. Scaling the variable to private consumption affects borrowing immediately as credit is used to finance purchases in the same period. The coefficient for the interest rate spread is about one eighth of that for mortgages, which is a consequence of the high volatility of i^c. Borrowing for consumption purposes also exhibits quite strong inertia.

The borrowing desired by companies is scaled to their investments, $I^f P_{I^f}$, where I^f denotes real corporate investment and P_{I^f} is its deflator (see equation 26a). The spread between the interest rate on newly issued corporate loans and Euribor, ϑ^f, serves as an important demand factor, although corporate lending is approximately half as sensitive to changes in spread as are mortgages and consumer credit. The reason for this may lie in the fact that companies are more able to cushion the higher price of financial services by temporarily lowering the price mark-up of their products. They would still invest and build up physical capital stock, preparing to meet demand for their products in the next phase of the cycle. Households, therefore, are more motivated to postpone lending and investing until the interest rate margin falls.

Corporations are also constrained from borrowing excessively in the same manner as households were, as the availability of credit depends on the interest payment on the debt already accumulated. The higher the interest payment ratio to earnings, YP, the less they can borrow, and the smaller corporate credit turnover, $E^{T,f}$.

The long-run relationship of corporate credit includes an additional factor to capture structural changes in the bank lending. Unlike the repayment rates for mortgages and consumer credit, the corporate credit repayment rate has changed substantially over time. δ^f has declined from 0.45 to about 0.2 between 2002 and 2010, while δ^h was close to 0.05 and δ^c close to 0.2 in the same period. A lower δ^f-value means that relatively smaller share of the new corporate credit is paid back within the same period, hence the new credit builds up the debt faster in the accumulation process where $E_t^f = (1 - \delta_{t-1}^f)E_{t-1}^f + E_t^{T,f}$. In that case, δ^f appears in equation 26a as highly significant and with a negative sign, reducing corporate credit turnover:

$$
\begin{aligned}
ln(E_t^{T,f^*}) = &-\underset{-2.200}{2.454} + ln(I_t^f P_{I^f,t}) - \underset{-4.412}{0.331} ln(\vartheta_t^f) \\
&+\underset{2.573}{0.270} ln(Y_{t-1}P_{t-1}(i_{t-1}^{s,f}E_{t-1}^f)^{-1}) - \underset{-5.045}{0.702} ln(\delta_t^f),
\end{aligned} \tag{26a}
$$

$$\Delta ln(E_t^{T,f}) = -\underset{-0.543}{0.007} - \underset{-2.957}{0.549} ln(E_{t-1}^{T,f} E_{t-1}^{T,f^{*-1}}) - \underset{-5.534}{58.858} \Delta(\vartheta_t^f) \tag{26b}$$
$$+\underset{2.251}{0.379} \Delta ln(I_t^f P_{I^f,t}) + \underset{1.086}{0.236} \Delta ln(E_{t-1}^{T,f}) - \underset{-3.191}{0.501} \Delta\delta_{t-1}^f.$$

Like the other types of bank lending, corporate credit corrects itself very quickly to the targeted levels as the error correction coefficient takes the estimated value of -0.549 (see equation 26b). In accordance with the low responsiveness to the interest rate spread in the long-run equation, the dynamic equation exhibits strong inertia. It matches the consideration that companies target smooth investment by using bank lending while the other sources of financing will still make corporate investment the most volatile component of GDP. $i^{s,f}$ follows the process $i_t^{s,f} = \chi_t^f(i_{t-1}^{s,f} + \phi^f \Delta_3 i_t^{ea}) + (1 - \chi_t^f) i_t^h$, where the weight parameter $\chi^f = (1 + e^{-1.061 - 9.938 E_t^{T,f} E_t^{f^{-1}}})^{-1}$. The weight, χ^f, has steadily fallen from 0.97 in 2002 to 0.63 in 2009.

3.3.3. Real sector

The domestic real sector is split into four components: capital formation, private consumption, inventory investments and NPISH (non-profit institutions serving households) consumption. The latter is left exogenous because of its marginal contribution to output.

Productive investments

The intermediate target of total investment demand reflects the change in the desired overall capital stock K^*. This is derived from the profit maximisation problem of a representative company (equation 17). Since only companies, either private or public owned, are profit maximising and seek optimal capital stock, it is only the fixed capital purchases of companies and government which are regarded as productive and build up the physical production capital. Although households' investments in housing generate value added by producing imputed rent, they are not competitive with corporate investments and therefore are regarded out of the productive capital stock.

Investments are modelled using a top-down principle, so a behavioural equation provides total demand for productive investment goods in the economy, I^p, where $I^p = I^g + I^f$, I^g denoting government and I^f corporate investments. [51] Assuming perfect crowding in and crowding out effects, corporate investments

[51] The two types of investment are shown added together for the ease of presentation. In reality, the chain-linking of the original data means that all the components of GDP are non-additive and higher aggregates are obtained by chain-linking.

are revealed by the identity $I^f = I^p - I^g$, in which the government investments are either exogenously determined or given by the model's fiscal rule.

Writing equation 17 in logarithmic form and substituting in the capital accumulation identity $K_t^p = (1 - \delta_K)K_{t-1}^p + I_{t-1}^p$ gives investment demand in the steady state: $ln(I^{p*}) = ln(K^{p*}) + ln(g + n + \delta_K)$, in which g denotes the speed of technological progress and n is labour growth. The latter shows that on a balanced growth path investments grow at the same speed as capital stock (given that $\partial(g + n + \delta_K)/\partial t = 0$ on a balanced growth path). In other words, investments are just sufficient to ensure that the capital to output ratio remains constant. It is important to mention here that this relationship only holds in the steady state. For the time that the economy is not on a balanced growth path, a higher marginal productivity of capital causes an increase in the capital to output ratio.

Replacing K^{p*} with the expression from equation 17 yields the long-run investment demand function, conditional on the real user cost of capital, $r_t + \delta_K + \rho_t$ (see equation 27a). The real user cost of capital includes two time varying components, the real lending rate, r, and the entrepreneurial risk premium, ρ. The real lending rate is defined as the difference between the nominal lending rate to companies and the investment deflator inflation: $i^f - \pi_I$, and the entrepreneurial risk premium is proxied by the interest spread between the local lending rate and Euribor: $\rho = i^f - i^{ea}$. Since banks price lending at the Euribor rate plus the risk premium, $i^f = i^{ea} + \vartheta^f$, any movement in ϑ^f changes both, the lending rate and the entrepreneurial risk premium. [52] Therefore, a euro area monetary policy shock to Euribor only affects the lending rate and leaves the entrepreneurial risk unchanged.

All this description applies to the investment demand that enables companies to build up the *desired*, *optimal* physical capital stock. In reality companies are *resource constrained*, they can either use operating surplus from the previous period, Q_{t-1}^f, interest earnings on deposits, $i_{t-1}^d D_{t-1}^f$, or new bank credit, $E^{T,f}$ to finance investments. They also have to pay interest on their previously generated debt, $i_t^{s,f} E_{t-1}^f$, which shows that the more indebted the companies are, the the less they can invest from the previous period's earnings and the more sensitive they are to monetary policy shocks, *ceteris paribus*. Resource constraint is estimated in equation 27b, where the coefficient for new credit is calibrated to 0.157 to mach the fact that on average about 40% of investment purchases are financed with bank credit and the rest of them with internal funds (Choueiri et al., 2009).

[52] Some earlier studies treat the Estonian country specific risk component in the nominal interest rates as a random walk process with the zero mean (Kattai, 2004a) and the spread between the interest rates has been explained by the euro area inflation differential (Sepp and Randveer, 2002). However, recent developments have proven that banks will respond to macroeconomic shocks by changing the risk premium on lending to households and companies.

In the world of limited resources, companies want to invest $I^{p^{*1}}$ but may be constrained so they can invest only $I^{p^{*2}}$. If $I^{p^{*2}} < I^{p^{*1}}$ then corporations cannot achieve their desired physical capital stock, if $I^{p^{*2}} > I^{p^{*1}}$ then they are able to finance investments above the optimal level, but this would not be economically efficient. This decision-making process is written into the error correction component of the dynamic equation (27c) where $I^{p^{*1}}$ and $I^{p^{*2}}$ appear in the Leontief production function bundle:

$$ln(I_t^{p^{*1}}) = ln(\alpha\eta^{-1}) + ln(Y_t) - ln(r_t + \delta_K + \rho_t) + ln(g + n_t + \delta), \quad \text{(27a)}$$

$$ln(I_t^{p^{*2}}) = ln(\underset{46.659}{0.786} Q^f_{t-1} P^{-1}_{I^p,t} + i^d_{t-1} D^f_{t-1} P^{-1}_{I^p,t} + \underset{-}{0.157} E_t^{T,f} P^{-1}_{I^p,t} \quad \text{(27b)}$$
$$- i_t^{s,f} E^f_{t-1} P^{-1}_{I^p,t}),$$

$$\Delta ln(I_t^p) = \underset{0.845}{0.008} - \underset{-3.555}{0.340} ln\{I^p_{t-1}[min(I^{p^{*1}}_{t-1}, I^{p^{*2}}_{t-1})]^{-1}\} \quad \text{(27c)}$$
$$+\underset{2.934}{0.170} \Delta ln(E^{T,f}_{t-1} P^{-1}_{I^p,t-1})(E^{T,f}_{t-2} P^{-1}_{I^f,t-2}) I^{f^{-1}}_{t-2} + \underset{3.362}{0.300} \Delta ln(Q^f_{t-1} P^{-1}_{I^p,t-1}).$$

In the short run, productive investments are driven by new credit turnover and operating surplus. The effect on investments of growth in new credit depends on the proportions of credit turnover and investments. Estimation of equation 27c shows that investments tend to overreact to credit turnover as the estimated dynamic coefficient is larger than the long-run relationship: 0.170 $(E^{T,f} P^{-1}_{I^f}) I^{f^{-1}} \approx 0.40 > 0.157$. Operating surplus and mixed income, on the other hand, do not generate any overreaction. This outcome captures the essence of investment activity during the credit boom, but it could also reveal the more volatile nature of investments in general.

Private consumption and investments by households

Households decide in each period how much to consume and how much to invest. For each period they receive gross wage income, $w(1+q)H$, government transfers, G, interests on deposits, $i^{s,d}D^h$, operating surplus and mixed income, Q^h, and ownership revenue, O. At the same time households pay income tax, T^h, social tax, T, and interests and principal payments on the outstanding stocks of consumer credit and mortgage loans, $(i^{s,c} + \delta^c)E^c$ and $(i^{s,h} + \delta^h)E^h$. The net total of these money flows equal private consumption C^h, newly issued consumer credit to cover negative savings, $E^{T,c}$, and change in households' deposits, ΔD^h

minus the difference between new mortgage loans and households' investments, $E^{T,h} - I^h P_{I^h}$. The latter stems from the quadruple bookkeeping principle used between the institutional sectors. [53] $E^{T,h} - I^h P_{I^h}$ of the new mortgages are used to finance home purchases on the secondary market and therefore the household sector retains that money, while $I^h P_{I^h}$ is transferred to companies to cover the cost of the purchases of new dwellings. Households' budget constraint therefore is:

$$\begin{aligned} & w_t(1+q)H_t + G_t + Q_t^h + O_t + i_{t-1}^{s,d} D_{t-1}^h \\ & -T_t^h - T_t - (i_{t-1}^{s,c} + \delta_{t-1}^c)E_{t-1}^c - (i_{t-1}^{s,h} + \delta_{t-1}^h)E^h \\ = \; & C_t^h P_{C^h,t} - E_t^{T,h} + \Delta D_t^h - (E^{T,h} - I_t^h P_{I^h,t}). \end{aligned} \tag{28}$$

Consumer credit and mortgage loans evolve according to the accumulation processes $E_t^c = (1 - \delta_{t-1}^c)E_{t-1}^c + E_t^{T,c}$ and $E_t^h = (1 - \delta_{t-1}^h)E_{t-1}^h + E_t^{T,h}$. Substituting these into equation 28 and rearranging it gives:

$$\begin{aligned} Y_t^h P_{C^h,t} &= w_t(1+q)H_t + G_t + Q_t^h + O_t + i_{t-1}^{s,d} D_{t-1}^h \\ & \quad -T_t^h - T_t - i_{t-1}^{s,c} E_{t-1}^c - i_{t-1}^{s,h} E^h \\ &= C_t^h P_{C^h,t} + \Delta D_t^h - \Delta E_t^c - \Delta E_t^h + I_t^h P_{I^h,t}, \end{aligned} \tag{29}$$

where $Y^h P_{C^h}$ is households' nominal disposable income. [54] The difference between disposable income and consumption are households' savings, which equation 29 shows as equal to investments plus change in net assets: $S^h = Y^h P_{C^h} - C^h P_{C^h} = I^h P_{I^h} + \Delta D - \Delta E^c - \Delta E^h$. Savings can be positive or negative, depending on whether households save a fraction of their disposable income or cover their excess consumption costs with borrowing from the banks.

Households are considered to spend disposable income on consumption goods according to the life-cycle hypothesis, which states that the representative agent consumes the permanent income and the real interest rate. Following Muellbauer and Lattimore (1995) private consumption is:

$$C_t^h = (a_{ML} V_t + b_{ML} Y_t^h)(1 + v_t), \tag{30}$$

[53] See Lequiller and Blades (2006).

[54] The formula for calculating of the households' disposable income closely matches the concept of Statistics Estonia (see Läänemets and Mertsina (2009)).

where V is real financial wealth, here defined as net money holdings, which equals households' deposits minus their debt, deflated with the private consumption deflator: $(D^h - E^h - E^c)P_{C^h}^{-1}$. [55] Y^h is a household's real disposable income and v represents a stochastic error term. Rearranging equation 30 gives $C_t^h = b_{ML}Y_t^h(1 + a_{ML}V_t b_{ML}^{-1} {Y_t^h}^{-1})(1 + v_t)$ and if logs are taken and linear approximation used it can be rewritten as:

$$ln(C_t^h) \approx c_{ML} + ln(Y_t^h) + d_{ML}V_t {Y_t^h}^{-1} + v_t. \tag{31}$$

Equation 31 implies there is long-run homogeneity of consumption with respect to income. This means that in equation 31 the permanent income hypothesis holds.

Equation 31 is econometrically estimated to retrieve the long-run rate of private consumption. The consumer confidence index has been added to the right hand side of the equation in order to capture motives for saving and the cyclical nature of the private consumption data. [56] Since the consumer confidence index enters as a deviation from its own historical mean, $\tilde{c} = c - \bar{c}$, it has no effect on consumption in the long run. The coefficient value 0.005 means that the standard deviation of $\tilde{c} = 10.4$ has caused private consumption to fluctuate by about 5.3% from its smooth long run target on average (see equation 32a). The estimated value of d_{ML} is approximately 0.02, showing that an increase of one percent in the permanent-current income proportion increases consumption by about two percent: [57]

$$ln(C_t^{h^*}) = ln(Y_t^h) + \underset{2.581}{0.021}(D_t^h - E_t^h - E_t^c)P_{C^h,t}^{-1} {Y^h_t}^{-1} + \underset{7.549}{0.004}\tilde{c}_t, \tag{32a}$$

$$\begin{aligned}\Delta ln(C_t^h) = & -\underset{-1.364}{0.003} - \underset{-1.593}{0.158} ln(C_{t-1}^h {C_{t-1}^{h^*}}^{-1}) + \underset{5.579}{0.673}\Delta ln(Y_t^h) \\ & + \underset{4.782}{0.933}\Delta ln(E_t^{T,c}P_{C^h,t}^{-1})(E_{t-1}^{T,c}P_{C,t-1}^{-1}){C_{t-1}^h}^{-1}.\end{aligned} \tag{32b}$$

[55] In the model framework households keep their financial assets only in time deposits. It is a fair reflection of the reality because Estonian households have a very small fraction of their assets in stocks or bonds. Consumption of housing wealth is implicitly built in the budget constraint, as households receive $E^{T,h} - I^h P_{I^h}$ for selling their property, which is added to deposits and/or consumed.

[56] Hall (1978) explains that rationally behaving households ought to be able to offset any cyclical pattern and restore the non-cyclical optimal consumption predicted by the hypothesis. However, non-cyclicality cannot be observed in the actual data, and therefore an additional cycle-explaining variable is needed for econometric reasons.

[57] For example, Willman and Estrada (2002) get the same estimate for the Spanish economy.

The short-run dynamics of private consumption are driven mainly by disposable income, 67% of which is spent in the same period, on average. The relevance of consumer credit in explaining private consumption depends on the lending activity. The greater the ratio of new credit to consumption, the larger the impact of a change of one percent in lending. The estimated coefficient gives 2-16% for the share of credit-financed goods during 2000–2009, but it mostly stays below 10%. The relatively small share come about because the effect of lending cycles is supposed to be only modest on private consumption. Pro-cyclical behaviour, however, is amplified by the consumer confidence indicator.

In the long run households are expected to invest in housing proportionally to their disposable income. The actual level of investment depends on the availability of mortgage loans, $E^{T,h}P_{I^h}^{-1}$, and on real estate prices, P_h. An increase in real estate prices compared to the general price level of consumer goods, P_{C^h}, lessen the incentives to invest in new housing stock:

$$\begin{aligned} ln(I_t^{h^*}) = -\underset{-28.183}{5.915} + ln(Y_t^h) + \underset{11.502}{0.513} ln(E_t^{T,h}P_{I^h,t}^{-1}) \\ -\underset{-2.356}{0.213} ln(P_{h,t}P_{C^h,t}^{-1}), \end{aligned} \tag{33a}$$

$$\begin{aligned} \Delta ln(I_t^h) = \underset{0.397}{0.003} - \underset{-4.389}{0.508} ln(I_{t-1}^h I_{t-1}^{h^{*-1}}) \\ +\underset{9.157}{0.291}\Delta ln(E_t^{T,h}P_{I^h}^{-1})(E_{t-1}^{T,h}P_{I^h,t-1}^{-1})I_{t-1}^{h^{-1}} + \underset{2.527}{0.202}\Delta ln(I_{t-3}^h). \end{aligned} \tag{33b}$$

The short-run dynamics of housing investments are dependent on lending activity and inertia. Despite the volatile nature of households' investments, they have only a little effect on general economic activity, since housing investments are only about 12–14% of total fixed capital formation.

Inventory investments

The basic principle of modelling a change in inventory investments, Z, involves fixing its stock value, Z^s, to output in the long run, Y^*. In logistic form the relationship becomes: $ln(Z_t^s) = a + ln(Y_t^*)$, where a measures the ratio of the stock of inventories to output. Using the accumulation identity $Z_t^s = Z_{t-1}^s + Z_{t-1}$ enables this to be rewritten it in terms of the change in inventories: $Z_t = e^a \Delta Y_{t+1}^*$, which shows that companies generate buffers for the next period. For corporations $\mathbb{E}_t \Delta Y_{t+1}^* \approx \Delta Y_t^*$ and the estimated equation takes the form $Z_t^* = e^a \Delta Y_t^*$ (see equation 34a). Any deviation from the "natural" level, Z^*, is associated with higher costs, as higher stock value increases maintenance costs, whereas a stock value that is too low may not provide a sufficient buffer during downturns. This is reflected by the adjustment term in the dynamic equation where the coefficient 0.332 implies that corrections are relatively quick (see equation 34b):

$$Z_t^* = \underset{9.455}{1.754} \Delta Y_t^*, \tag{34a}$$

$$\Delta Z_t = \underset{0.719}{67.603} - \underset{-1.808}{0.332}(Z_{t-1} - Z_{t-1}^*) + \underset{0.984}{0.091}(\Delta J_{t-1} - 1.529 \Delta Y_{t-1}) \tag{34b}$$
$$-\underset{-0.898}{0.445} \Delta(r_t^f Z_t^s) - \underset{-1.642}{0.187} \Delta Z_{t-1}.$$

Changes in inventories mirror the sales cycle. Sales, J, consist of storable goods, which in this particular work are proxied by the sum of private consumption and exports. The relationship is pro-cyclical, meaning that if sales exceed their long-run level, given as a proportion of potential output, corporations create buffer stocks of raw materials used in the production process.

The term $r^f Z^s$ captures the cost of holding inventories. The price faced by companies is reflected by the real interest rate r^f. An increase in the interest rate raises opportunity costs and thereby motivates companies to lessen their stock of inventories.

3.3.4. External sector

External trade is split into exports of goods and services and imports of goods and services. It was earlier defined that goods produced and consumed are of the same generic category. The same applies for goods that are traded externally. In the model it is assumed that imported and domestically produced goods are perfect substitutes.

Imports

The cointegration relationships of imports of goods and imports of services, M_G and M_S, are modelled as functions of the domestic import demand indicator and relative prices. Import demand, M_D, is proxied by the weighted sum of private and public consumption, productive investments, inventory investments and exports: $M_D = \varsigma_{C^h} C^h P_{C^h} + \varsigma_{I^h} I^h P_{I^h} + \varsigma_{C^g} C^g P_{C^g} + \varsigma_{I^g} I^g P_{I^g} + \varsigma_{I^f} I^f P_{I^f} + \varsigma_Z Z P_Z + \varsigma_X X P_X$, where ς is the import share of each expenditure item. The weights for each demand component are calibrated from the input-output tables and take the following values: $\varsigma_{C^h} = 0.34$, $\varsigma_{I^h} = 0$, $\varsigma_{C^g} = 0.25$, $\varsigma_{I^g} = 0.58$, $\varsigma_{I^f} = 0.58$, $\varsigma_Z = 1.1$ and $\varsigma_X = 0.59$. The relative price of domestic and foreign goods is measured in the GDP deflator at factor cost $P(1-z)$ and the import deflator P_M ratio. Long-run equations for imports of goods and services are estimated in a system. The estimation shows that 84.3% of imports are imports of goods and the remaining 15.7% are imports of services, which roughly corresponds to the historical proportions:

$$ln(M^*_{G,t}) = ln(\underset{118.7}{0.843}M_{D,t}) + \underset{9.247}{0.587}ln(P_t(1-z)P^{-1}_{M_G,t}), \tag{35a}$$

$$\begin{aligned} ln(M^*_{S,t}) = ln((1-\underset{118.7}{0.843})M_{D,t}) + \underset{0.626}{0.135}ln(P_t(1-z)P^{-1}_{M_S,t}) \\ +\underset{2.522}{4.844} - \underset{-4.683}{0.466}ln(time). \end{aligned} \tag{35b}$$

Due to nominal convergence, domestic production prices increase faster than foreign prices, which implies that domestically produced goods become more expensive than imported ones. Under the assumption of perfect substitutability, this would increase demand for imported goods and services. An increase in the GDP deflator from 66.4% (Eurostat estimate for 2009) to the 100% of the EU15 would increase the value of $P(1-z)/P_{M_G}$ and the value of $P(1-z)/P_{M_S}$ by 51%. [58] As a result of this, the ratio of imports of goods to GDP is expected to increase by a factor of $1 - 0.51^{0.587} = 0.32$ and the ratio of imports of services to GDP by a factor of $1 - 0.51^{0.135} = 0.09$ *ceteris paribus*.

In the short run, the dynamics of imports of goods are determined by the weighted demand for imports with unit elasticity, where the estimated coefficient is 0.842 which basically equals 0.843, the estimated long run effect (equation 35a). According to the estimate any change in import demand will be transmitted into the imports immediately. Relative prices, on the other hand, exhibit less importance in the short run. An increase in the foreign price level by one percent lessens the amount of imported goods by 0.2 percent if the domestic production price remains unchanged (see equation 36a). The estimated short-run effect is approximately one-third of the long-run effect, showing that the imports of goods react to price changes sluggishly:

$$\begin{aligned} \Delta ln(M_{G,t}) = -\underset{-0.271}{0.001} - \underset{-3.968}{0.354}ln(M_{G,t-1}M^{*^{-1}}_{G,t-1}) + \underset{7.796}{0.842}\Delta M_{D,t} \\ +\underset{0.930}{0.202}\Delta ln(P_{t-3}(1-z)P^{-1}_{M_G,t-3}) + \underset{4.152}{0.389}\Delta ln(M_{G,t-1}), \end{aligned} \tag{36a}$$

[58] It is assumed that the prices of imports of goods and services have already converged, though there is no official estimate for this. The same assumption is made, for example by Dabušinskas et al. (2006).

$$\Delta ln(M_{S,t}) = \underset{1.442}{0.007} - \underset{-1.861}{0.151} ln(M_{S,t-1} M^{*-1}_{S,t-1}) + \underset{2.882}{0.273} \Delta M_{D,t} \qquad (36b)$$
$$+ \underset{2.548}{0.440} \Delta ln(P_t (1-z) P^{-1}_{M_S,t}) + \underset{2.938}{0.282} \Delta ln(M_{S,t-3}).$$

Equation 36b proves that the demand for imported services behaves somewhat differently from the demand for goods. Firstly, imported services tend to overreact to demand impulses, and the short-run effect 0.273 is almost twice as large as the estimated long-run effect, $1 - 0.843$. Secondly, they also tend to overreact to relative price changes.

Exports

Cointegration relationships for exports of goods and exports of services, X_G and X_S, share the same configuration as for imports. Exports are determined by foreign demand X_D plus the change in relative prices. The foreign demand indicator consists of the weighted imports of Estonia's main trade partners. [59]

In general, the higher increase in export prices P_X compared to competitors' prices, P_{CX}, lowers the price competitiveness of local producers, and as a result a fall is to be expected in the volume of goods and services exported (*ceteris paribus*). Taking the initial levels of P_{CX} and P_X and given that the relative export price converges to one, the resulting loss in price competitiveness is about 20%. The effect on export flows depends on the price elasticity parameters, which are 1.411 and 0.121 for exports of goods and exports of services respectively. According to the estimates, goods lose 28% (0.2×1.411) and services 2% (0.2×0.121) of their competitiveness during the course of price convergence. The estimated cointegration equations are:

$$ln(X^*_{G,t}) = \underset{5.694}{5.089} + \underset{16.492}{1.791} ln(X_{D,t}) + \underset{4.450}{1.411} ln(P_{CX,t} P^{-1}_{X_G,t}), \qquad (37a)$$

$$ln(X^*_{S,t}) = \underset{52.103}{8.131} + \underset{15.626}{0.684} ln(X_{D,t}) + \underset{2.155}{0.121} ln(P_{CX,t} P^{-1}_{X_S,t}). \qquad (37b)$$

One thing to notice is that exports of goods have higher than unitary elasticity with respect to foreign demand in the long run while the estimated elasticity for exports of services is less than one. Sensitivity to foreign demand is similar in the short term though (see equations 38a and 38b). Exports of services are less

[59] Sepp and Randveer (2002) have used Finnish GDP to proxy foreign demand shocks. This was inspired by the fact that the highest correlation of the Estonian business cycle was with that of Finland (also shown in Kaasik et al. (2003)). However, effective export demand has better explanatory properties, which is also supported by the high significance of the estimated coefficient value.

sensitive to price movements than are exports of goods, in both long and short run:

$$\begin{aligned}\Delta ln(X_{G,t}) = \underset{0.1296}{0.008} - \underset{-1.839}{0.186} ln(X_{G,t-1}X^{*-1}_{G,t-1}) + \underset{4.484}{0.850}\Delta X_{D,t} \\ +\underset{2.689}{0.666}\Delta ln(P_{CX,t-2}P^{-2}_{X_G,t-1}) + \underset{-}{0.200}\Delta ln(M_{G,t}),\end{aligned} \tag{38a}$$

$$\begin{aligned}\Delta ln(X_{S,t}) = \underset{0.980}{0.005} - \underset{-5.440}{0.620} ln(X_{S,t-1}X^{*-1}_{S,t-1}) + \underset{4.016}{0.528}\Delta X_{D,t} \\ +\underset{2.027}{0.278}\Delta ln(P_{CX,t}P^{-1}_{X_S,t}).\end{aligned} \tag{38b}$$

A proportion of Estonian exports of goods are re-exports or the exports of goods that have been temporarily imported for inward processing. The share of this category has stabilised at about 20% of total exports and we calibrate the coefficient for the imports on that basis. Contemporaneous imports are inserted into the equation, because inward processing takes less than one quarter and goods are re-exported during the same period.

3.3.5. Prices

Real wage

In the long run real wages are determined by labour marginal product revenue, derived from the profit maximisation problem of a representative company (see equation 19). The hourly real wage, W, is defined as the nominal gross wage deflated by the net GDP deflator: $W = w(1+q)(P(1-z))^{-1}$. Households' equilibrium real wage per hour equals labour productivity, YH^{-1}, multiplied by labour share of income, $1-\alpha$, and divided by the mark up, η:

$$ln(W^*_t) = ln(Y_t H^{-1}_t) + ln((1-\alpha)\eta^{-1}), \tag{39a}$$

$$\begin{aligned}\Delta ln(W_t) \quad = \quad & const_t - \underset{-2.126}{0.225} ln(W_{t-1}W^{*-1}_{t-1}) + \underset{1.995}{0.243}\Delta ln(Y_t H^{-1}_t) \\ & -\underset{-2.592}{0.015} ln(u_t u^{*-1}_t) + \underset{5.074}{1.452}\Delta ln(\lambda_{t-2}).\end{aligned} \tag{39b}$$

The short-run dynamics of real wages (equation 39b) are driven by changes in productivity and the labour market gap, which is the spread between the actual unemployment rate and NAWRU (Non-Accelerating Wage Rate of Unemployment), u and u^*. The labour market gap is one of the key elements of the whole model, because the stabilization of the model economy works through wage and price adjustment, following the Phillips curve ideology. The estimated coefficient implies that an unemployment rate that is higher than NAWRU by one percentage point lowers annual real wage growth by 0.75% ($u^* = 0.07$, see Appendix 5 for the NAWRU filtering technique).

The intercept of the dynamic equation is restricted to ensure that dynamic homogeneity holds in sample and out of sample. The cointegration equation implies that real wage growth equals labour productivity growth in the long run, so the same must hold true for the dynamic equation. Taking the structure of equation 39b and given that $u_t u_t^{*-1}$ converges to one and $\Delta ln(\lambda)$=0 in the steady state, the restriction takes the form $const_t = (1 - 0.243)\tilde{\gamma}_t$, where $\tilde{\gamma}$ is the long-run trend productivity growth. $\tilde{\gamma}$ is proxied with the potential per capita GDP growth because this measure conveys the information on the decreasing economic growth rate with only minor cyclical influences: $\tilde{\gamma}_t = (\Delta_8 ln(Y_t^*/L_t^{pop}) + 1)^{1/8} - 1$, where L^{pop} is total population. [60] In sample the mean value of the time-varying intercept is 0.012 with a standard deviation of 0.0008.

GDP deflator

The intermediate target for the GDP deflator equals the unit labour cost times mark up. The equation determining the long run growth rate of the GDP deflator at factor cost, $P^*(1 - z)$, originates from the initial profit maximisation problem (see equation 20). Equation 40a represents it in logarithmic form:

$$ln(P_t^*(1 - z)) = ln(\eta(1 - \alpha)^{-1}) + ln(H_t Y_t^{-1}) + ln(w(1 + q)), \tag{40a}$$

$$\begin{aligned}\Delta ln(P_t(1 - z)) = const_t - \underset{-0.926}{0.101} ln(P_{t-1} P_{t-1}^{*-1}) \\ + \underset{3.102}{0.370} \Delta ln(w_t(1 + q)).\end{aligned} \tag{40b}$$

The GDP deflator and its dynamics are crucial for adjusting of the model economy by linking final consumption prices and the costliness of production. According to the dynamic equation, two-thirds of the wage inflation passes through immediately, with an estimated coefficient of 0.37 (the overall wage impact would

[60] The previous version of the model (Kattai, 2005) used exogenously given deterministic trend-productivity growth to impose DHR. The shortcoming of the method was the *ad hoc* specification of the trend, whereas the current construction of the DHR is more consistent with the behaviour of the model-economy.

be $1 - \alpha = 0.6$). The rest of the pass-through takes place via the error correction process.

Equation 40b is also estimated under TV-DHR. According to the structure of equation 40b the restriction is $const_t = \tilde{\pi}_t - 0.37(\tilde{\pi}_t + \tilde{\gamma}_t)$, where $\tilde{\pi}$ is the long-run GDP deflator inflation. $\tilde{\pi}_t + \tilde{\gamma}_t$ equals the long-run nominal wage growth, based on the properties of equation 19. Since in practice $\tilde{\pi}_t \approx \tilde{\gamma}_t$, the imposed DHR takes the shape $const_t = (1 - 2 \times 0.37)\tilde{\gamma}_t$. The restricted intercept has a mean value of 0.004 and standard deviation of 0.0003.

Import deflators

In the long run the goods import deflator, P_{M_G}, and the services import deflator, P_{M_S}, depend on foreign competitors' prices, P_{CM}, and the domestic net GDP deflator, $P_t(1-z)$. The competitors' price index is constructed as the effective CPI of the main trade partners, weighted by their share of Estonian imports: $P_{CM} = \chi_M P_{FIXI} + (1 - \chi_M)(P_{FLOI} er_M^{-1})$, where P_{FIXI} is the effective CPI of the main trade partners in the euro area and P_{FLOI} is the effective CPI of the main trade partners, whose currencies float against the Estonian kroon. er_M represents the Estonian kroon's effective exchange rate. All indicators are weighted according to the country's share of Estonian imports. The share parameter χ_M reflects the weight of euro-based countries in Estonian imports and equals 0.6.

The domestic production price in the import deflators' cointegration relationships refers to the pricing to market effect, where foreign producers and local importers lower their prices in order to gain competitiveness in the relatively low-priced Estonian markets. The relative estimated shares of foreign and domestic prices are 0.72 and 0.28 respectively for the imported goods deflator and 0.16 and 0.84 for the imported services deflator (see equations 41a and 41b). Estimation results indicate that pricing to market is much stronger for services, while foreign goods prices transmit almost perfectly into the price of imports:

$$ln(P^*_{M_G,t}) = -\underset{-41.374}{1.825} + \underset{39.794}{0.725} ln(P_{CM,t}) + (1 - \underset{39.794}{0.725}) ln(P_t(1-z)), \quad (41a)$$

$$ln(P^*_{M_S,t}) = -\underset{-4.357}{0.246} + \underset{6.900}{0.158} ln(P_{CM,t}) + (1 - \underset{6.900}{0.158}) ln(P_t(1-z)). \quad (41b)$$

A figure of 40% for non-euro-based trading partners implies that exchange pass-through to the goods imports price is about 29% (0.725×0.4) and 6% for services imports (0.158×0.4). This is different from what has been found by Campa and Goldberg (2002) for OECD countries, who observed pass-through of approximately 80% in the long run on average. [61]

In the short run, price impulses from trade partners dominate for imports of goods and for imports of services. Domestic price component did not appear statistically significant (see equations 42a and 42b):

$$\Delta ln(P_{M_G,t}) = \underset{2.186}{0.002} - \underset{-4.179}{0.378} ln(P_{M_G,t-1} P^{*^{-1}}_{M_G,t-1}) + \underset{1.514}{0.218} \Delta ln(P_{CM,t}) \quad \text{(42a)}$$
$$+\underset{3.922}{0.042} \Delta ln(P_{oil,t} \$_t) + \underset{3.232}{0.235} \Delta ln(P_{M_G,t-1}),$$

$$\Delta ln(P_{M_S,t}) = \underset{3.798}{0.008} - \underset{-3.972}{0.315} ln(P_{M_S,t-1} P^{*^{-1}}_{M_S,t-1}) + \underset{3.333}{0.437} ln(P_{CM,t-4}) \quad \text{(42b)}$$
$$+\underset{1.967}{0.281} \Delta ln(P_{M_S,t-2}).$$

The price of goods imports is also shaped by the movements of oil prices, P_{oil}, originally in US dollars but converted into the Estonian kroon by multiplication of the price by the official exchange rate, \$. The overall import deflator, P_M, is obtained by weighting the goods and services import deflators: $P_M = P_{M_G} M_G M^{-1} + P_{M_S} M_S M^{-1}$.

Export deflators

The set-up of the cointegration relationships for the goods export deflator, P_{X_G}, and services export deflator, P_{X_S}, is similar to that which was used for the import deflators. These deflators consist of the weighted average of foreign competitors' prices, P_{CX}, and the domestic GDP deflator. In the export deflators equations foreign competitors' prices are weighted according to the countries' shares of Estonian exports: $P_{CX} = \chi_X P_{FIXE} + (1 - \chi_X)(P_{FLOE} er_X^{-1})$, where P_{FIXE} is the effective CPI of the main trade partners in the euro area and P_{FLOE} is the effective CPI of the main trade partners whose currencies float against the Estonian kroon. Both are weighted by the countries' share of Estonian exports. er_X stands for Estonian kroon's effective exchange rate, also weighted by countries' share in Estonian exports. The share parameter χ_X reflects the weight of euro-based trade partners in Estonian exports, and is equal to 0.5.

Competitors' prices enter the long-run equation for goods exports deflator with a share of 0.555 and a share of the domestic price of 0.445. The domestic GDP deflator is clearly the most important factor in determining the price of exported

[61] Pass-through has also been found to be weaker in Estonia also in the previous studies. Dabušinskas (2003), for example, showed that about 30% of import prices were affected by exchange rate movements. Overall, the long-run pass-through was found to be 40–50%.

services, as its contribution is about 88%, while competitors' prices account for only 12% of price movements (see equations 43a and 43b):

$$ln(P^{*}_{X_G,t}) = -\underset{-27.012}{1.423} + \underset{25.725}{0.555}ln(P_{CX,t}) + (1 - \underset{25.725}{0.555})ln(P_t), \tag{43a}$$

$$ln(P^{*}_{X_S,t}) = -\underset{-1.933}{0.238} + \underset{2.291}{0.122}ln(P_{CM,t}) + (1 - \underset{2.291}{0.122})ln(P_t). \tag{43b}$$

Goods exports exhibit some inertia in their prices, captured by the autoregressive component in the dynamic equation. The proportions of the transmissions of foreign and domestic price signals into goods export prices are in the short run fairly similar to what was estimated for the long run (see equation 44a). However, the same does not hold true for services export prices, the only statistically significant factor is the autoregressive component. In any case, a large error correction coefficient makes the price of exported services to converge quickly to its equilibrium target (see equation 44b):

$$\begin{aligned}\Delta ln(P_{X_G,t}) = &-\underset{0.797}{0.0003} - \underset{-6.667}{0.359}ln(P_{X_G,t-1}P^{*^{-1}}_{X_G,t-1}) + \underset{3.970}{0.812}\Delta ln(P_{CX,t}) \\ &+\underset{3.199}{0.523}\Delta ln(P_t) + \underset{4.117}{0.449}\Delta ln(P_{X_G,t-1}),\end{aligned} \tag{44a}$$

$$\begin{aligned}\Delta ln(P_{X_S,t}) = &\underset{0.336}{0.002} - \underset{-5.309}{0.633}ln(P_{X_S,t-1}P^{*^{-1}}_{X_S,t-1}) \\ &+\underset{1.648}{0.453}\Delta ln(P_{t-2}).\end{aligned} \tag{44b}$$

The aggregate export deflator, P_X, is given by weighting the goods and services export deflators: $P_X = P_{X_G}M_X X^{-1} + P_{X_S}X_S X^{-1}$.

Investment deflator

The basic idea of the long-run equation for the investment deflator, P_I, is in line with how the price indices were modelled before. In principle, as a proportion of investment goods are imported and the other part is produced domestically, the long-run rate of the investment deflator is the weighted average of the import deflator and the GDP deflator. A considerably higher share for the import deflator indicates that most investment goods are imported. The estimated share of 0.72 $(1 - 0.282)$ is in rough correspondence with the import share of investments in the input-output tables, where it equals 0.58:

$$ln(P^*_{I,t}) = \underset{8.395}{0.041} + \underset{8.196}{0.282} ln(P_t) + (1 - \underset{8.196}{0.282}) ln(P_{M,t}), \tag{45a}$$

$$\Delta ln(P_{I,t}) = -\underset{-2.087}{0.007} - \underset{-3.137}{0.236} ln(P_{I,t-1} P^{*^{-1}}_{I,t-1}) + \underset{2.157}{0.254} \Delta ln(P_t) \tag{45b}$$
$$+\underset{3.876}{0.431} \Delta ln(P_{t-1}) + \underset{3.990}{0.217} \Delta ln(P_{M,t-4}) + \underset{1.445}{0.164} \Delta ln(P_{I,t-4}).$$

Estimation of the dynamic equation indicates the higher importance of the GDP deflator. The domestic component may have higher relevance in the short-run due to installation costs, for example.

Harmonised consumer price index

The HICP is not modelled explicitly but is the weighted average of four components: HICP core, HICP food, HICP fuel and household energy. Each of these is modelled with a separate error correction equation (except household energy, which is exogenous) based on the same composition technique as used before. The HICP is then used to determine some of the other deflators, namely the private and NPISH (Non-Profit Institutions Serving Households) consumption deflators. The government consumption deflator is an exemption, because most of the government consumption is related to labour cost, so its deflator is regressed on wages.

Core harmonised consumer price index

HICP core, P_{HC}, has the highest share of the HICP, constituting about 60% of the total HICP. The long-run equation combines the GDP and import deflators with estimated shares of 0.36 and 0.64 respectively (see equation 46a). These proportions may seem biased, putting too much weight on import prices, but equations 41a and 41b show that about 28% of goods imports and about 84% of services imports are priced at domestic levels. Effectively this means, given the relative shares of goods and services imports, that approximately 39% of total imports are priced at local levels and the domestic component in the core HICP is close to 60%:

$$ln(P^*_{HC,t}) = \underset{3.215}{0.014} + \underset{12.271}{0.357} ln(P_t) + (1 - \underset{12.271}{0.357}) ln(P_{M,t}), \tag{46a}$$

$$\Delta ln(P_{HC,t}) = \underset{2.808}{0.003} - \underset{-2.546}{0.082} ln(P_{HC,t-1} P^{*^{-1}}_{HC,t-1}) + \underset{4.094}{0.098} \Delta ln(P_{M,t}) \tag{46b}$$
$$+\underset{1.412}{0.043} \Delta ln(P_t) + \underset{4.094}{0.506} \Delta ln(P_{HC,t-1}).$$

The dynamic equation gives only low importance to the instantaneous price signals from imports and domestic production prices. A very high coefficient value for the autoregressive component highlights the remarkable stickiness of the core HICP (see equation 46b).

Harmonised food price

Food's share of the harmonised consumption basket has fallen gradually from 30% to about 20%. Instead of using the import deflator as an indicator of foreign prices, food prices in Estonia, P_{HF}, are directly linked to food prices in the EU15, P_{FF}, with a relative estimated share of 0.30. The rest of the long-run growth comes from an increase in local producer prices. In addition, the nominal exchange rate, er_M is included in the cointegration relationship to capture the large price movements in the past, mainly during the Russian crisis period, which were affected by the prices of food imported from non-EU countries. The estimated coefficient was highly significant and the inclusion of the exchange rate improved the equation's statistical properties. The estimated equations are:

$$\begin{aligned} ln(P^*_{HF,t}) = \underset{4.604}{0.179} + \underset{10.519}{0.697} ln(P_t) + (1 - \underset{10.519}{0.697}) ln(P_{FF,t}) \\ - \underset{-4.161}{0.147} ln(er_{M,t}), \end{aligned} \tag{47a}$$

$$\begin{aligned} \Delta ln(P_{HF,t}) = -\underset{-0.596}{0.001} - \underset{-3.238}{0.143} ln(P_{HF,t-1} P^{*^{-1}}_{HF,t-1}) + \underset{1.706}{0.119} \Delta ln(P_{t-4}) \\ + \underset{4.887}{1.221} \Delta ln(P_{FF,t}) + \underset{3.347}{0.275} \Delta ln(P_{HF,t-1}). \end{aligned} \tag{47b}$$

Food prices are the most volatile component of total HICP. The coefficient for the EU15 food prices in the dynamic equation is much greater than its relative share in the cointegration relationship, indicating that Estonian food prices overreact to any changes in this index. This is an expected outcome, because historically Estonian food prices have been about three times more volatile than the food price in the EU15 on average. Domestic production costs transmit into the food prices with a significant 4-quarter lag. Food prices' own lag indicate a strong persistence in the pricing mechanism (see equation 47b).

Harmonised fuel price

HICP fuel has the lowest share in total HICP, equal to only about 5%. The long run value of the fuel price, P_{HO}, is assumed to follow directly the world oil price and the domestic cost component, the excise tax on fuel, T_{oil}. The oil price is set in U.S. dollars (P_{oil}) and then converted to a price in Estonian kroons by multiplying the price in dollars by the kroon-dollar exchange rate, \$:

$$ln(P^*_{HO,t}) = -\underset{-76.748}{5.81} + \underset{30.935}{0.481} ln(T_{oil,t}) + \underset{22.867}{0.325} ln(P_{oil,t}\$_t), \tag{48a}$$

$$\begin{aligned}\Delta ln(P_{HO,t}) = \underset{0.216}{0.001} - \underset{-4.867}{0.775} ln(P_{HO,t-1}P^{*^{-1}}_{HO,t-1}) + \underset{10.332}{0.305}\Delta ln(P_{oil,t}) \\ +\underset{6.551}{0.437}\Delta ln(T_{oil,t}) + \underset{2.683}{0.327}\Delta ln(\$_t).\end{aligned} \tag{48b}$$

The dynamics of fuel prices are determined by world oil prices, excise tax and the dollar exchange rate. Oil price fluctuations on world markets and the exchange rate transmit immediately to local fuel prices. The same applies to the excise tax. The error correction coefficient implies that any misalignment from the equilibrium value is corrected almost immediately.

House prices

House prices are determined by the rule that the cost of one square meter, P_h, is in the long run proportional to the average quarterly wage, wh. That proportion can be disturbed by increased lending activity, $E^{T,h}$, which also allows real estate price bubbles to occur conditional on bank lending:

$$ln(P^*_{h,t}) = \underset{13.347}{2.450} + ln(wh) + \underset{19.149}{0.420} ln(E^{T,h}_t), \tag{49a}$$

$$\begin{aligned}\Delta ln(P_{h,t}) = \underset{1.424}{0.009} - \underset{-4.399}{0.420} ln(P_{h,t-1}P^{*^{-1}}_{h,t-1}) + \underset{6.071}{0.240}\Delta ln(E^{T,h}_t) \\ +\underset{8.121}{0.661}\Delta ln(P_{h,t-1}).\end{aligned} \tag{49b}$$

A high AR(1) coefficient indicates that house prices are strongly autoregressive. Consequently shocks to house prices arising from sources other than bank lending are long-lived. Credit related shocks are less persistent because the high error correction coefficient clears deviations from the long-run level relatively quickly.

Real estate prices are a factor that shapes the credit cycles by affecting investment demand and through that demand for mortgage loans (equations 33a, 33b, 24a and 24b). There may be a demand-driven increase in mortgages, because of a favourable interest shock, for example, and this money is spent on housing investments. The market realises that there are more external funds available in the economy to finance home purchases, and real estate prices rise. Higher real estate prices lower households' motivation to invest (as equation 33a predicts). The circular effect then comes back to the demand for mortgages, which contracts due to the fall in investment demand. The same process can be initiated by an increased credit supply, with the same effects on the households' behaviour.

3.3.6. Labour market

In the equilibrium companies demand $Y^{\frac{1}{1-\alpha}}K^{\frac{-\alpha}{1-\alpha}}A^{-1}$ hours of labour work, as was derived in equation 18. At the same time, the household sector supplies a total number of hours of $(1-u^*)L^{F^*}h^*$, where L^{F^*} is the available labour force in the economy and h^* denotes the hours worked per worker, both corresponding to the equilibrium state. The actual hours worked are a combination of the demand by companies and the supply from households with almost equal weights:

$$\begin{aligned} ln(H_t^*) = \underset{12.723}{0.460}((1-\alpha)^{-1}ln(Y_{t-2}K_{t-2}^{-\alpha}) - ln(A_{t-2})) \\ +(1-\underset{12.723}{0.460})ln((1-u_t^*)L_t^{F^*}h_t^*), \end{aligned} \tag{50a}$$

$$\begin{aligned} \Delta ln(H_t) = -\underset{-2.186}{0.292}ln(H_{t-1}H_{t-1}^{*-1}) + \underset{4.136}{0.387}(\Delta ln(Y_{t-2}) - \Delta ln(Y_{t-2}^*)) \\ +\underset{1.455}{0.146}\Delta ln(H_{t-1}). \end{aligned} \tag{50b}$$

In the short run hours react to economic activity, depending on how much actual GDP growth deviates from the potential: $\Delta ln(Y) - \Delta ln(Y^*)$. Using deviation from the potential rather than output growth directly is to guarantees that the labour market clears when the economy is in the equilibrium, where $\Delta ln(Y) = \Delta ln(Y^*)$ by definition. Clearing is somewhat inert, and in the equation it is accounted for by the inclusion of the autoregressive component.

The labour force, L^F, is partially shaped by underlying demographic trends and partially by the labour market institutions. Demographic factors are the overall population, L^{pop}, and the share of population that is of working age, τ. Institutional factors such as social benefits, pension age and similar determine the labour force participation rate, λ. The targeted equilibrium labour force is provided in equation 51a:

$$ln(L_t^{F*}) = ln(\lambda^*) + ln(\tau L_t^{pop}), \tag{51a}$$

$$\begin{aligned} \Delta ln(L_t^F) = \underset{1.399}{0.001} - \underset{-4.903}{0.640}ln(L_{t-1}^F L_{t-1}^{F^*-1}) + \underset{3.307}{0.096}\Delta ln(W_tH_tY_t^{-1}) \\ +\underset{2.783}{0.305}\Delta ln(L_{t-2}^F). \end{aligned} \tag{51b}$$

The dynamics of the labour force are very strongly driven by the adjustment process, and the error correction coefficient shows that about 65% of the misalignment is abolished within one quarter. The rest of the dynamics result from changes in the wage-productivity ratio, WHY^{-1}, and self-adjustment. The wage-productivity ratio adds slight cyclical behaviour to the labour force since in the past when real wages were growing faster than productivity, people have been motivated to enter the labour market.

The long-run level of employment is entirely determined by the households' labour supply. In the equilibrium, households supply $(1-u^*)L^{F^*}$ physical units of labour and the long-run relationship becomes: $ln(L_t^*) = ln(1-u_t^*)L_t^{F^*}$. Short-run fluctuations in employment are caused by changes in the economic activity. Cyclical pressures are defined in terms of the difference between actual and potential GDP growth:

$$\begin{aligned}\Delta ln(L_t) = -\underset{-}{0.100} ln(L_{t-1}L_{t-1}^{*-1}) + \underset{2.238}{0.111}(\Delta ln(Y_{t-1}) - \Delta ln(Y_{t-1}^*)) \\ + \underset{5.798}{0.279}(\Delta ln(Y_{t-4}) - \Delta ln(Y_{t-4}^*)) + \underset{2.427}{0.224}\Delta ln(L_{t-1}).\end{aligned} \tag{52a}$$

As in equation 50b, it is necessary to ensure that the labour market clears in the equilibrium. The estimation indicates that there is an initial quicker reaction to economic growth, with a lag of one quarter. The more delayed impact arrives four quarters later, and is supposedly related to the length of work contracts. The coefficient of the autoregressive component is about twice as large as that was estimated for total hours (equation 50b), meaning that hours worked per employee adjust more rapidly than does employment. Since the equation is symmetric, it holds true in both the expansion and the recession phases. Hours worked per person are calculated by the identity $h = HL^{-1}$.

As it was mentioned before, most of the adjustment in the model economy works through the labour market, through the Phillips curve induced price reactions, shown in equation 39b. An unemployment rate, $u = (L^F - L)L^{F^{-1}}$, higher than NAWRU lowers inflationary pressures by slowing down wage growth and thereby slowing inflation in production and consumer prices. As a result, the competitiveness of exports increases and this supports economic growth. The opposite happens when the unemployment rate falls below the NAWRU rate.

3.3.7. Government sector

The basic outline of the government block can be described as the dependency of expenditure on revenues collected. In other words, the government takes taxes and other revenues as provided by economic activity and shapes its expenditures according to that constraint. This mechanism is somewhat different from that seen in other ”traditional” macro models. For example Vetlov (2004) and Willman and Estrada (2002) use the direct tax rate as an instrument to affect revenues in a desired direction. This means that the model-economy closes on the revenue side, not on the expenditure side as in the Estonian model.

Government revenues are split into five categories: social tax (T), personal and corporate income tax, T^h and T^f respectively, value-added tax, T_{VAT}, excise tax, T_{EXC}, and other income (T_O). On the expenditures side there are four items distinguished: government transfers to households, G, government consumption (C^g), capital formation (I^g) and other expenditures (G_O). Budget balance therefore becomes:

$$\begin{aligned} B_t &= T_t + T_t^h + T_t^f + T_{VAT,t} + T_{EXC,t} + T_{O,t} \\ &\quad -G_t - C_t^g P_{C_t^g} - I_t^g P_{I_t^g} - G_{O,t}. \end{aligned} \tag{53}$$

All the items in equation 53 appear in nominal terms, except public consumption and investments, which are in real terms and therefore deflated with their respective deflators. Individual tax revenues are represented as the tax base times the effective tax rate and all the expenditure items except G_O are expected to evolve proportionally to the size of the economy:

$$T_t = qH_t w_t, \tag{54}$$
$$T_t^h = tr_t^h[(1-q)H_t w_t - d_t L_t], \tag{55}$$
$$T_t^f = tr^f Q_t^f, \tag{56}$$
$$T_{VAT,t} = tr_{VAT} C_t^h P_{C^h,t}, \tag{57}$$
$$T_{EXC,t} = tr_{EXC} C_t^h P_{C^h,t}, \tag{58}$$
$$T_{O,t} = 0.05 Y_t^* P_t, \tag{59}$$
$$ln(G_t) = -4.97 + 1.18 ln(Y_t^* P_t) + 0.14 ln(U_t w_t (1-q) h_t), \tag{60}$$
$$C_t^g P_{C_t^g} = -4742 + 0.31 Y_t^* P_t, \tag{61}$$
$$\Delta ln(I_t^g P_{I_t^g}) = \Delta ln(Y_t). \tag{62}$$

tr^h, tr^f, tr_{VAT} are the effective tax rates on personal income, corporate income and value added respectively, while tr_{EXC} stands for the effective excise tax rate. d denotes tax-free personal income, which is deducted from periodical earnings. Government’s other income is represented as a share of potential output, deflated by the GDP deflator. The same applies to the government’s consumption and transfers to households, the latter also dependent on the unemployment rate and the wage level, which stand for unemployment benefits. Other income, consumption and transfers are scaled to potential output to reflect the low cyclical response in these items. Government's investments, on the other hand, are more volatile and follow the economic cycle entirely.

Government's fiscal policy is mimicked by a fiscal rule. According to this rule, the government's fiscal policy has two goals with a natural trade-off between them. One goal for the government is to target small output variations. This is done by increasing consumption during downturns and causing a budget deficit, and cutting expenditures during upswings to result in a budget surplus. The other option is to have sound fiscal policy, defined as keeping the budget in balance. The optimal choice for the government is given by minimising a quadratic loss function subject to a linear structure of the economy. The fiscal rule is expressed as:

$$B_t^* = \bar{B} + \frac{\Omega}{1-\Omega}\Xi\tilde{y}_t, \tag{63}$$

where B^* is the optimal level of budget surplus, $\bar{B}$ is the targeted long-run level of surplus, and Ω describes the relative weight put on either goal. The higher Ω is, the more important the output stabilisation. Kattai and Lewis (2004) have shown that the values of $\bar{B}$ and Ω are 0 and 0.517 respectively. These findings imply that Estonian fiscal policy is not biased toward deficit or surplus. The Ω value, at approximately 0.5, indicates that the importance of stabilising output and of the budget is roughly equal. Parameter Ξ stands for the government multiplier, indicating by how much the fiscal balance would react if the observed output gap $\tilde{y} = YY^{*-1} - 1$ changed by one percentage point. [62] A Ξ value greater than one shows that spending one kroon may increase output by more than one kroon and a λ value of less than one reflects the opposite. The value for lambda is calibrated and equals 1.13.

The fiscal rule presented in equation 63 is initially derived *ex post* for descriptive analysis and is not directly applicable for simulation purposes. The reason for this is that it is not realistic to assume that any budget deficit or surplus may occur in real life. Therefore, the rule is augmented by replacing $\tilde{y}$ with a function $\Phi(\tilde{y})$:

$$B_t^* = \bar{B} + \frac{\Omega}{1-\Omega}\Xi\Phi(\tilde{y}_t). \tag{64}$$

[62] Potential output is based on the companies' production function (equation 11) and equals: $Y_t^* = K^\alpha(A_t(1-u_t^*)\lambda^*\tau L_t^{pop}h_t^*)^{1-\alpha}$.

$\Phi(\tilde{y})$ is a restriction, which works so that if the output gap exceeds some critical level defined within the model, the budget surplus or deficit would remain at some predefined level. Restricting the lower boundary of the budget deficit is the most critical. In accordance with the Maastricht fiscal soundness criteria, $\Phi(\tilde{y})$ is defined so that the budget deficit would not exceed 3% of GDP, even if the output gap were strikingly negative. [63] The fiscal block and the model closes by defining government's other expenditure, G_O, as a function of the other budgetary items and the fiscal rule:

$$\begin{aligned} G_{O,t} &= T_t + T_t^h + T_t^f + T_{VAT,t} + T_{EXC,t} + T_{O,t} && (65) \\ & \quad -G_t - C_t^g P_{C_t^g} - I_t^g P_{I_t^g} - B_t^*. && (66) \end{aligned}$$

Technically, government debt is expressed by the accumulated budget balances, $\sum B_t$. However, the Estonian government has been running a fiscal policy which balances the budget over the cycle and therefore public debt is very small and insignificant from the modelling perspective. For this reason the debt has not been modelled explicitly.

4. SHOCK SCENARIO IMPLEMENTATION

4.1. Description of shock scenarios and simulation properties of the macro model

The macro model is used to generate five different shock scenarios. The scenarios considered are the monetary policy shock, domestic lending risk premium shock, foreign demand shock, foreign price shock and government consumption spending shock. The shocks are selected to cover alternative sources of economic disturbances, originating from both the foreign and domestic markets, and the financial and real sectors. All the shocks are defined as ”negative scenarios”, meaning they are harmful for the economy. The shocks are not sized so as to push the banking sector to its limits, the aim is rather to explore the reactions of the real economy and financial variables. The exercise helps to understand how the macro model works, how the negative scenarios materialise and what the main transmission channels are. In the later phase the same shock scenarios are run conditional on the indebtedness of the private sector in order to detect whether the level of debt influences the amplitude of the reaction of the real economy.

[63] The recent economic downturn has justified this restriction, as the government managed to keep the deficit below the critical value despite the extreme recession and fall in revenues.

The government's stabilisation policy is turned off when the model is run so that the impulse responses would be "non-distorted". The public sector is expected to change its spending only by the amount that its revenues change by, keeping the budget in balance. The only exception is the government consumption shock, which has a direct impact on the budget balance. In effect the contraction of government consumption leads to an improvement of the fiscal balance and it must be allowed by the fiscal rule.

Monetary policy shock

The first shock scenario, monetary policy shock, mimics the response of the economy to a raise in the euro area's common interest rate, the six month Euribor of $100bp$ for eight quarters. Figure 10 illustrates the reactions in the financial and real variables (see also Appendix 6 for the more detailed output). The shock transmits into the Estonian economy via two main channels. The first channel is the influence on the costliness of the *existing* financial liabilities of the private sector. Households' disposable income falls as expenditures rise on financial services and force them to cut private spending. Equally, the corporate sector has to cut its fixed capital formation due its higher debt servicing costs. The full impact of the negative impulse at the macro level is somewhat delayed because it takes time for the existing loan contracts to be re-priced.

Higher interest payments affect households' disposable income first, while the adjustment in labour compensation lags due to the rigidities in the labour market but becomes dominant once the adjustment takes place. The fall in total hours worked is split almost equally between declines in the number of workers and in the hours worked per person. Private consumption reacts even more than households' disposable income or GDP as consumer confidence is deteriorated by the shock event.

The second channel operates through *new* credit demand. Credit turnover shrinks in response to the contractionary monetary policy making it more expensive to finance investments from bank lending. Consequently private sector investments fall and hence so does output. Housing and corporate investments shrink almost equally, with the latter only slightly more responsive. This matches the historical variation of the two, as they are almost equal. Government investments are less cycle sensitive and fall only slightly. Government investments do not show any overreaction after the transitory shock, whereas companies and households tend to correct their earlier underinvestment to some extent. It is also worth of noting that investments start to recover immediately after the shock but there is a lag of almost one year in the other variables. This is caused by the rigidities in the labour market and a sluggish reaction of prices.

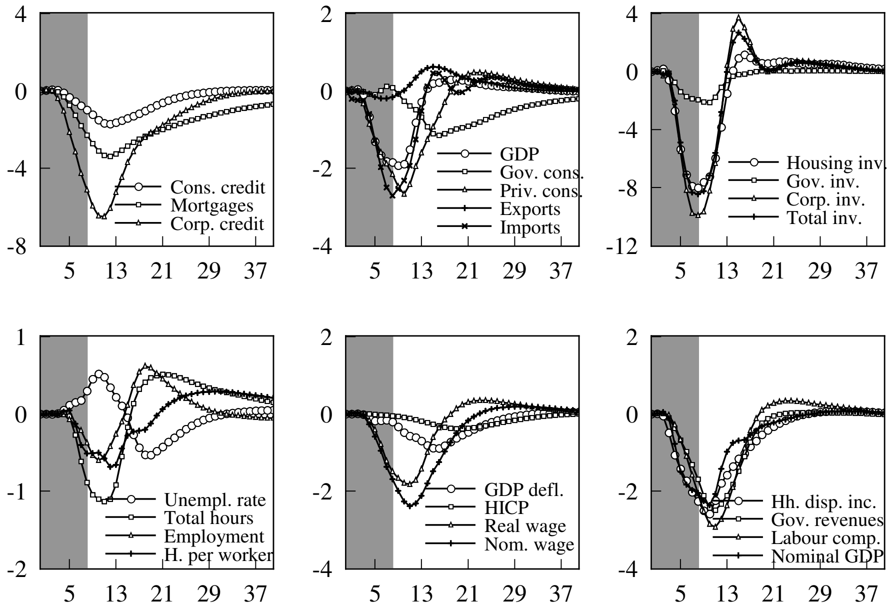


Figure 10: Impulse responses to an increase in 6-month Euribor by $100bp$ for 8 quarters (deviations are in percentages, except for the unemployment rate, which is in percentage points; quarters on the horizontal axis, grey area denotes the shock period). Source: author.

The shock simulation shows the relatively high sensitivity of the economy to an increase in the Euribor rate. An increase in the Euribor of $100bp$ causes GDP to fall by 1.66% from the baseline on average in the second year of the shock (see Appendix 6). This is about three times higher than the response obtained from the previous version of the model without the bank lending channel, which gives a fall of 0.52% (Kattai, 2005). A contraction of GDP by 0.52% falls within the range that models without explicit bank lending channels produce. Fagan and Morgan (2005) review 16 models that have been in used in various European central banks, and GDP responses to this shock range between -0.15 and -0.62. The increased sensitivity of the model compared to its previous version can be attributed to the inclusion of the banking sector and the opportunity for households and companies to finance their consumption/investment with bank lending, because this is the major change in the model.

Although the sensitivity of the model has increased considerably, the shock to the Euribor of $100bp$, which roughly equals its own standard deviation, makes

GDP growth slow down by only about one seventh of its standard deviation. From this point of view, the responsiveness of the economy to the monetary policy shock cannot be considered to be too high.

The simulated monetary policy shock is almost completely exogenous to the Estonian economy since it is dictated by developments in the euro area. Synchronisation with the events in the euro area would mean that in reality foreign export demand and prices ought also to react and transmit into the Estonian economy. The scenario is designed to treat the Euribor shock in isolation to see its ”pure” effect. For this reason exports deviate from the baseline solution only a little, but the effect would be bigger if the scenario also accounted for the fall in foreign demand and prices. These two effects are explored later individually to see their implications.

Risk premium shock

The second shock introduces an increase in the risk premium of the local lending rates. The risk premium is projected to increase by $20bp$ for all credit sectors. [64] The size of the shock is scaled to generate a maximum deviation in GDP that is approximately as big as the change in the Euribor shock scenario, so that GDP shrinks by almost 2% at its peak in both cases (see Figure 11). This makes the scenarios comparable with each other as each scenario shows which sectors and/or variables accommodate the shock impact, when the overall impact in terms of the fall in GDP is the same.

The transmission channels through which the risk premium affects the economy are the same as those described for the Euribor shock scenario. Despite the shock being equal for all the sectors in both scenarios, the reactions in credit show different patterns. For companies and consumer credit clients, an increase in the lending premium of amount given is roughly equivalent to the five-times-larger increase in the base interest. Mortgage clients, however, are clearly more sensitive to the risk premium shock. The difference is explained by the way the interest rates are set in the lending contracts, as the risk premium is fixed for an individual contract on top of the base lending rate, Euribor. A Euribor shock can be treated as temporary by a client, as it may move back to lower levels in the future, but the risk premium is fixed for the whole duration of the contract. [65] Therefore, as the average duration of a housing loan contract is three times longer than the average duration of a consumption credit contract and 2.5 times longer than an average corporate credit contract, new mortgage clients are more sensitive to an increase

[64] A shock of a same size to consumer credit, mortgage and corporate lending rate is in line with the empirical evidence, as all rose by almost the same amount in 2009Q1.

[65] In principle it is possible to review the risk premium after signing the contract but it is costly for the credit client.

in the risk premium of the equal size. Consequently housing investments shrink relatively more.

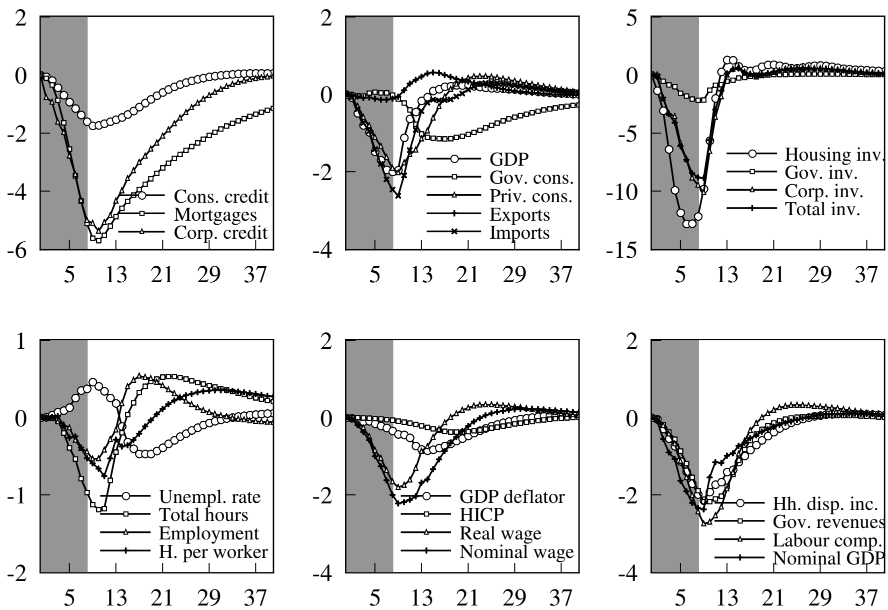


Figure 11: Impulse responses to an increase in the credit risk premium by $20bp$ for 8 quarters (deviations are in percentages, except for the unemployment rate, which is in percentage points; quarters on the horizontal axis, grey area denotes the shock period). Source: author.

The economy-wide reaction is quite similar to that in the previous scenario in other respects (see also Appendix 7 for more details). Since the household sector has been more influenced by the shock through the behaviour of mortgage clients, one difference can be noted in private consumption. The deeper cut in the turnover of mortgages reduces the outstanding stock of mortgages and relieves households' financial obligations to the banks. With looser budget constraints, households can cushion the shock impact more efficiently, and this is visible in a smaller fall in private consumption than was seen with the Euribor shock.

Foreign demand shock

The foreign demand shock is also designed to give comparable results in the reaction magnitude of GDP. To achieve a fall in GDP of slightly under 2%, trade partners' effective export demand has been lowered by 3% over the same time span of 8 quarters. The main channel through which the negative developments are transmitted into the Estonian economy is the trade channel. Although the shock to foreign demand is immediate, exports fall gradually in response. The slow adjustment of exports to the lower levels lasts throughout the whole period that foreign demand is below its baseline. Recovery from the weak foreign demand shock is not symmetric as exports pick up straight after foreign demand is restored (see Figure 12).

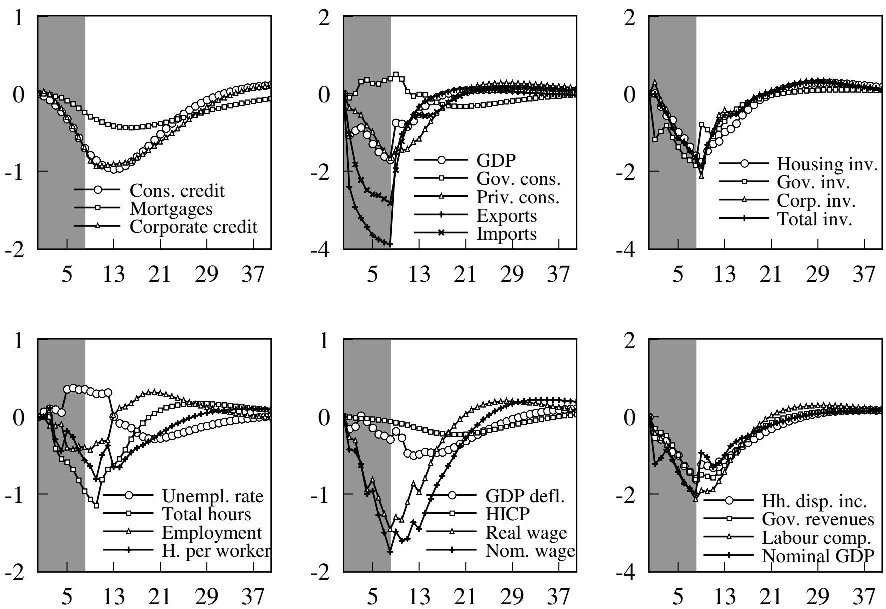


Figure 12: Impulse responses to a fall in export demand by 3% for 8 quarters (deviations are in percentages, except for the unemployment rate, which is in percentage points; quarters on the horizontal axis, grey area denotes the shock period). Source: author.

Credit to private sector exhibits low responsiveness to the real economy shock, with mortgages the most inert. The behaviour is mirrored in investments as well, which fall only a little more than GDP does. The foreign demand shock is therefore not a big threat to the economy because the production capacities do not suffer from a drastic fall in investment. This is the reason why the recovery can be very quick when the shock erodes.

One peculiarity is a temporary increase in the real government consumption.

This is caused by the shift in the price structure. Government consumption is fixed in nominal terms and follows the long-run trend growth but the government consumption deflator, which is indexed to nominal wages, declines and lifts real government consumption, although it does not increase in nominal terms (see also Appendix 8).

Foreign price shock

The fourth scenario considers a fall in the price levels of Estonia's trade partners (see Figure 13). The shock that has a comparable impact on the domestic real economy is a drop in the kroon-denominated export and import prices of Estonia's trade partners of 3% over 8 consecutive quarters. The shock combines the change in the effective price level of the trade partners and in the effective exchange rate.

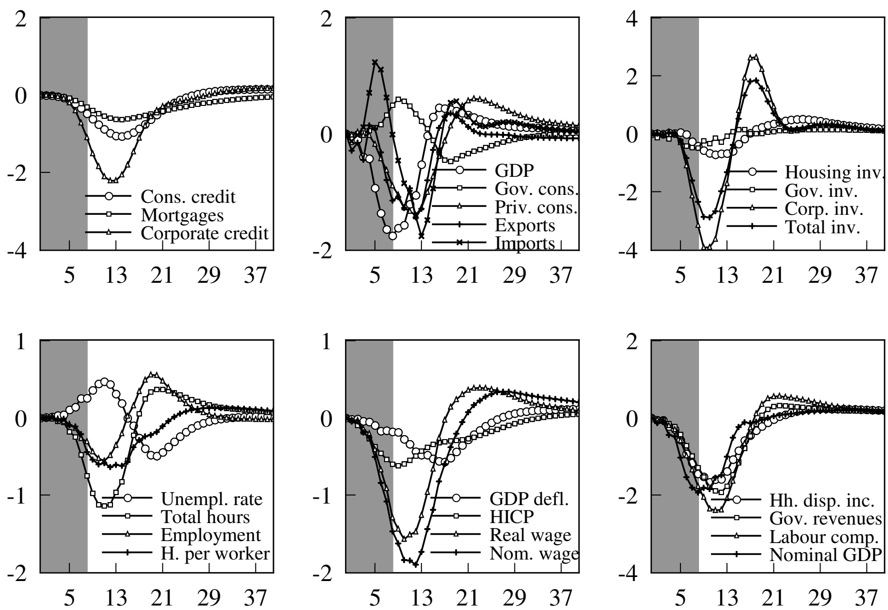


Figure 13: Impulse responses to a fall in foreign competitors' prices by 3% for 8 quarters (deviations are in percentages, except for the unemployment rate, which is in percentage points; quarters on the horizontal axis). Source: author.

The domestic economy is initially hit via the trade channel through a worsening of the terms of trade (see Appendix 9). Initially the lower import prices boost imports of goods and services, but these imports fall below their baseline afterwards to meet the lower domestic demand. Exports lose price competitiveness momentarily since local production prices adjust only slowly. Although prices deviate less extensively from the baseline than they do in the other scenarios, the reaction is not quick enough to offset the fall in the terms of trade.

The fall in the price competitiveness of exports and the decreasing export volumes force companies to cut production. This requires an adjustment in production capital and in the labour input. Since the share of labour input is fixed in the production function, total hours and employment go through similar contractions to those seen in the previous scenarios. Total work hours demanded by the companies are initially lowered by cuts to physical labour units and hours in the proportion 1:1. It is also a characteristic of all the scenarios that in the adjustment process following the shock, the number of people employed tends to overreact to compensate for the downturn whereas the hours adjust to their previous level basically without any overreaction. The reason for this is that full time workers cannot work more hours than is allowed by law and therefore hours per worker can be restored only to their previous levels, not above. In addition to this, there is no structural effect on the labour market and the proportion of part time workers remains unchanged.

Financial variables are not very sensitive to the foreign price shock. New mortgage demand and housing investments in particular show very little response but new consumer credit demand is also quite insensitive. Corporate credit demand sinks the most because due the fall in exports and lower demand for their products means that there are less investments that need external financing.

Government consumption shock

The last scenario, discretionary consolidation of government consumption expenditures affects the whole economy through falling domestic demand. The scenario improves the general government's budget position but the excess resources are not directed to supporting the economy, but rather they are saved. Cutting the spending by 5% for 8 quarters results in a GDP decline of almost 2% at its peak, which is as much as in the previous scenarios. The other GDP expenditure items do not respond to the policy change immediately but only gradually. Apart from exports, which show almost no change or even there is modest increase due to the improved terms of trade, GDP components continue to fall until the end of the shock (see Figure 14 and Appendix 10 for further details). This property emphasises that the longer the shock lasts, the greater the deviation of the real economy from its baseline is.

Credit to private sector is very insensitive to the government spending shock. This is also reflected in investments, which do not deviate from their baselines as much as they did in response to previous shocks. Only modest fall in investments allows the economy to return to its baseline fairly quickly, as physical production capital has not been damaged too much.

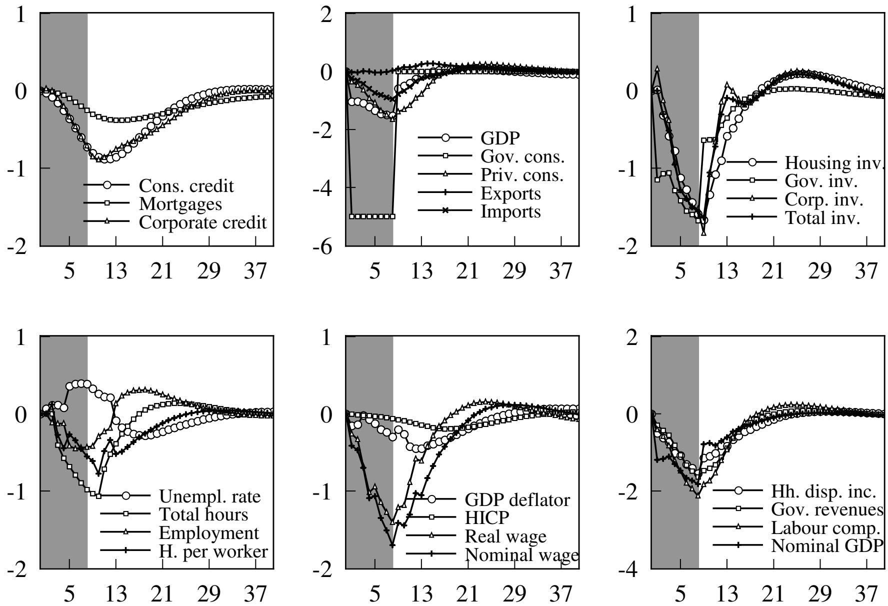


Figure 14: Impulse responses to a fall in real government consumption by 5% for 8 quarters (deviations are in percentages, except for the unemployment rate, which is in percentage points; quarters on the horizontal axis, grey area denotes the shock period). Source: author.

The five scenarios together illustrate that GDP falling below its baseline by given amounts is always related to almost identical tensions in the labour market regardless of the source of the shock. GDP itself, on the other hand, may hide quite a different structure in the response of the expenditure items. Interest rate shocks (Euribor and risk premium shocks) cause considerably greater volatility in investments, which are channeled through relatively larger responses in bank lending. However, shocks arising from the real economy are accompanied by smaller deviations in investments and credit.

A common feature of the shocks is that the deterioration of the economy continues for a while after the initial shock impulse has vanished. The economy adjusts sluggishly because of rigidities in the labour market and in price setting. The inert reactions may imply that banks cannot count on the risks diminishing immediately after the disturbances have disappeared but need to wait until the vulnerabilities show improvement.

4.2. Simulation properties of the credit risk model

Worsening macroeconomic conditions are instantly mirrored in the balance sheets of the banks, which show deteriorating asset quality. [66] Figure 15 depicts increase in the average default rates of credit clients and change in the average distress measures of the banks. Each row of sub-figures stands for one shock scenario, described in the previous section. The responses of default rates, non-performing loan and loan loss provision rates to the shocks are depicted in the first, second and third column respectively. Responses are given for 24 consecutive quarters, which is sufficient to include maximum deviations from the baseline solutions, denoting the highest level of risk.

A comparison of the default rate reactions reveals that mortgage clients tend to be slightly more responsive than consumer credit clients or companies in general. This is not a surprising result because mortgage owners have a relatively larger debt burden and tighter budget constraints which means the changes tend to hurt more. However, from the responses of non-performing loan and loan loss provision rates, it appears that asset quality falls most in the consumer credit sector. This finding is intriguing because consumer credit stands out as the riskiest asset in terms of responsiveness to the deteriorating state of the macro economy, even though the default rate in this sector did not rise as much as that in the mortgage sector. This phenomenon stems from the heterogeneity at bank level. Changes in the average default rate provoke a very strong reaction in the non-performing consumer loans in certain banks. [67]

The Euribor and risk premium shocks are most influential in terms of the response magnitude that they create in the non-performing loan rates. The higher responsiveness to the interest rate is coded into the credit risk model, where the real interest rate was estimated to be the most important factor determining the default rates of credit clients. Companies and households are most sensitive to hikes in the interest rate because it constrains them in two ways: it increases debt servicing costs and it also lowers the demand for and supply of new credit. The effect is amplified in the economy through the second round effects, which lower the income of the borrowers on top of their already increased costs.

In contrast to this, shocks that originate from the real economy and do not

[66] As already seen, the estimation of the borrowers' default rate equations indicated only a slight lag to the macro variables (see Table 2).

[67] As already seen, the average estimated value of the parameter $\psi^{b,c}$ was greater than 1 in Table 3, at 1.21.

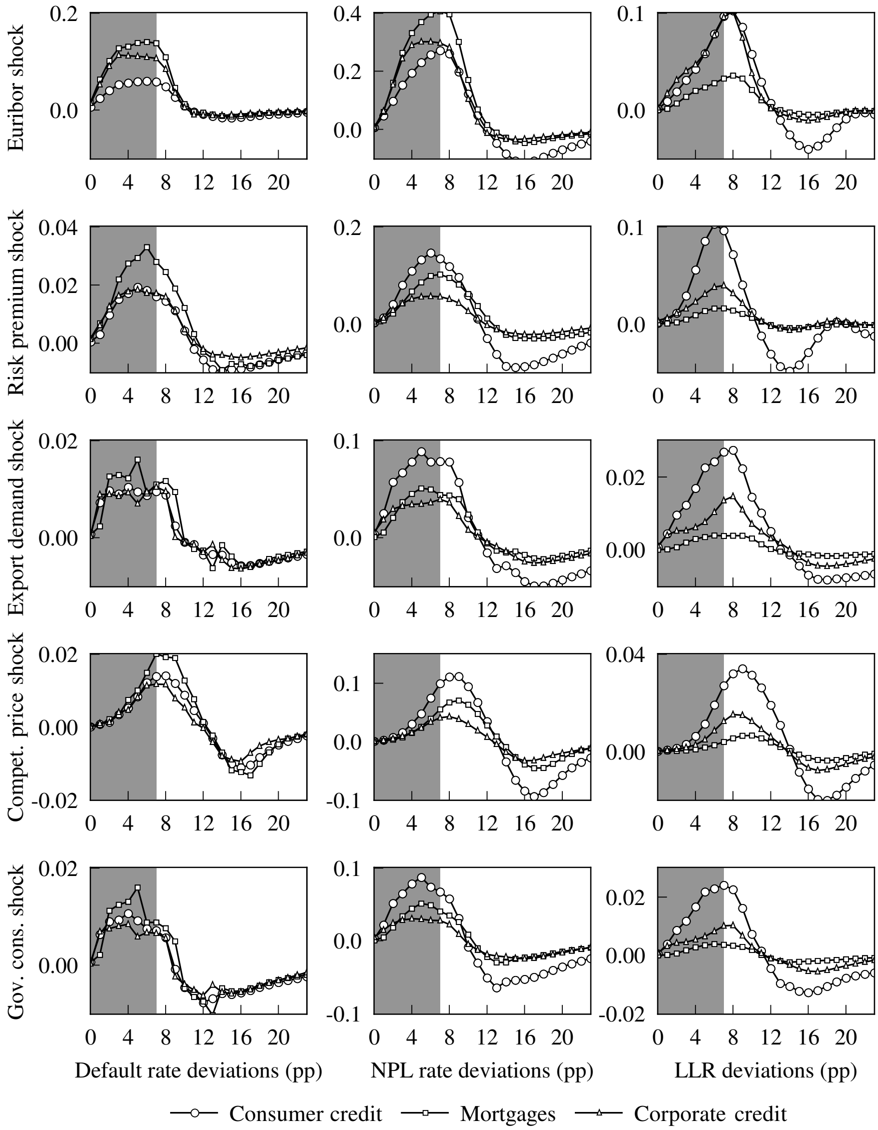


Figure 15: Deviations of distress indicators from the baseline solutions in response to the Euribor, risk premium, export demand, competitors' price and government consumption shocks (deviations in percentage points, quarters on the horizontal axis, grey area denotes the shock period). Source: author.

change either the costliness of lending or the cost of debt servicing are easier to withstand because it is only the income side which is affected. Households and companies keep their borrowing options largely as they were before the shock. There is some contraction in the supply of credit because the borrowing constraint tightens due to the fall in income. But this channel has a relatively mild effect compared to the direct interest shock.

It is noticeable that average loan loss provisions do not deviate from their baseline values as much as non-performing loans do. The reason for this lies in the applied LGD values but also in the provisioning practices of the banks, as foreign branches are not obliged to provision their local loan losses. The absence of provisioning by some of the banks dampens the reaction in the sector's *average* loan loss provision rate.

Another characteristic of all the reaction lines is that they fall below the baseline levels after the shock has vanished. As shown in Figures 10, 11, 12, 13 and 14 the macromodel produces an overreaction in many variables. This behaviour transmits into the credit risk model making distress measures overreact as well.

The previous section showed that it takes some time after the reversal of the shock for the macro economy to recover. Taking the macro model simulation results to the credit risk model shows no substantial delay in the recovery of the banking sector from distress. The distress starts to vanish almost immediately after the shock ends. The rapid recovery is supported by the decline in the indebtedness of the private sector, which was estimated to lower the default rates of the borrowers and thereby lower the distress on the banks (see Table 2).

4.3. Implications of private sector indebtedness

In the following section the same shock scenarios that were discussed in the previous section are implemented in the macro model once again and then taken to the credit risk model. This time all the scenarios are generated 25 times, with a different debt ratio for the private sector each time, as this is supposed to show whether there are any differences in the reaction amplitudes.

The key element in producing these scenarios is that the debt stocks in the three credit sectors change in a manner that is fully consistent with the rest of the economy. It is not meaningful to change the level of credit using an *ad hoc* assumption, or by simply applying add factors to the levels of debt. This approach would violate the building principles of the bank lending channel in the macro model, in which the accumulated credit stock depends on the newly released credit and on the depreciated part of it. The preferred and economically reasonable solution is to mimic the *quantitative* tightening of the credit supply by banks. The mechanism is introduced to the model by a shift in the long term level of credit turnover in equations 24a, 25a and 26a. A shift parameter ζ_m is added to the long-run credit turnover equations for sectors $m \in \{c, f, h\}$:

$$\begin{aligned} ln(E_t^{T,h^*}) = 1.059 + ln(I_t^h P_{I^h,t}) - 0.655 ln(i_t^h - i_t^{ea}) \\ +0.265 ln(Y_{t-1}^h P_{C^h,t-1}(i_{t-1}^{s,h} E_{t-1}^h)^{-1}) + \zeta_h, \end{aligned} \tag{67a}$$

$$\begin{aligned} ln(E_t^{T,c^*}) = -2.546 + ln(C_t^h P_{C^h,t}) - 0.643 ln(i_t^c - i_t^{ea}) \\ +0.097 ln(Y_{t-1}^h P_{C^h,t-1}(i_{t-1}^{s,c} E_{t-1}^c)^{-1}) + \zeta_c, \end{aligned} \tag{67b}$$

$$\begin{aligned} ln(E_t^{T,f^*}) = -2.454 + ln(I_t^f P_{I^f,t}) - 0.331 ln(i_t^f - i_t^{ea}) \\ +0.270 ln(Y_{t-1} P_{t-1}(i_{t-1}^{c,f} E_{t-1}^f)^{-1}) - 0.702 ln(\delta_t^f) + \zeta_f. \end{aligned} \tag{67c}$$

The shift parameter ζ_m produces a level effect in credit turnover but has no impact on the behaviour of credit supply or demand since the parameters remain unchanged. The negative ζ_m can be interpreted as a drop in the resources supplied from the foreign parent banks, maintaining the same borrowing constraint for the borrowers. It is a purely *quantitative* effect, not a behavioural one, that the shift parameter introduces. The alternative option of restricting the credit supply could be achieved by tightening the borrowing constraint by changing its parameter value. Although changing the coefficient values makes it possible to modify credit turnover and the stock of credit, it leads to two unwanted interpretations. Firstly, clients' maximum debt servicing costs as a share of disposable income would be different from that which banks have historically allowed, violating comparability with the past data. And secondly, it would change the elasticities of credit turnover and through that the behaviour of the borrowers, which is not wanted in the conditional scenario analysis.

It is assumed that there is no change in the interest rates, whatever the simulated credit stock is. The Euribor rate stays unaffected and competition between the banks is supposed to shape the risk premiums in the same way regardless of the size of the market. The only remaining factor that can cause different responses in the economy to the negative shocks, is the changed debt level, as is targeted by the design of the shock scenario analysis.

Shift parameters take the values $\zeta_h = (-1.1, 0.1)$, $\zeta_c = (-1.2, 0.1)$ and $\zeta_f = (-0.82, -0.16)$ out of the sample period with the steps 0.05, 0.05 and 0.04 respectively. The parameter ranges are chosen to produce credit to output ratios that are roughly as they were in 2004, that is before the rapid financial deepening, up to the present values. The effects of the indebtedness in the three credit sectors are treated independently, so that only one shift parameter takes a value different from zero at a time. Although other shift parameters remain unchanged, credit adjusts in the other two sectors to some extent as well. The structure of the model keeps all the variables consistent with each other, and therefore lowering the financial intermediation for one sector leads to a decrease in the variables that the credit is used for. Less consumer credit translates into lower private consumption, lower number of mortgages pull down housing investment and less corporate credit lowers productive investments. Whichever real variable is affected, it causes GDP to contract, and the demand for the other two types of credit adjusts correspondingly when the second round effects start to take place. Keeping the other credit stocks unchanged would contradict the structure of the economy.

A larger value for ζ_m, which corresponds to higher indebtedness in sector m, is expected to amplify the shock responses of the macro variables. Amplified shocks would show up in larger maximum deviations from the baseline solutions, indicating a greater threat to the soundness of a bank. In principle bank distress could grow with the length of the shock as well. A smaller but longer-lasting shock could elevate bank distress as much as a more severe but shorter shock. This mechanism, however, is not included in the credit risk model.

Figure 16 visualises the hypothetically increased reaction amplitude of the macro indicators to exogenous shocks at different debt ratios $e^m|\zeta_m$. Deviations are presented in absolute terms in the figure because some of the macro variables increase in stressful times (unemployment) while the others decrease (GDP growth, inflation).

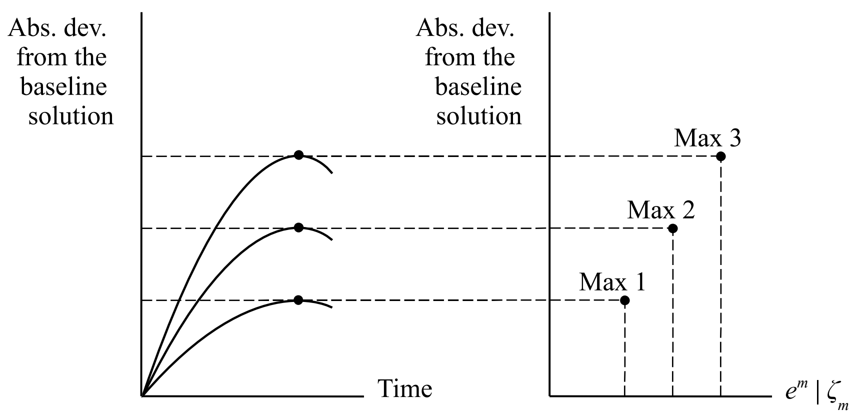


Figure 16: Absolute deviation of a macro variable from a baseline solution conditional on the debt ratio. Source: author.

Figure 17 depicts the maximum deviations of the macro variables in response to the shocks defined in section 4.1. conditional on the underlying debt ratios. Each subfigure resembles the right hand graph in figure 16, except that deviations are represented not in absolute terms but in their actual values. The macro variables under inspection are inflation, the real estate price index, the unemployment rate and GDP growth. The figure does not contain interest rates, which are exogenous (the shocks are not large enough to trigger an increase in the risk premiums).

Inflation responds most to the competitors' price shock but the simulations express almost no difference in how inflation reacts to all the defined shocks when the economy operates at the different levels of indebtedness. The exception emerges in the interest rate and risk premium shocks when corporate debt takes different values. The link is via the price setting mechanism. Companies' access to bank credit is a vital source for financing investments and expanding production. Production volumes affect the wage determination process and production costs, which then finally transmit into consumption prices. The same shocks have become slightly more influential on inflation due to the increased mortgages as well.

As may be expected, the Euribor rate and risk premium shocks prevail when it comes to the factors upon which the real estate price depends. Real estate market activity and real estate prices are heavily dependent on the availability of credit. Once the contractionary monetary policy or the risk premium shock hit financial intermediation, borrowers react by cutting their borrowing from the banks. An increased price of borrowing and lessened demand for real estate lowers its price level. The simulations show that the degree of reaction of the real estate price in response to both shocks is affected by the volume of mortgages in the economy. There is also some change in the maximum responsiveness traceable at different corporate debt levels.

There is also evidence of changing reaction amplitude in the unemployment rate. Even consumption credit, which has a relatively low share in the overall debt, is able to influence the real sector's vulnerability. The most influential shocks are again the Euribor and risk premium shocks. The change in the sensitivity of the unemployment rate is more pronounced for mortgages and even more pronounced when the corporate sector's indebtedness is considered.

The lowest row of graphs illustrates the maximum deviations of GDP growth. Since unemployment is largely influenced by economic activity, the two lowest panels are almost mirror images of each other. The level of credit to all sectors matters for how big is the impact of Euribor and risk premium shocks on GDP growth. The change in the reaction magnitude is seen most clearly in the corporate credit sector. Behind this is the increased sensitivity of investments. As Joyce and Nabar (2009) have shown, higher debt servicing costs lead to a greater con-

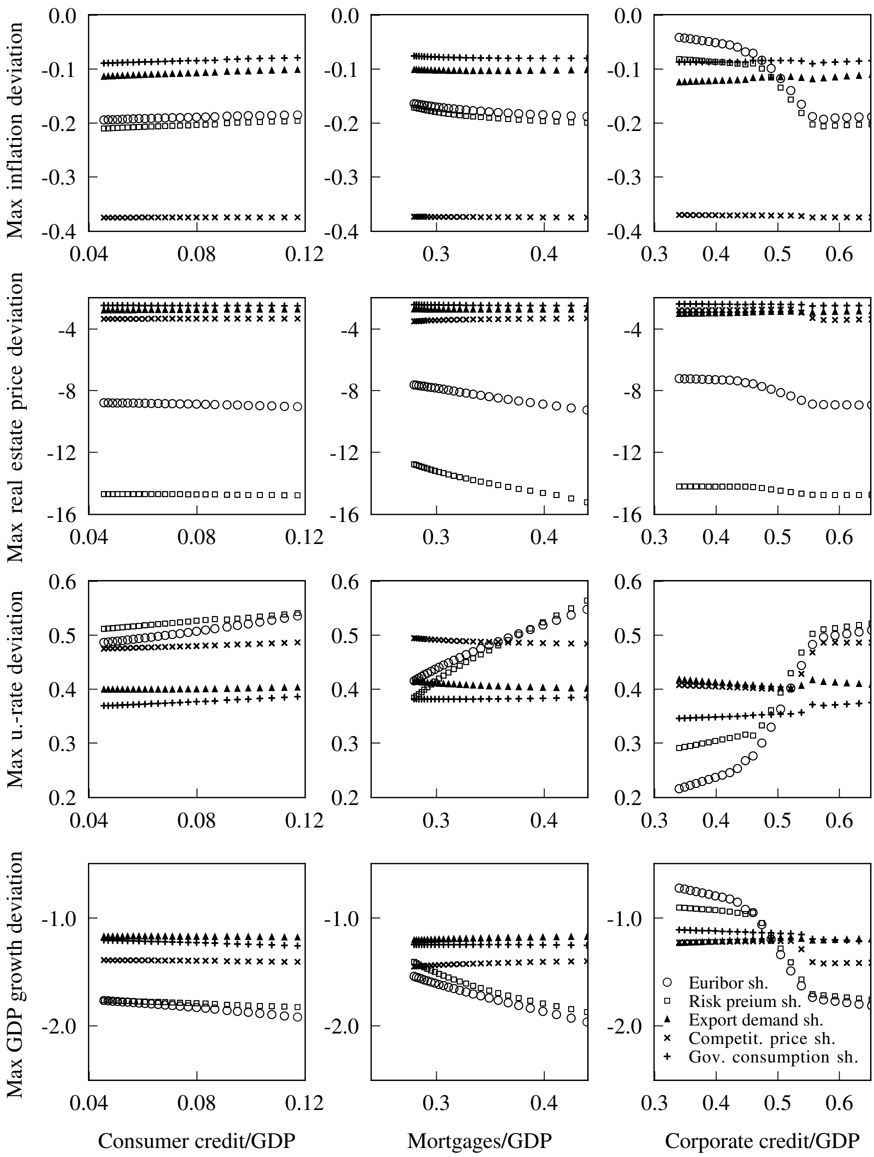


Figure 17: Maximum deviations of inflation (*pp*), real estate prices (%), unemployment rate (*pp*) and GDP growth (*pp*) from the baseline solutions in response to the Euribor, risk premium, export demand, competitors' price and government consumption shocks. Source: author.

traction in the investments to output ratio, which also here accounts for the larger responses of investments and GDP.

The five scenarios taken together show that it is interest rate shocks that interact with indebtedness the most. This is supported by Lindgren et al. (1998) who identify monetary policy shocks as the most influential for the banks' balance sheets, but also with Ferguson, Jr. et al. (2007), who show the same. The interest rate shock is the most influential because it directly affects the availability of credit and impacts spending decisions, but also because it creates feedback effects between financial and real sectors that amplify and prolong the response to the shock. [68] Shocks that originate from the real sector, either domestically or externally, cause almost the same degree of harm to the real economy, whatever the level of indebtedness. The impacts of the shocks arising from the real economy are easier to offset because financing purchases with bank lending has not become more restrictive.

In the next step the scenarios described above are mapped to the credit portfolios of the banks by inserting the macro model simulation values into the credit risk model and running it. Figure 18 shows the maximum responses of the distress measures: average default rates, average NPL rates and average LLP rates. The maximum reactions of the distress indicators depend on the sensitivity of the macro variables, conditional on indebtedness and also on the sensitivity of the default rates. [69]

The results indicate a clear connection between the indebtedness of the private sector and reaction magnitudes of the asset quality of the banks. This fits the general finding that a banking crisis is more plausible in countries with higher debt ratios [70]. Shock simulations show that credit risk has risen with increased private sector indebtedness in all credit sectors, regardless the source of the shock, and this holds true for all distress measures. Shocks of equal size are expected to generate reactions in the distress indicators that are approximately twice as large at the current level of indebtedness compared to as they were with the debt ratios as they were around 2004 (see Figure 18). [71]

[68] Bayoumi and Melander (2008) highlight the importance of the feedback effect in their study of the role of the bank capital to asset ratio and lending standards in the shock propagation mechanism.

[69] As already seen, the extraction of the default series in section 2.2. revealed that indebtedness is statistically significant variable in explaining the default rates of all three credit sectors.

[70] Proven by Demirgüç-Kunt and Detragiache (1998), Domaç et al. (2003), Klomp (2010), Wong et al. (2010), Čihák and Schaeck (2010), Komulainen and Lukkarila (2003) and Büyükkarabacak and Valev (2010).

[71] The relatively lower vulnerability of the banks in the low indebtedness environment may be the reason why Männasoo and Mayes (2009) found indebtedness insignificant in explaining bank distress in less advanced transition countries, which are in countries with lower indebtedness.

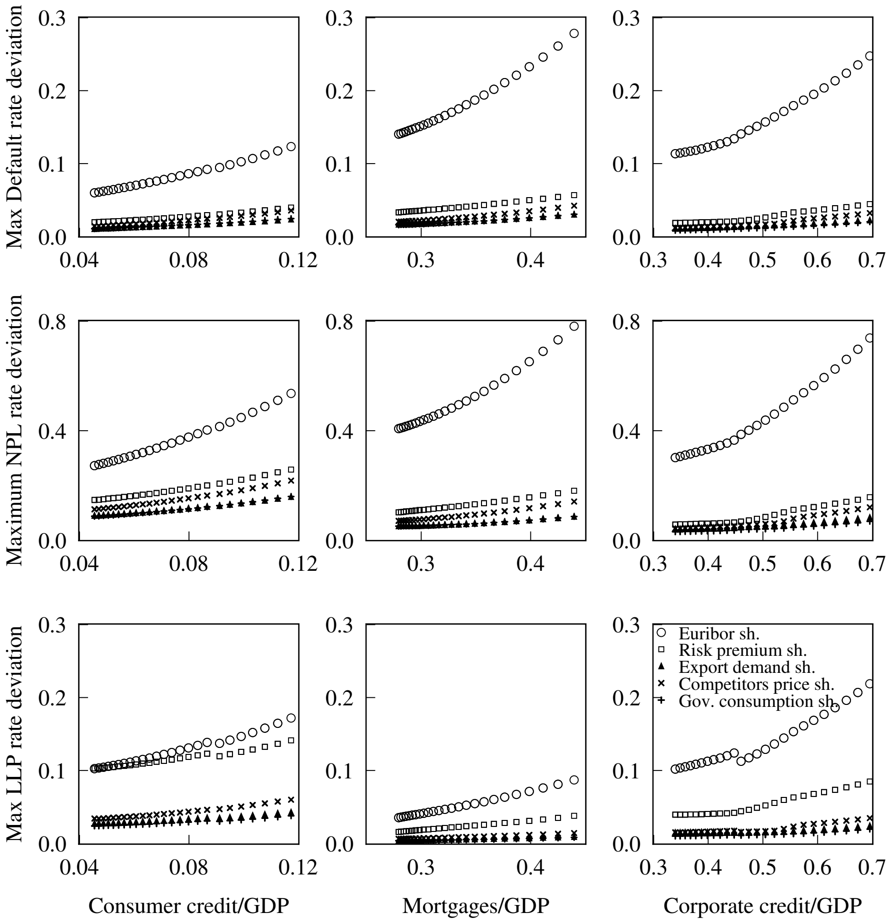


Figure 18: Maximum deviations of the default rates, non-performing loan rates and loan loss provisions rates from the baseline solutions in response to the Euribor, risk premium, export demand, competitors' price and government consumption shocks (deviations in percentage points). Source: author.

Reasons for the increased vulnerability to alternative kinds of shock are different. Shocks that emerge from the real economy have not become more hurtful for the real economy, as shown in Figure 17, but vulnerability of the banks has risen because of the increased sensitivity of the default rates. Interest rate shocks, on the other hand, are amplified by both the increased sensitivity of the default rates and the increased responsiveness of the real economy.

All the shocks are comparable on the grounds that they cause a similar fall in the GDP from its baseline solution. Given this, contractions in the economy of equal size tend to have most impact on the soundness of the banks when they are induced by financial, interest rate related shocks. The proportion of credit that becomes non-performing when the Euribor rises is largest for mortgages, although not by much in comparison to corporate credit. Consumer credit is the most sensitive in the occurrence of any other shock. If non-performing loans are treated as the most characteristic distress measure, then it can be said that banks have become more vulnerable because of their increased credit exposure to households. This finding is well in line with the paper by Büyükkarabacak and Valev (2010), who claim on the basis of cross country evidence that the increased indebtedness of households is more likely to cause banking crises than is the increased indebtedness of companies.

Interestingly, the opposite evaluation of the riskiest exposure is found when the judgement is based on loan loss provision rates. Leaving aside consumer credit, which accounts for only about 9% of the overall credit stock, loan loss provisions react the most in the corporate credit sector. The same can be witnessed in the data, which shows that the provisioned corporate loan loss rate jumped by about 5.5pp in 2007–2009, whereas the provisioned losses from mortgages increased by about 1.5pp within the same period. The only explanation for this is that mortgages are better collateralised and the loss given default rate is lower than in the corporate credit sector. Since provisioned losses are more precise measure of a bank distress, the conclusion is that the increased credit exposure of banks to companies has increased their vulnerability the most.

The importance of the interest related shocks was already stressed in section 2.3. but the results reported in figure 18 also permit the consequences of monetary policy and the risk premium shock to be separated. The slowdown in economic activity which is triggered by the risk premium shock is less damaging for the soundness of the banks than are the effects of the Euribor raise, although the risk premium shock increases distress more than do the shocks arising from the real economy.

This outcome highlights the importance of the counter-cyclical monetary policy in order to dampen the risks on the banks. Also Aisen and Franken (2010) have shown that counter-cyclical monetary policy has been extremely important in alleviating the credit crunch among the eighty counties that were looked at in their study. Unfortunately monetary policy instruments are not directly controlled by the state or by the supervisory agency in any country which belongs to the eurozone. In this case the best solution for a country is to have a highly synchronised economic cycle with the currency union, so that the optimal monetary policy for a country would match the one for the whole area. Estonia, being a very open economy, is well synchronised via the trade links and financial markets (Danilov, 2003), and benefits from that.

The finding of relatively high and increased sensitivity of credit quality to risk premium shocks is appealing because it shows that banks themselves can reduce risks. Instead of accounting on the counter-cyclical monetary policy, banks themselves should run a counter-cyclical or at least neutral risk premium policy. This would help the borrowers to accommodate shock impacts and avoid defaulting. Increased risk premiums in stressful times, on the other hand, which make additional borrowing overly expensive, narrow borrowing incentives and possibilities to accommodate shock impacts. However, it may be that this tool has lost its effectiveness over the course of financial deepening. For example Inklaar and Koetter (2008) find evidence that it has been less mature European economies which have benefited more from easier access to credit in terms of output and productivity growth.

Overall, financial deepening may provide a source of an extra growth through more rapid capital accumulation, as it has happened in Estonia, but it comes at the cost of increased vulnerability of companies and through balance sheet links it also increases vulnerability of the banks. Households are most likely to suffer from the real-estate-credit-boom cycles, increasing their debt ratio too much at the peak of the cycle and becoming exposed to default risk when the boom ends and income contracts. Consequently banks are exposed to a larger credit risk, facing bigger deteriorations in their credit quality if the economy is hit by any shock, *ceteris paribus*.

5. CONCLUSIONS

The recent global crisis has strongly motivated researchers to explore the links between the financial and real sectors more thoroughly. Academic society and practitioners at the supervisory authorities have realised that existing models are often incapable of describing the complex interlinkages between the two sectors, and so they have started to fill in the gap.

A major strand of the related literature is dedicated to analysing the soundness of the financial sector. The field is of great practical importance because the role of the financial sector becomes especially important in determining the economic development of a country in stressful times. Banks should ideally to be able to cope with shocks that may grow either from inside the financial system or from the real economy, without defaulting. Often that is not the case. The reasons for this may lie in undervaluation of the risks through inadequate assessment of vulnerabilities or underestimation of the possible shocks.

The emerging shocks are highly unpredictable. Models that are designed to test the soundness of the financial sector are at best helpful for understanding how the shocks would affect the financial sector, but they rarely say anything about the magnitude or about the origin of the shocks. Therefore practitioners use stress test models, which enable them to assess the resilience of the financial system to hypothetical shock scenarios. The models can be taken to the historical shock scenarios as well, it is widely recognised that stressful times are hardly ever similar in nature or scale.

Uncertainty about the probabilistic shock events makes it more vital to understand the vulnerabilities of the financial sector. This is because the shocks are not harmful on their own but in interaction with the underlying vulnerabilities. The list of possible vulnerabilities is long, typically including characteristics from the financial sector itself and macroeconomic variables. Each of them deserves deep investigation to build up knowledge of how it may become a potential threat to the stability of the financial system. The present thesis has picked out one of them, private sector indebtedness, for in-depth analysis.

Interest in private sector indebtedness in particular is motivated by the fact that a number of countries which went through a rapid credit expansion before the latest crisis faced severe pressures on their financial systems, especially their banks. Although it is well-known that the crisis was largely caused by a deterioration of the credit standards, it remains an open question whether there may have also been a pure volume effect caused by the increased levels of indebtedness of households and companies. Higher financial obligations to the banks would mean less options for households and companies to cushion the unfavourable effects of the shock and therefore the rise in the default rates would be bigger than in a lower debt level environment.

The thesis puts the this hypothesis to the test by building a stress test system and investigating the issue using the specified framework. The system consists of two models, the credit risk model and the macro-econometric model for running simulations. Both models are built on Estonian data, which makes a good reference in a number of ways. The Estonian financial sector is relatively simple to model because the sector is highly bank-oriented. Banks keep the vast majority of their assets in credit to the private sector, which combines with the previous consideration to mean that credit risk outweighs the other types of risk. Concentrating on only one type of risk keeps the analysis simpler and better focused. Another point that makes Estonian data so valuable is that the economy has gone through a very rapid deepening of credit. The restructuring of the banking system and the coinciding low-interest environment caused a credit boom which lifted private sector indebtedness from 30% of GDP to 110% of GDP within just six years. Therefore the country provides macroeconomic data conditional on low and high levels of indebtedness within a narrow window.

The credit risk model separates four major banks in the market and aggregates the rest of the market participants into one group without losing the representativeness of the model. The high concentration of the sector leaves only 9% of the market share to the remaining 16 banks. The health of the banks' credit exposures is explained by GDP growth, the unemployment rate, the real interest rate and the real estate price. The estimation of the model proved that the average default rates in all three disentangled credit sectors—consumer credit, mortgages and corporate credit—have risen with the increase in indebtedness. The logistic function for modeling the default rates also implies that the increased indebtedness has made the default rates more sensitive to variations in the other macro indicators too.

One of the virtues of the specified credit risk model is that its structure enables it to extract the missing default rates of the groups of credit clients in a fully consistent manner. The non-performing loan equations mimic the actual data generation process of the non-performing loans, with the default rate being the unobserved regressor. The thesis shows that the default rates can be stripped out using the data on non-performing loan rates, underlying vulnerabilities (macro indicators) and the average recovery rate of the clients.

The extracted default rates suggest that non-performing loans are not very good indicators of the credit clients' payment discipline. A large share of the dynamics of the non-performing loans is driven by the recovery process of previously non-performing loans. When the economy is in recession the recovery rate falls and non-performing loans may show no change although the default rates have already started to decline. This kind of movement has been found to hold true for Estonia. The different dynamics of the new NPLs and the healed ones makes it arguable whether regressing NPL ratios directly on the underlying vulnerabilities can be methodologically correct. By doing so, the estimated parameters try to capture two processes at the time and may therefore be unstable.

The macro-econometric model for the Estonian economy benefits from a number of elements that are added to capture economic processes and the links between the sectors of the economy. The most important development regards the modelling of the banking sector and bank lending, which is central to analysis of the macroeconomic consequences of private sector indebtedness. The approach used is able to catch financial deepening and also to replicate credit cycles. Both of these are unavoidably crucially relevant properties for data replication.

The outstanding stocks of consumer credit, mortgages and corporate credit are modeled to evolve similarly to the PIM method which is in use for describing capital accumulation. In this method, change in credit stocks equals newly issued credit (turnover) minus depreciation (principal payment). The speed at which the credit stock grows depends on the credit turnover. A steady decrease in the lending risk premiums have led to substantial financial deepening, which is limited by the banks' supply constraint. The supply constraint is based on the clients' debt servicing costs as a proportion of their income. If the income rises, banks increase their supply because they associate an increase in income with lower risks. An increase in interest rates has the opposite effect, as it increases the obligors' financial burden and so banks cut lending. The mechanism adds the necessary financial frictions into the model, providing alternative approach to the popular collateral constraint and financial accelerator principles.

The interest rates that matter for the credit servicing cost are the rates on stocks rather than the interest rates on new loans, as is the case in reality. Shocks to interest rates therefore take some time to transmit fully into servicing costs because the interest rates on stocks adjust sluggishly. The sluggish adjustment is modeled by re-pricing of the existing contracts on a regular basis. As most of the contracts are denominated in Euros and tied to the six-month Euribor rate, the contracts are re-priced twice a year on average. The full transmission of the interest rate shocks depends on credit growth—the higher is the growth, the steeper the transmission because the proportion of new credit given out at the new rates is relatively bigger. It follows that an expansionary monetary policy has a more sudden effect whereas a contractionary monetary shock transmits relatively slower.

Although it functions on the background and does not have visible effects in the short run, the macro-econometric model has been built to satisfy the dynamic homogeneity condition. The issue is raised from the original problem set, which states that behavioural equations built in the error correction form must contain a mutually consistent cointegration relationship and dynamic equation. If the condition is not met the growth of then the endogenous variable predicted by the cointegration relationship and that predicted by the dynamic equation diverge, hindering the properties of the model the equation belongs in. The literature finds that restricting only the supply side equations is enough to guarantee that the whole model behaves consistently. The present thesis argues that setting the restriction on an equation which is built on the data of a catching-up economy is different from the standard solution proposed in the literature. Converging economies are likely to face decreasing growth rates in many of their macro variables on the path to their respective steady states. This property requires the dynamic homogeneity restriction to be time varying.

The macro model also benefits from the inclusion of a fiscal policy rule which, in contrast to the mainstream solution, lets government pursue the targeted fiscal policy by adjusting its expenditures. The approach used the most in the macro models mimic the behaviour of the government by letting tax rates vary. However the research finds that it is more appropriate and more in line with reality that the government responds to the deteriorating economic environment by changing its expenditures and letting the revenues function automatically. The fiscal policy rule states the governments action as a function of the long run targeted budget balance and maximum allowed deficit. Cuts in Estonian public spending throughout the crisis have well justified the specification of the fiscal rule.

The macro model is used to run five alternative scenarios to see how the model economy accommodates the initial shock impulses. The scenarios considered are increases in the Euribor rate and the lending risk premiums, falls in foreign demand and in the foreign competitors' price levels and a cut in government consumption spending. The shocks are chosen to resemble various sources of disturbances, that affect the economy through different channels. All the shocks are scaled to produce equal responses in GDP for comparability of the scenarios. Comparison of all of them reveals that regardless of the shock, the two most important macro variables affecting default rates, GDP and unemployment, always respond proportionally. This is because companies demand labour input in proportion to their production, as is fixed by the production function. Dividing GDP by expenditure items, however, shows a rich variation in responses. Investments are most volatile when it comes to the monetary policy shocks, while shocks from the real economy are less disruptive.

The same five scenarios are produced with the macro model by gradually changing the level of private sector indebtedness. The simulation exercise indicates that indebtedness has affected responsiveness of the macro variables that are relevant for the default rates of certain shocks. Varying the levels of consumer credit has the smallest effect, which is natural given its low share in the overall credit stock. However, inflation, the unemployment rate and GDP growth show slight increases in maximum deviation amplitude at different levels of consumer credit.

Mortgages and corporate credit have a substantial effect on the responsiveness of the indicators. The increase is especially pronounced with corporate credit. Across all the shocks considered, the disturbances related to the interest rate stand out as being those which change their harmfulness as the debt ratio increases. The reason is that they directly affect debt servicing costs, and this lessens the resources that can be spent on expenditure items. More financial obligations in this context means less ability to accommodate the shock and the responses are amplified due to the tightened budget constraints. The impacts of the shocks that arise from the real economy are easier to offset because households and companies are able to get through the distressed times by financing their expenditures with bank lending. This channel does not operate when the shock is related to bank lending, and then the private sector has to cope with its increased financial obligations without having the option of dampening the fall in expenditures with external financing.

Taking the macro-scenarios to the credit risk model confirms that increased vulnerability in the banking sector, which is in line with the general findings in the related literature. All the shocks that were considered increased in magnitude over the course of financial deepening. Although the macro model showed only modest change in the responsiveness of the macro variables to the real economy shocks, there is clear evidence that banks' credit portfolios have become more vulnerable. The effect comes from the clients' increased default rates, driven by their increased liabilities. The interest rate remains the most damaging factor for the same reasons that were used to explain the higher responsiveness of the real economy: unlike shocks to the real economy, interest rate shocks put the budgets of banks' clients under stress from both the income and expenditure sides.

In the light of the earlier discussion, it can be seen that financial services and bank lending play a crucial role in cushioning the shocks that emerge from the real sector. Paradoxically, if the banks do not tighten lending to the private sector and do not increase risk premiums, then they are better off and under lesser stress because the bank lending channel is able partially to absorb the shock impacts. In other words, the less the banks' interest rate policy responds to economic contractions, the smaller their own credit risk. The same can be achieved with the counter-cyclical monetary policy. Estonia, being a member of the eurozone, does not have possibility to conduct independent monetary policy but the monetary policy signals are imported from the euro area. Therefore a smooth risk premium policy would be the key to a sounder banking system. The role of the acyclical risk-premium becomes more important when the level of indebtedness is relatively high and less so when the level is lower.

Further work can be done on the estimation of the credit risk model using panel data techniques. Although financial sector data is available at a monthly frequency, the estimation may benefit from a pooling of the data and an increase in the degrees of freedom. Doing so, also small banks could be treated separately, which have been aggregated into one group in the thesis.

In addition, it may become necessary to modify the structure of the non-performing loan equation. There is evidence that banks change intensity with which they take care of problematic loans. In stressful times, when the ratio of non-performing loans is high, banks seek more thoroughly possibilities to restructure problematic loans so that the clients would not default. This is not done so actively when the overall ratio of non-performing loans is low. Consequently the estimated relationship between macro indicators and non-performing loans may be flawed if this phenomena is not accounted for. It can be tested by including bank-specific data for credit-quality portions.

Other possible future work could be done in expanding the macro-econometric model by incorporating all the distress measures that appear in the credit risk model at the aggregate level. The structure of the financial variables in the credit risk model and in the macro-econometric model are identical already and inclusion of the default rates, non-performing loans and loan loss provisions would be relatively easy. The benefit of this would be that it would stress the banking sector with only one modelling tool. An analysis of financial stability at the more detailed bank level could still be carried out with the credit risk model but the model would then serve as a tool which distributes the aggregate financial variables between individual institutions.

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APPENDICES

Appendix 1. Equations and identities in the credit risk model

Dependent variable	Equation/Identity	No.
NPL positions	$N_t^{b,m} = (\eta^{b,m} + \psi^{b,m}\Pi_{t-2}^m)E_{t-2}^{b,m} + $ $+\left(1-\rho^{b,m}\right)N_{t-1}^{b,m}$	15
Bank's overall NPLs	$N_t^b = \sum_m N_t^{b,m}$	5
NPLs in sector m	$N_t^m = \sum_b N_t^{b,m}$	3
Aggregate NPLs	$N_t = \sum_b \sum_m N_t^{b,m}$	1
LLP positions	$L_t^{b,p} = \lambda^{b,p} e^{-\kappa^{b,p}\tilde{z}_{t-2}} N_t^{b,p} - M_{t-1}^{b,p} + \phi^{b,p}$	20
Bank's overall LLPs	$L_t^b = \sum_p L_t^{b,p}$	5
LLPs in sector p	$L_t^p = \sum_b L_t^{b,p}$	4
Aggregate LLPs	$L_t = \sum_b \sum_p N_t^{b,p}$	1
PD in sector m	$\Pi^m = e^{f(\beta^m,X)}/(1+e^{f(\beta^m,X)})$	3
	$f(\beta^m, X) = -\beta_0^m + \beta_1^m \tilde{u}_{t-l} - \beta_2^m \tilde{y}_{t-o} +$ $+\beta_3^m \tilde{r}_{t-j}^{s,m} + \beta_4^m \tilde{e}_t^m$	
Real i-rates	$r_t^{s,m} = i_t^{s,m} - \tau^m \pi_t + (1-\tau^m)\overline{\pi}$	
Nominal i-rates, new loans	$i_t^m = i_t^{ea} + \vartheta_t^m$ or $i_t^m = i_t^m$	3
Nominal i-rates on stock	$i_t^{s,m} = \mu^m + \chi_t^m[i_{t-1}^{s,m} + \gamma(i_t^{ea} - i_{t-6}^{ea})] +$ $+(1-\chi_t^m)i_t^m$	3
	$\chi_t^m = [1 + e^{\theta^m + \alpha^m \Delta ln(E_t^m)}]^{-1}$	
Exposure, bank, sector	$E_t^{b,m} = E_{t-1}^{b,m} E_t^m / E_{t-1}^m$	15
Banks' portfolio	$E_t^b = \sum_m E_t^{b,m}$	5
Sector's exposure	$E_t^m = \sum_b E_t^{b,m}$	3
Aggregate exposure	$E_t = \sum_b E_t^b$	1
Bank's NPL ratio in sector m	$R_t^{N^{b,m}} = N_t^{b,m}/E_t^{b,m}$	15
Bank's overall NPL ratio	$R_t^{N^b} = N_t^b/E_t^b$	5
NPL ratio, sector m	$R_t^{N^m} = N_t^m/E_t^m$	3
Aggregate NPL ratio	$R_t^N = N_t/E_t$	1
Bank's LLP ratio, sector p	$R_t^{L^{b,p}} = L_t^{b,p}/E_t^{b,p}$	20
Bank's overall LLP ratio	$R_t^{L^b} = L_t^b/E_t^b$	5
LLP ratio in sector p	$R_t^{L^p} = L_t^p/E_t^p$	4
Aggregate LLP ratio	$R_t^L = L_t/E_t$	1
Recovery rates	$\rho_t^m = \bar{\rho}^m + \xi_y^m \tilde{y}_t + \xi_u^m \tilde{u}_t + \xi_\rho^m \rho_{t-1}^m$	3

Appendix 2. List of parameters and variables in the macro model

Acronym	Description
α	Income share of capital (p)
ε	Elasticity of demand (p)
χ^c	Weight of consumer loans' stock interest rate (o)
χ^f	Weight of corporate loans' stock interest rate (o)
χ^h	Weight of mortgage loans' stock interest rate (o)
χ_M	Weight of euro-based imports (o)
χ_X	Weight of euro-based exports (o)
δ^c	Repayment ratio of consumer credit (r)
δ^f	Repayment ratio of corporate credit (r)
δ^h	Repayment ratio of mortgage credit (r)
δ_K	Depreciation rate of physical production capital (r)
η	Mark-up (o)
λ	Labour force participation rate (r)
ρ	Entrepreneurial risk premium (o)
ς_{C^g}	Import share of government consumption (r)
ς_{C^h}	Import share of household consumption (r)
ς_{I^f}	Import share of corporate investments (r)
ς_{I^g}	Import share of government investments (r)
ς_{I^h}	Import share of household investments (r)
ς_X	Import share of exports (r)
ς_Z	Import share of inventory investments (r)
τ	Share of working age people (r)
Υ^c	Consumer credit clients' debt to asset ratio (o)
Υ^f	Corporate credit clients' debt to asset ratio (o)
Υ^h	Mortgage credit clients' debt to asset ratio (o)
$	Kroon-dollar exchange rate (o)
A	Level of production technology (o)
C	General consumption, theoretical (R)
C^g	Government consumption (R)
C^h	Households' consumption (R)
d	Tax-free personal income
D^f	Deposits of corporations (N)
D^h	Households' deposits (N)
er_M	Effective exchange rate of kroon, import weighted (o)
er_M	Effective exchange rate of kroon, export weighted (o)
E^c	Outstanding stock of consumer credit (N)
$E^{T,c}$	Consumer credit turnover (N)
E^f	Outstanding stock of corporate credit (N)

Notes: N – nominal variable, R – real variable, P – price index, p – parameter, r – rate, o – other.

Acronym	Description
$E^{T,f}$	Corporate credit turnover (N)
E^{h}	Outstanding stock of mortgage loans (N)
$E^{T,h}$	Mortgages turnover (N)
G	Government transfers to households (N)
G_O	Government other expenditures (N)
H	Total hours worked (o)
i^{d}	Interest rate on new deposits (r)
i^{ea}	Six month Euribor (r)
$i^{s,d}$	Interest rate on stock of deposits (r)
i^{c}	Interest rate on new consumer loans (r)
$i^{s,c}$	Interest rate on stock of consumer loans (r)
i^{f}	Interest rate on new corporate loans (r)
$i^{s,f}$	Interest rate on stock of corporate loans (r)
i^{h}	Interest rate on new mortgage loans (r)
$i^{s,h}$	Interest rate on stock of mortgage loans (r)
I^{f}	Corporations' fixed capital formation (R)
I^{g}	Government fixed capital formation (R)
I^{h}	Households' fixed capital formation (R)
I^{p}	Productive investments (R)
J	Sales indicator (R)
K	Physical capital stock (R)
L^{pop}	Total population (o)
M	Imports of goods and services (R)
M_D	Import demand indicator (R)
M_G	Imports of goods (R)
M_S	Imports of services (R)
N^{c}	Non-performng consumer loans (N)
N^{f}	Non-performng corporate loans (N)
N^{h}	Non-performng mortgage loans (N)
O	Households' ownership revenues (N)
P	GDP deflator (P)
P_{CM}	Foreign competitors' import prices (P)
P_{CX}	Foreign competitors' export prices (P)
P_{FF}	Foreign food price (P)
P_{FIXI}	Effective price level of the trade partners with fixed ER (P)
P_{FLOI}	Effective price level of the trade partners with floating ER (P)
P_h	Real estate price (P)
P_{HC}	Core HICP (P)
P_{HF}	Harmonized food price (P)
P_{I^f}	Corporate investment deflator (P)
P_{I^h}	Households' investment deflator (P)

Notes: N – nominal variable, R – real variable, P – price index, p – parameter, r – rate, o – other.

Acronym	Description
P_K	User cost of capital (P)
P_M	Import deflator (P)
P_{M_G}	Imports of goods deflator (P)
P_{M_S}	Imports of services deflator (P)
P_{oil}	Oil price in U.S. dollars (P)
P_X	Export deflator (P)
P_{X_G}	Exports of goods deflator (P)
P_{X_S}	Exports of services deflator (P)
q	Tax rate on labour (r)
Q^f	Operating surplus and mixed income of corporations (N)
Q^h	Households' operating surplus and mixed income (N)
Q	Gross operating surplus and mixed income (N)
r	Real lending rate of corporations (r)
R^{FI}	Net foreign income (N)
R^{FT}	Net foreign transfers (N)
S	Total savings in the economy (N)
S^f	Corporate savings (N)
S^g	Government savings (N)
S^h	Household savings (N)
T	Social tax (N)
T_{EXC}	Excise tax (N)
T^f	Corporate income tax (N)
T^h	Personal income tax (N)
T_o	Government other income (N)
T_{oil}	Excise tax on fuel (r)
T_{VAT}	VAT (N)
tr_{EXC}	Effective excise tax rate (r)
tr^h	Personal income tax rate (r)
tr^f	Corporate income tax rate (r)
tr_{VAT}	VAT rate (r)
u	Unemployment rate (r)
U	Unemployment (o)
u^*	Natural unemployment rate NAWRU (r)
X	Exports of goods and services (R)
X_D	Export demand of trade partners (R)
X_G	Exports of goods (R)
X_S	Exports of services (R)
w	Hourly gross wage (N)
W	Hourly gross wage (R)
Y	GDP (R)
Y^h	Households' disposable income (R)

Notes: N – nominal variable, R – real variable, P – price index, p – parameter, r – rate, o – other.

Acronym	Description
z	Indirect tax rate (r)
Z	Change in inventory investments (R)
Z^s	Stock of inventory investments (R)

Notes: N – nominal variable, R – real variable, P – price index, p – parameter, r – rate, o – other.

Appendix 3. Time varying dynamic homogeneity restriction

DHR is imposed on the error correction model with the following representation: [72]

$$\Psi(\Lambda)\Delta ln(Y_t) = c + \Gamma(\Lambda)\Delta ln(X_t) - \theta\left(ln(Y_{t-k}) - \varpi ln(X_{t-k})\right) + \upsilon_t \quad (68)$$

where c is the intercept,$\Psi(\Lambda)\Delta ln(Y_t)$ is the lag polynomial of endogenous variable Y and $\Gamma(\Lambda)\Delta ln(X_t)$ is the lag polynomial of the exogenous variables' vector X. The expression $ln(Y_{t-k}) - \varpi ln(X_{t-k})$ is the error correction term and υ is the disturbance term. On the balanced growth path the endogenous variable and the vector of exogenous variables grow at the rates γ_Y and γ_X respectively. Denoting steady state values of Y with Y^* and X with X^*, the following relationship must hold on the balanced growth path:

$$\Psi(\Lambda)\gamma_Y = c + \Gamma(\Lambda)\gamma_X - \theta\left(ln(Y_t^*) - \varpi ln(X_t^*)\right) \quad (69)$$

In the steady state, the endogenous variable equals its intermediate (long run) target $ln(Y_t^*) = \varpi ln(X_t^*)$, implying that $\gamma_Y = \varpi\gamma_X$. As a result, the short run dynamics of the error correction model are consistent with the long run part of it only if $\varpi\Psi(\Lambda)\gamma_X = c + \Gamma(\Lambda)\gamma_X$. In a converging economy γ_X is not a vector of constant equilibrium rates but the rates decrease as the economy matures. Consequently the intercept of the model must capture this systematic change too. The restriction imposed on estimated error correction model is $c_t = [\varpi\Psi(\Lambda) - \Gamma(\Lambda)]\widetilde{\gamma}_{Xt}$, where $\widetilde{\gamma}_{Xt}$ is the trend growth of explanatory variables.

Imposing a DHR is done in two steps. Firstly an unrestricted equation is estimated to specify the lag structure and to select the set of short run determinants. In the second stage a restriction is set on the intercept and the initial equation is re-estimated in the restricted form.

[72] The notation here does not follow the notation of the acronyms in the macro model.

Appendix 4. Estimation statistics of the macro model's equations

Equation	Sample	Observations	DW-statistic	R^2 Adjusted
24a	2003Q2 – 2009Q4	27	1.033	0.970
24b	2003Q3 – 2009Q4	26	2.102	0.852
25a	2006Q4 – 2009Q4	13	2.733	0.935
25b	2006Q4 – 2009Q4	13	2.229	0.906
26a	2004Q1 – 2009Q4	24	1.894	0.929
26b	2003Q3 – 2009Q4	26	1.857	0.735
27b	2003Q2 – 2009Q4	27	1.010	0.858
27c	2003Q2 – 2010Q1	28	2.369	0.785
32a	2003Q1 – 2009Q3	27	0.241	0.905
32b	2003Q2 – 2009Q3	26	2.697	0.908
33a	2003Q3 – 2009Q3	25	1.035	0.937
33b	2003Q4 – 2009Q4	25	2.186	0.883
34a	1997Q2 – 2009Q2	49	1.548	0.678
34b	1998Q4 – 2009Q3	44	2.250	0.610
35a	1996Q1 – 2009Q2	54	0.632	0.983
35b	1996Q1 – 2009Q2	54	0.865	0.949
36a	1996Q1 – 2009Q3	55	2.351	0.723
36b	1996Q1 – 2009Q2	54	2.219	0.825
37a	1996Q1 – 2010Q1	57	0.583	0.944
37b	1996Q1 – 2010Q1	57	1.377	0.919
38a	1998Q1 – 2010Q1	49	2.197	0.531
38b	1996Q1 – 2010Q1	57	2.128	0.572
39b	2000Q3 – 2009Q4	38	2.226	0.613
40b	2000Q3 – 2009Q4	38	2.145	0.464
41a	1996Q1 – 2010Q1	57	0.881	0.924
41b	1997Q1 – 2010Q1	53	1.380	0.971
42a	1999Q1 – 2009Q4	44	1.599	0.914
42b	1998Q1 – 2010Q1	49	1.880	0.889
43a	1996Q1 – 2009Q3	55	0.578	0.948
43b	2002Q1 – 2009Q3	31	1.747	0.933
44a	1996Q1 – 2009Q3	55	2.011	0.708
44b	2000Q1 – 2009Q3	39	2.221	0.444
45a	1996Q1 – 2010Q1	57	0.389	0.945
45b	1996Q2 – 2009Q2	53	1.913	0.417
46a	1998Q1 – 2009Q3	47	0.337	0.970
46b	1998Q1 – 2009Q3	47	2.030	0.752
47a	1996Q1 – 2009Q3	55	0.327	0.960
47b	1997Q1 – 2009Q3	51	1.946	0.736
48a	1996Q1 – 2009Q1	53	1.213	0.993
48b	1996Q2 – 2009Q1	52	1.624	0.844

Equation	Sample	Observations	DW-statistic	R^2 Adjusted
49a	2003Q3 – 2010Q1	27	0.796	0.955
49b	2004Q1 – 2010Q1	25	1.187	0.881
50a	2000Q1 – 2009Q4	40	1.090	0.850
50b	2000Q3 – 2009Q4	38	2.441	0.821
51b	2000Q2 – 2009Q4	39	1.904	0.641
52a	1999Q4 – 2010Q1	42	1.754	0.803

Appendix 5. NAWRU estimation

NAWRU is independently estimated by a state-space modeling technique. [73] The approach is inspired by the "triangle" model of inflation, developed by Gordon (1997). [74] With some modifications to the initial model the unobserved NAWRU is filtered from the following system of equations:

$$
\begin{aligned}
\pi_{w,t} &= \beta_1 \mathbb{E}\pi_t + \beta_2(1 - u_t^* u_t^{-1}) + \beta_3 \Delta u_{t-1}/u_t \\
&\quad + \beta_4 \pi_{oil,t} + \beta_5(\pi_{w,t-1} + \pi_{w,t-5}) + \nu_t, \\
u_t^* &= \beta_6 u_{t-1}^* + \varepsilon_t.
\end{aligned}
\tag{70}
$$

Observed wage inflation rate, π_w, is generated by the inflation expectations, $\mathbb{E}\pi_{w,t}$, here proxied by moving average inflation of previous four quarters. Parameter β_1 is constrained to be unity—it is necessary condition to have stable inflation. The second term stands for the unemployment gap. Unemployment gap is classified as a demand factor to the wage inflation, creating accelerating or decelerating impulses. $\Delta u_{t-1}/u_t$ is inserted in to the equation in order to control for fast the changes in the unemployment rate. Supply shocks are captured by oil price movements, $\pi_{oil,t}$, and the last regressor stands for the inertia in wage inflation. Error terms ν and ε have zero means and variations σ_ν and σ_ε. To get time-varying NAWRU estimate $\sigma_\varepsilon \neq 0$ must hold.

[73] In the previous version of the model the "restated Phillips curve" was used, initially developed by Friedman (1968). This framework, however, had a major drawback—it only gave a constant estimate of NAIRU (Non-Accelerating Inflation Rate of Unemployment) (see for (Whelan, 1999) for example). It is natural to assume that NAIRU or NAWRU has changed in Estonia in response to the changes in economic policy and labour market institutions during the past 20 years.

[74] "Triangle" in the name of the model is meant to refer to the dependence of the inflation rate to three basic determinants: inertia, demand and supply (Gordon, 1997).

Appendix 6. Risk scenario: increase in the 6-month Euribor

	Year 1	Year 2	Year 3
Prices			
HICP	-0.00	-0.03	-0.10
Households' consumption deflator	-0.00	-0.03	-0.10
Gross fixed capital formation deflator	-0.01	-0.10	-0.27
GDP deflator	-0.03	-0.18	-0.50
Compensation per employee	-0.07	-1.15	-2.24
Real compensation per employee	-0.04	-0.98	-1.75
Import deflator (goods and services)	-0.00	-0.03	-0.09
Export deflator (goods and services)	-0.01	-0.12	-0.31
Terms of trade	-0.01	-0.10	-0.22
Economic activity (constant prices)			
Real GDP	-0.18	-1.66	-1.57
Private consumption	-0.29	-1.73	-2.38
Government consumption	-0.02	0.03	-0.30
Gross fixed capital formation	-0.58	-7.20	-5.96
Exports (goods and services)	-0.04	-0.18	0.10
Imports (goods and services)	-0.33	-2.12	-2.01
Contributions to real GDP growth			
Domestic demand (excl. changes in stocks)**	-0.30	-3.34	-3.37
Net exports**	0.28	1.90	2.12
Changes in inventories**	-0.16	-0.22	-0.29
Real disposable household income	-0.40	-1.83	-2.18
Household saving ratio(% of disposable income)***	-0.06	-0.05	0.09
Trade balance*	0.25	1.65	1.83
Current account plus new capital account*	0.21	1.42	1.05
Fiscal developments (% of GDP)			
Total receipts*	-0.04	-0.41	-0.85
Total expenditures*	-0.04	-0.41	-0.85
Balance*	0.00	0.00	0.00
Labour market			
Unemployment rate (% of labour force)***	0.01	0.18	0.45
Total employment	-0.00	-0.20	-0.53
Total compensation to employees	-0.07	-1.35	-2.76
Gross fixed capital formation			
Private sector non-residential	-0.63	-8.35	-6.79
General government	-0.20	-1.74	-1.77
Housing	-0.75	-7.09	-6.17
Credit and house prices			
Loans to the private sector	-0.22	-2.71	-4.85
House prices	-0.43	-7.17	-6.76

Notes: * abs. differences as % of GDP, ** contributions to growth, *** abs. differences (levels).

Appendix 7. Risk scenario: increase in the lending risk premium

	Year 1	Year 2	Year 3
Prices			
HICP	-0.01	-0.04	-0.13
Households' consumption deflator	-0.01	-0.04	-0.13
Gross fixed capital formation deflator	-0.04	-0.13	-0.29
GDP deflator	-0.07	-0.24	-0.53
Compensation per employee	-0.30	-1.47	-2.47
Real compensation per employee	-0.23	-1.23	-1.62
Import deflator (goods and services)	-0.01	-0.04	-0.10
Export deflator (goods and services)	-0.04	-0.15	-0.32
Terms of trade	-0.04	-0.11	-0.22
Economic activity (constant prices)			
Real GDP	-0.56	-1.78	-1.04
Private consumption	-0.45	-1.50	-1.70
Government consumption	-0.01	0.03	-0.38
Gross fixed capital formation	-2.41	-7.68	-4.72
Exports (goods and services)	-0.06	-0.13	0.17
Imports (goods and services)	-0.53	-1.97	-1.77
Contributions to real GDP growth			
Domestic demand (excl. changes in stocks)**	-1.01	-3.40	-2.55
Net exports**	0.47	1.80	1.92
Changes in inventories**	-0.04	-0.18	-0.41
Real disposable household income	-0.40	-1.51	-1.74
Household saving ratio(% of disposable income)***	0.03	0.01	-0.03
Trade balance*	0.38	1.53	1.73
Current account plus new capital account*	0.34	1.26	0.83
Fiscal developments (% of GDP)			
Total receipts*	-0.10	-0.48	-0.77
Total expenditures*	-0.10	-0.48	-0.77
Balance*	0.00	0.00	0.00
Labour market			
Unemployment rate (% of labour force)***	0.05	0.28	0.37
Total employment	-0.04	-0.32	-0.44
Total compensation to employees	-0.34	-1.78	-2.58
Gross fixed capital formation			
Private sector non-residential	-2.23	-7.87	-5.56
General government	-0.62	-1.90	-1.29
Housing	-5.18	-12.41	-4.29
Credit and house prices			
Loans to the private sector	-1.04	-3.65	-4.95
House prices	-5.09	-13.82	-4.27

Notes: * abs. differences as % of GDP, ** contributions to growth, *** abs. differences (levels).

Appendix 8. Risk scenario: fall in foreign demand

	Year 1	Year 2	Year 3
Prices			
HICP	-0.01	-0.04	-0.10
Households' consumption deflator	-0.01	-0.04	-0.10
Gross fixed capital formation deflator	-0.04	-0.12	-0.20
GDP deflator	-0.08	-0.23	-0.36
Compensation per employee	-0.62	-1.37	-1.51
Real compensation per employee	-0.54	-1.15	-1.15
Import deflator (goods and services)	-0.01	-0.04	-0.08
Export deflator (goods and services)	-0.08	-0.16	-0.23
Terms of trade	-0.06	-0.12	-0.15
Economic activity (constant prices)			
Real GDP	-0.98	-1.53	-0.77
Private consumption	-0.55	-1.36	-1.40
Government consumption	0.15	0.31	0.23
Gross fixed capital formation	-0.42	-1.40	-1.24
Exports (goods and services)	-3.00	-3.79	-0.98
Imports (goods and services)	-1.90	-2.70	-1.16
Contributions to real GDP growth			
Domestic demand (excl. changes in stocks)**	-0.36	-1.06	-1.09
Net exports**	-0.60	-0.43	0.38
Changes in inventories**	-0.02	-0.04	-0.05
Real disposable household income	-0.64	-1.28	-1.14
Household saving ratio(% of disposable income)***	-0.03	0.05	0.12
Trade balance*	-0.76	-0.69	0.22
Current account plus new capital account*	-0.70	-0.23	0.78
Fiscal developments (% of GDP)			
Total receipts*	-0.17	-0.46	-0.55
Total expenditures*	-0.17	-0.46	-0.55
Balance*	0.00	0.00	0.00
Labour market			
Unemployment rate (% of labour force)***	0.08	0.36	0.31
Total employment	-0.08	-0.40	-0.35
Total compensation to employees	-0.70	-1.77	-1.85
Gross fixed capital formation			
Private sector non-residential	-0.29	-1.37	-1.25
General government	-1.02	-1.64	-0.93
Housing	-0.39	-1.28	-1.44
Credit and house prices			
Loans to the private sector	-0.06	-0.39	-0.73
House prices	-0.46	-1.80	-2.30

Notes: * abs. differences as % of GDP, ** contributions to growth, *** abs. differences (levels).

Appendix 9. Risk scenario: fall in foreign competitors' prices

	Year 1	Year 2	Year 3
Prices			
HICP	-0.14	-0.49	-0.56
Households' consumption deflator	-0.14	-0.49	-0.56
Gross fixed capital formation deflator	-0.22	-1.23	-0.87
GDP deflator	-0.03	-0.15	-0.31
Compensation per employee	-0.13	-0.98	-1.81
Real compensation per employee	-0.10	-0.82	-1.50
Import deflator (goods and services)	-1.26	-2.07	-0.70
Export deflator (goods and services)	-2.02	-1.32	0.63
Terms of trade	-0.77	0.76	1.35
Economic activity (constant prices)			
Real GDP	-0.26	-1.43	-1.37
Private consumption	-0.01	-0.54	-1.27
Government consumption	0.01	0.27	0.49
Gross fixed capital formation	0.00	-1.26	-2.60
Exports (goods and services)	-0.19	-0.55	-1.19
Imports (goods and services)	0.17	0.74	-0.94
Contributions to real GDP growth			
Domestic demand (excl. changes in stocks)**	0.00	-0.66	-1.56
Net exports**	-0.31	-1.15	0.00
Changes in inventories**	0.05	0.38	0.08
Real disposable household income	-0.01	-0.54	-1.04
Household saving ratio(% of disposable income)***	0.00	0.02	0.11
Trade balance*	-0.36	-1.40	-0.29
Current account plus new capital account*	-0.72	-0.30	0.51
Fiscal developments (% of GDP)			
Total receipts*	-0.04	-0.30	-0.65
Total expenditures*	-0.04	-0.30	-0.65
Balance*	0.00	0.00	0.00
Labour market			
Unemployment rate (% of labour force)***	0.02	0.19	0.43
Total employment	-0.02	-0.20	-0.50
Total compensation to employees	-0.15	-1.17	-2.30
Gross fixed capital formation			
Private sector non-residential	0.02	-1.68	-3.53
General government	-0.08	-0.41	-0.25
Housing	0.01	-0.17	-0.66
Credit and house prices			
Loans to the private sector	-0.03	-0.44	-1.37
House prices	-0.13	-1.36	-2.92

Notes: * abs. differences as % of GDP, ** contributions to growth, *** abs. differences (levels).

Appendix 10. Risk scenario: fall in government consumption

	Year 1	Year 2	Year 3
Prices			
HICP	-0.02	-0.05	-0.10
Households' consumption deflator	-0.02	-0.05	-0.10
Gross fixed capital formation deflator	-0.05	-0.11	-0.19
GDP deflator	-0.10	-0.22	-0.33
Compensation per employee	-0.67	-1.41	-1.30
Real compensation per employee	-0.57	-1.19	-0.97
Import deflator (goods and services)	-0.01	-0.04	-0.08
Export deflator (goods and services)	-0.07	-0.12	-0.20
Terms of trade	-0.06	-0.09	-0.12
Economic activity (constant prices)			
Real GDP	-1.10	-1.46	-0.43
Private consumption	-0.60	-1.40	-1.20
Government consumption	-5.00	-5.00	0.00
Gross fixed capital formation	-0.44	-1.44	-0.93
Exports (goods and services)	-0.01	-0.02	0.14
Imports (goods and services)	-0.39	-0.85	-0.58
Contributions to real GDP growth			
Domestic demand (excl. changes in stocks)**	-1.54	-2.26	-1.01
Net exports**	0.37	0.81	0.70
Changes in inventories**	0.07	-0.00	-0.13
Real disposable household income	-0.70	-1.29	-0.92
Household saving ratio(% of disposable income)***	-0.03	0.06	0.12
Trade balance*	0.20	0.57	0.61
Current account plus new capital account*	0.26	0.38	-0.01
Fiscal developments (% of GDP)			
Total receipts*	-0.19	-0.48	-0.48
Total expenditures*	-0.21	-0.51	-0.48
Balance*	0.02	0.03	0.01
Labour market			
Unemployment rate (% of labour force)***	0.09	0.38	0.25
Total employment	-0.09	-0.44	-0.28
Total compensation to employees	-0.76	-1.84	-1.58
Gross fixed capital formation			
Private sector non-residential	-0.29	-1.43	-0.93
General government	-1.14	-1.56	-0.59
Housing	-0.42	-1.36	-1.25
Credit and house prices			
Loans to the private sector	-0.06	-0.41	-0.69
House prices	-0.48	-1.95	-2.07

Notes: * abs. differences as % of GDP, ** contributions to growth, *** abs. differences (levels).

SUMMARY IN ESTONIAN—KOKKUVÕTE

ERASEKTORI VÕLAKOORMUSE JA PANGANDUSSEKTORI HAAVATAVUSE VAHELISTE SEOSTE MODELLEERIMINE EESTI NÄITEL

Uurimistöö olulisus

2008.a. alguse saanud globaalne kriis tõstis esile vajaduse mudelite järele, mis võimaldaksid analüüsida finantsinstitutsioonide ja finantssektori haavatavust. Mudelite arendamine hoogustus kolmes valdkonnas: makrofinantsmudelid (ingl. k. *macro-financial models*) [75], varased hoiatussüsteemid (ingl. k. *early warning models*) [76] ja tugevusanalüüsi mudelid (ingl. k. *stress test models*) [77]. Nimetatud kolm mudelitüüpi erinevad üksteisest ülesehituselt ja kasutusvõimaluste poolest. Samas iseloomustab neid suur ühisosa—kõik kolm mudelit hindavad finantsinstitutsioonide või finantssektori vastupanuvõimet majandust tabada võivate negatiivsete šokkide suhtes.

Šokkide määratlemine ning nende suuruse mõõtmine on praktikas üsna keeruline ülesanne. Seda on suhteliselt lihtsam teha *ex post*, kuid *ex ante* on šokid ootamatud ning ettearvamatud. (Banerji, 2010) toob sellega seoses välja, et finantsinstitutsiooni vastupanuvõime ning finantssektori stabiilsuse seisukohalt pole oluline mitte mitte üksnes šokk ise vaid haavatavusindikaatori (ingl. k. *vulnerability*) ja seda tabava šoki koosmõju. Šokkide määramatuse tingimuses on seega isegi olulisem uurida ning mõista, kuidas teadaolevad haavatavusindikaatorid (ingl. k. *vulnerabilities*) seostuvad finantssektori vastupanuvõimega.

Senised uuringud on välja toonud hulgaliselt erinevaid haavatavusindikaatoreid. Näiteks Borio ja Lowe (2002) käsitlevad haavatavusindikaatoritena SKPd ning kapitalimahutusi põhivarasse, Sirtaine ja Skamnelos (2007) pankade välisvõlgnevust, Babihuga (2007) tööotuse ja inflatsiooni määrasid, Festić (2010) otseseid välisinvesteeringuid, Männasoo ja Mayes (2009) erasektori laenumahtu suhtena SKPsse, Hadad et al. (2007) rahaagregaate M1 ja M2, Marcucci ja Quagliari-

[75]Näiteks Meh ja Moran (2010) ning Gerali et al. (2010).

[76]Alternatiivseid käsitlusi pakuvad Borio ja Drehmann (2009), Davis ja Karim (2008b), Barrell et al. (2010) ning Davis ja Karim (2008a).

[77]Näiteks Cardarelli et al. (2010), Alexander ja Sheedy (2008), Graeve et al. (2008) ning Alexander ja Baptista (2009).

ello (2008) vahetuskurssi, Simons ja Rowles (2009) nafta hinda ning Kalirai ja Scheicher (2002) hüvitisi töötajatele. Nimetatud näitajad moodustavad vaid osa võimalikest indikaatoritest. Iga haavatavusindikaatori toimemehhanismide täpne tundmine on oluliseks eelduseks mõistmaks, millele finantssektori stabiilsus tugineb. Seda just põhjusel, et majandustingimuste halvenedes erinevate haavatavusindikaatorite mõjud akumuleeruvad ning võimendavad üksteist.

Paljudes riikides kriisile eelnenud kiire pangalaenukasv viitab pankade endi laenutegevuse olulisusele hilisemate sündmuste arengus. Teisisõnu tõstab see esile erasektori laenukoormuse kui ühe olulise haavatavusindikaatori. Erasektori laenukoormuse mõju on seni uuritud peamiselt seoses majanduse langusfaaside ulatusega. Kuigi Giannone et al. (2010) leiavad, et sügavama finantsturuga riigid läbivad langusfaase kergemalt, on selline järeldus pigem erand kui reegel. Enamik teostatud uuringutest seostab kõrgemat erasektori laenukoormust suurema tundlikkusega negatiivsete šokkide suhtes ning ulatuslikuma majanduslangusega kriisisituatsioonides. Näiteks Uusküla et al. (2005) täheldavad kõrgema võlgnevusega riikide puhul sügavamat kuid ühtlasi ka pikemat langusfaasi. Lane ja Milesi-Ferretti (2010) uurivad laenukasvu seoseid hilisema majanduslangusega ning näitavad, et kriisile eelnenud kiire laenukasv on seostatav majanduse sügavama langusfaasiga. Võttes aluseks, et pankade haavatavus sõltub laenuklientide maksekäitumisest ning viimane omakorda reaalmajanduse tundlikkusest šokkide suhtes, siis võib eelneva põhjal järeldada, et erasektori laenukoormuse kasv on ka pangad haavatavamaks muutnud. [78]

Varasemad uurimistööd, mis käsitlevad finantssektori haavatavust ning erasektori võlakoormuse rolli selles, kasutavad paneelandmeid panganduskriiside kohta. Valdav osa neist täheldab erasektori laenukoormuse kasvust tingitud pangandussektori haavatavuse kasvu (Demirgüç-Kunt and Detragiache (1998), Domaç et al. (2003), Klomp (2010), Wong et al. (2010), Čihák and Schaeck (2010), Komulainen and Lukkarila (2003) and Büyükkarabacak and Valev (2010)). Paneelandmetel põhinevad uuringud ei võimalda aga selgitada, milliste kanalite kaudu suurenenud laenukoormus pankasid haavatavamaks muudab ning kas haavatavus on suurenenud mistahes šokkide suhtes. Käesolev uurimistöö pakub lahendusena välja tugevusanalüüsi kontseptsiooni, mis koosneb makroökonomeetrilisest mudelist ning krediidiriskimudelist.

Mõlemad mudelid on koostatud Eesti andmetel, mis on töö sisu arvestades sobivaks näiteks neljal erineval põhjusel. Esiteks on Eesti finantssektor väga tugevalt pangandusele orienteeritud. See võimaldab vaid pangandussektorit modelleerides hõlmata peaaegu tervet finantssektorit. Teiseks moodustavad väljasta-

[78] Männasoo ja Mayes (2006) tõendavad, et pangad satuvad raskustesse just halveneva makromajanduskeskkonna tõttu.

tud laenud umbes 90% pankade varadest. Seega on pankade ning finantssektori kui terviku jaoks kõige olulisemaks riskiks krediidirisk, mille modelleerimine katab valdava osa finantssektori riskidest. Kolmandaks, Eesti pangandussektor on väga kontsentreeritud. Neli suuremat panka jagavad umbes 91% laenuturust, muutes krediidiriski mudeli koostamise ja hindamise mikrotasandil suhteliselt lihtsamaks. Neljandaks, Eestis toimus aastatel 2004–2009 kiire finantssüvenemine, mille tulemusena majapidamiste kohustused pankade ees kasvasid 20%lt SKP suhtes 55%le ning ettevõtete kohustused vastavalt 30%lt 65%ni. Kiirelt suurenenud laenukoormus annab varasematele uuringutele toetudes alust eelduseks, et reaalsektori tundlikkus on negatiivsete šokkide suhtes kasvanud. Kui see peab paika, siis on ka pangad erasektorile väljastatud laenude tõttu ilmselt muutunud haavatavamaks.

Uurimistöö eesmärk ja ülesanded

Käesoleva uurimistöö eesmärgiks on koostada mudelvahend erasektori laenukoormuse ning pangandussektori haavatavuse vaheliste seoste hindamiseks. Uurimistöö eesmärgi täitmiseks on püstitatud kolm ülesannet. Esimese ülesande sisuks on pankade haavatavust mõõtva krediidiriski mudeli koostamine ja hindamine. Teine ülesanne seisneb makroökonomeetrilise mudeli koostamises ja hindamises. Kolmandaks ülesandeks on pangandussektori haavatavuse testimine, erasektori suurenenud laenukoormuse mõjude hindamine pangandussektori haavatavusele ning saadud järelduste kõrvutamine varasemate uuringute tulemustega. Kahest mudelist koosneva analüüsivahendi loomise on tinginud mikrotasandi eelistamine pangandussektori haavatavuse mõistmisel. Kõikide pankade laenukvaliteedi andmete ning makromajandust kirjeldavate andmete sidumine ühte mudelisse oleks suurt andmemahtu arvestades ebaefektiivne.

Uurimistöö meetod ja andmed

Eestis tegutsevate pankade krediidiriskimudel ning Eesti majanduse makromudel moodustavad üheskoos tugevusanalüüsi süsteemi, mis seob makromajanduse andmed pankade laenukvaliteedi andmetega. Erasektori võlakoormuse rolli pankade haavatavuse mõjutajana on käesolevas töös uuritud šokistsenaariumeid matkides. Stsenaariumianalüüs on üks tugevusanalüüsi süsteemi kasutusvaldkondadest lisaks tundlikusanalüüsile (ingl. k. *sensitivity analysis*), ekstreemumianalüüsile (ingl. k. *extreme value*) ja maksimaalse kahju (ingl. k. *maximum loss*) analüüsile. Matkitavad stsenaariumid jaotatakse kirjanduses omakorda minevikuanaloogial põhinevateks (ingl. k. *historical*) ning hüpoteetilisteks (ingl. k. *hypothetical*). Käesolevas uurimistöös on makromudeli abil loodud viis hüpoteetilist stsenaariumit, matkides majanduse reageerimist šokkidele, mis pärinevad kodumaistest allikatest, väliskeskkonnast ning reaal- ja finantssektorist. Nendeks šokkideks on Euroala rahapoliitika ülekandumist kajastav Euribori tõus, kodumaisel turul tegutsevate pankade laenuintressi marginaali tõus, kaubanduspartnerite nõudluse vähenemine, kaubanduspartnerite hinnataseme langus ning valitsemissektori tarbimise vähenemine. Kõiki šokke on mudeliga korratud erasektori erineva võlataseme juures, mis võimaldab hinnata muutusi majanduse reageerimise ulatuses. Kirjeldatud stsenaariumeid krediidiriski mudelisse sisestades on hinnatud muutusi pankade haavatavuses.

Krediidiriski mudel liigitub kategooriasse *bilansimudelid* (ingl. k. *balance sheet models*), mille sisuks on pankade bilansiandmete, käesoleval juhul laenudes hoitava vara kvaliteedi regresseerimine makroindikaatorite suhtes. Krediidiriski mudel eristab kolme laenukvaliteedi ikaatorit, milleks on viivslaenude ja laenukahju provisjonide määr. Lisaks nimetatud indikaatoritele sisaldab krediidiriski mudel laenuklientide makseraskustesse sattumise määra (ingl. k. *default rate*). Kolme riskiindikaatori sidumine ühte krediidiriski mudelisse on tarvilik laenukahjude mitmeetapilise tekkeprotsessi üksikasjalikuks kirjeldamiseks.

Teadaolevalt on töös kasutatud mitmeetapiline modelleerimine esimene taoline omalaadsete mudelite seas. Laenuklientide makseraskustesse sattumise määra abil on mudelis kirjeldatud uute lisanduvate viivislaenude mahtu. Viivislaenude kogumaht kujuneb dünaamiselt sõltudes uutest lisanduvatest viivislaenudest ning varasematest perioodidest üle kantud viivislaenudest. Krediidiriski mudel võtab viivislaenude dünaamika kirjeldamisel arvesse, et osa eelmistel perioodidel viivises olevatest laenudest muutuvad klientide maksevõime taastudes taas toimivaks. Laenuklientide maksevõime taastumine on ajas muutuv, sõltudes majanduskeskkonna tugevusest. Provisjoneeritud laenukahju arvestuse aluseks on viivises olev laenusumma ning laenukahju määr.

Krediidiriski mudeli andmed pärinevad Eesti Panga sisemisest andmebaasist. Mudeli koostamisel on kasutatud kommertspankade poolt väljastatud laenude, viivislaenude ning laenukahju provisionide andmeid, eristades seejuures nelja suuremat panka ning summeerides ülejäänud turuosaliste andmed. Iga panga puhul on seejuures eristatud tarbimislaenusid, eluasemelaenusid ning ettevõtete laenusid. Loetletud aegread on konfidentsiaalsed ning see seab tulemuste esitamisele teatavad piirangud. Ökonomeetrilise hindamise tulemusi ning järeldusi haavatavuse kohta on võimalik esitada vaid sektori kohta tervikuna, pankasid eristamata.

Töös koostatud makromudel kuulub keskmise suurusega makoökonomeetriliste mudelite hulka. Mudeli eripäraks on sellele lisatud pangandussektori plokk, mis sisaldab pangalaenu kanalit ning seob reaalsektori toimimise pankade laenutegevusega. Erasektorile antavad laenud on jagatud kolmeks, eristades tarbimislaene, eluasemelaene ning ettevõtete laene. Laenude jaotus makromudelis ning krediidiriski mudelis on identne, muutes mõlemad mudelid teineteisega konsistentseks. Makromudeli laenuvõrrandid on ehitatud finantsjäikust sisaldavatena. Majapidamiste ja ettevõtete laenumahu kasvu tõkestab laenuteenindamise kulude ja sissetulekute suhtele seatud piirang. Pangandussektor ning selle seos reaalmajandusega on töös esitletud mudelis oluliselt detailsem võrreldes teiste samatüübiliste mudelitega.

Makromudel on suhteliselt suur, koosnedes umbes kahesajast võrrandist ja samasusest, mis kirjeldavad olulisemate majandussektorite käitumist ning nende omavahelisi seoseid. Olulisemate sektoritena on mudelisse kaasatud majapidamised, ettevõtted, valitsus, pangandussektor ning välissektor. Mudelmajanduse ülesehitusel on lähtutud Eesti majandusele kõige olulisematest tunnustest. Nendeks tunnusteks on väiksus, avatus, kovergeerumine kõrgema tulutaseme suunas ning iseseisva aktiivse rahapoliitika puudumine. Viimane kehtib nii eurotsooni liikmeks olemise perioodil kui ka eelnevalt toiminud valuutakomitee süsteemi puhul.

Nii nagu makroökonomeetrilistele mudelitele omane, on ka töös esitatud mudeli käitumisvõrrandid esitatud veaparandusmudeli kujul. Veaparandusmudeli eeliseks on pikajaliste ning lühiajaliste arengute eristamine kaheastmelises hindamisprotsessis. Nimetatud eelis on eriti oluline konvergeeruva majanduse modelleerimise puhul, mille aegread võivad sisaldada arvukalt struktuurseid nihkeid.

Makromudeli koostamiseks tarvilikud andmed pärinevad mitmest erinevast allikast. Valdav osa vajaminevatest aegridadest on laetud Eesti Statistikaameti andmebaasist: rahvamajanduse arvepidamise andmed, ettevõtete statistika, hinna- ja palgaandmed. Makromudel kasutab veel ka Eesti Konjunktuuriinstituudi poolt avaldatavat kindlustundeindikaatorit ning Maa-ameti andmeid kinnisvara hindade kohta. Välissektori andmed pärinevad Eurostati andmebaasist.

Uurimistöö tulemused ja järeldused

Tugevusanalüüsi tulemused kinnitavad varasemate uuringute seisukohti, mille kohaselt kasvanud erasektori võlakoormus suurendab pankade haavatavust. Alates 2004.a. on finantssüvenemine ning erasektori laenukoormuse kasv suurendanud pankade laenuportfelli kvaliteedi tundlikkust majandust tabavate šokkide suhtes umbes kaks korda. Matkitud šokistsenaariumid näitasid, et pankade laenuportfelli kvaliteedi halvenemine on reaal- ja finantssektorist pärinevate šokkide suhtes seda ulatuslikum, mida suurem on laenukoormus mistahes krediidisektoris: tarbimislaenude, eluasemelaenude või ettevõtluslaenude sektoris.

Kui juhinduda viivislaenude tundlikkuse muutumisest, siis näitavad šokistsenaariumid, et pankade haavatavus on kasvanud eelkõige tänu majapidamiste suurenenud võlakoormusele. See on kooskõlas ainsa teadaoleva uuringuga, mis eristab majapidamiste ning ettevõtete võlakoormust pangandussektori haavatavuse analüüsil (Büyükkarabacak and Valev, 2010). Kui aga anda hinnang muutunud haavatavusele laenukahju provisjonide alusel, siis osutub haavatavuse kasvu põhjustajana domineerivaks ettevõtete suurenenud laenumaht. Vahe viivislaenude ning laenukahju provisjonide tundlikkuses tuleneb krediidiriski mudeli alusel laenuliikide erinevast kahjumäära (ingl. k. *loss given default*) tundlikkusest šokkide suhtes.

Tugevusanalüüsil kasutatud šokistsenaariumid on loodud selliselt, et negatiivne impulss makromajandusele põhjustaks sama suure languse sisemajanduse koguproduktis baaslahendi suhtes. Selline stsenaariumite defineerimise viis võimaldab vaadelda, kas pankade laenuportfelli kvaliteedi langus sõltub šoki allikast. Analüüsi tulemused näitavad, et laenuportfelli halvenemine on ulatuslikum, kui majanduskeskkonna halvenemine on tingitud intressimäära šokkidest. Seda esiteks põhjusel, et krediidiriski mudelis selgitab intressimäär suure osa laenuklientide makseraskustesse sattumise põhjustest. Teiseks näitab makromudel stsenaariumite loomisel, et reaalmajanduse reaktsioon on erasektori võlakoormuse suurenedes kasvanud üksnes intressišokkide suhtes, samas kui reaktsiooni ulatus on reaalsektorist tulenevatele šokkidele jäänud samaks.

Intressimäära šokkide puhul on töös eristatud rahapoliitika šokke, mis kanduvad laenuturule Euribori kaudu ning kohalike pankade riskipreemia šokke. Pankade haavatavuse seisukohast osutub olulisemaks rahapoliitilika šokk, mille poolt põhjustatud langus majandusaktiivsuses mõjutab pankade krediidiportfelli kvaliteeti enam kui riskipreemia šokist tingitud samaväärne majandusaktiivsuse langus. See tulemus viitab, et pangandussektori stabiilsuse seisukohalt on oluline vastutsükliline rahapoliitika, mis tasandaks negatiivsete impulsside mõju reaalmajandusele ning erasektori laenuteenindusvõimele. Euroala liikmelisus ei võimalda iseseisvat rahapoliitikat teostada, mistõttu on ainsaks alternatiiviks Eesti ja euroala majandustsüklite kõrge sünkroniseeritus ning euroala kui terviku vastutsükliline rahapoliitika, mille signaalid kanduvad rahvusvaheliste finantsturgude kaudu ka Eesti laenuturule. Eesti tuleb selles osas kasuks majanduse väiksus ning avatus, mis seob siinse majanduskeskkonna arengud partnerriikide arengutega (Danilov, 2003).

Riskipreemia šokkide mõju laenuportfelli kvaliteedile on küll väiksem kui rahapoliitilisel šokil, kuid siiski suurem kui reaalmajandusest tulenevatel šokkidel. Seega ei olene pankade haavatavus mitte üksnes sellest, kui hästi toetab šoki mõjude absorbeerimist vastutsükliline rahapoliitka, vaid ka pangad ise saavad krediidiriski vähendada. Laenuintressi marginaalide tõstmine majanduskeskkonna halvenedes pärsib majapidamiste ja ettevõtete suutlikkust šoki mõjusid tasandada, kuna kallinenud laenuintress vähendab laenemismotiivi ning suurendab laenuteenindamise kulusid. Tulemuseks on suhteliselt suurem hulk makseraskustesse sattuvaid kliente ning pankade jaoks tähendab see suuremat osa mittetoimivaid laene portfellis, *ceteris paribus*.

Soovitusi tulevasteks uuringuteks

Viivislaenude tekkeprotsess võib tegelikkuses olla keerukam kui käesolevas uurimistöös esitatud krediidiriski mudel seda kirjeldab. Praegune suhteliselt detailne mudel viivislasenude dünaamika kirjeldamiseks võtab arvesse uute viivislaenude teket ning olemasoleva jäägi osalist paranemist sõltuvana majanduskeskkonna arengutest. Võrrandite ökonomeetrilisel hindamisel saadud tulemusi võib aga mõjutada asjaolu, et pangad muudavad majandustsükli erinevates faasides probleemsete laenudega tegelemise intensiivsust. Majanduskeskkonna halvenedes ning probleemsete klientide hulga suurenedes otsitakse intensiivsemalt võimalusi laenude restruktureerimiseks, et seeläbi aidata laenudel toimivana püsida. Seevastu kiire majanduskasvu perioodil, mil viivislaenude maht on suhteliselt väike, kalduvad pangad probleemseid laene kergekäelisemalt viivisesse laskma. Erinevused probleemsete laenudega tegelemise intensiivsuses kajastuvad viivislaenude statistikas, avaldades mõju makroindikaatorite selgitustäpsusele. Lahenduseks oleks pangaspetsiifiliste andmete kasutamine laenuportfelli kvaliteedi struktuuri kohta viivislaenude võrrandites.

Krediidiriski mudeli puhul tuleks kaaluda ka alternatiivseid ökonomeetrilisi hindamismeetodeid. Lühikestest aegridadest tulenevaid probleeme ökonomeetrilisel hindamisel võib tasakaalustada paneelandmetel põhineva mudeli hindamine. Pankade arvukuse dimensiooni kasutamine võib parandada parameetrite hinnanguid ning mudeli selgitustäpsust.

Uurimistöös rakendatud tugevusanalüüsi kontseptsioon ei võimalda vaadelda reaalmajandusele avalduvat tagasimõju, kui pangad peaksid piisavalt suure šoki tulemusena raskustesse sattuma. Praegune analüüsivahendi ülesehitus lähtub püstitatud uurimiseesmärgist, mille puhul pole oluline, kas pankade toimimine on majandust tabavate šokkide tulemusena ka reaalselt ohustatud. Töö üheks edasiarenduseks võiks olla pangandussektori haavatavuse lisamine makromudelisse, kasutades selleks laenukvaliteedi indikaatoreid agregeeritult. Kuigi, nii nagu ka eelpool märgitud, pangandussektori haavatavuse analüüsimine on eelkõige mõttekas mikrotasandil, üksikuid pankasid eristades, võimaldaks selline lähenemine arvestada finantssektori tagasimõjudega. Täpsem, institutsioonipõhine analüüs jääks siiski eraldiseisva riskimudeli kanda.

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