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HOUSING AND BANKING IN A SMALL OPEN ECONOMY DSGE MODEL

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CONTENTS

ABBREVIATIONS

AR – autoregressive
CES – constant elasticity of substitution
CGP – capital goods producer
CPI – consumer price index
CSB – Central Statistical Bureau of Latvia
DSGE – dynamic stochastic general equilibrium
EU – European Union
EU25 – EU countries between 1 May 2004 and 1 January 2007
FCMC – Financial and Capital Market Commission
GDP – gross domestic product
HICP – harmonised index of consumer prices
i.i.d. – independent and identically distributed
LTV – loan-to-value
NEER – nominal effective exchange rate
OECD – Organisation for Economic Co-operation and Development
UIP – uncovered interest parity

ABSTRACT

The severe repercussions of the latest financial crisis highlighted the crucial role of the financial sector in the propagation of economic and financial shocks. In this paper we analyse the role of financial market frictions in business cycle fluctuations and in the transmission of monetary policy in a small open economy pursuing fixed exchange rate strategy. To this end, we develop and estimate a DSGE model for Latvia with financially constrained households and firms, embedding monopolistically competitive banking sector facing capital constraints. This general equilibrium framework is useful to study the potential of macro-prudential tools and their interaction with other macroeconomic and monetary policy instruments. Our findings suggest that the banking sector mutes the response of bank retail rates to an increase in the foreign policy rate and thus attenuates the drop in real aggregates. A permanent bank capital contraction subdues output, consumption, investment, domestic lending and foreign borrowing in the long run. Under a temporary shock to bank capital, asset prices and housing investment are first to recover, for loans it takes several years, while output, consumption and capital investment rebound at a slower pace. In the long run, a tighter capital requirement leads to higher output, capital investment and domestic lending while reducing household deposits and foreign liabilities of banks.

Key words: DSGE models, Bayesian estimation, banks, financial frictions, macro-financial linkages, small open economy

JEL: C11, E32, E43, E44, F41, R21

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INTRODUCTION

The severe repercussions of the latest financial crisis highlighted the crucial role of financial sector and importance of financial market frictions in the propagation of economic and financial shocks. Huge losses incurred by banks significantly impaired their liquidity and capital stance, eventually forcing many banks to reduce their activities and asset positions. This deleveraging may have been a hindrance to obtain funds for external financing dependent borrowers, thus reducing their consumption and investment opportunities and thereby ultimately reinforcing the economic downturn.

While the potential role of financial intermediation in the business cycle via financial accelerator mechanism has long been recognised in macroeconomic literature, the role of banks in amplifying macroeconomic fluctuations has hitherto been largely neglected, in particular, in the setup of general equilibrium models. A number of recent papers have attempted to fill this gap by incorporating the banking sector and financial frictions into DSGE modelling frameworks in order to assess possible amplifying impact on economic fluctuations of shocks directly hitting financial intermediaries (see e.g. A. Gerali et al. (2010), P. M. Darracq et al. (2010), M. Kolasa and G. Lombardo (2011)). Furthermore, the financial crisis has brought to the fore the significance of relevant macro-prudential tools and policies to be implemented by policymakers in order to contain risks of financial boom and bust cycles and thereby secure a more sustainable economic growth.

In this paper, we analyse the role of financial market frictions in business cycle fluctuations and transmission of monetary policy against this background. To this end, we develop and estimate a small open economy DSGE model for Latvia with financially constrained households and firms, embedding monopolistically competitive banking sector with capital constraints. Using this setup, we examine implications of various financial frictions for credit supply and demand, and furthermore examine real economic effects of increasing capital requirement. In this regard, the general equilibrium framework presented in this paper is useful for analysing the potential of macro-prudential tools and their interaction with other macroeconomic and monetary policy instruments.

From conventional wisdom, a broad set of nominal and real frictions is necessary in DSGE modelling to match the model with data (see e.g. L. J. Christiano et al. (2010), and F. Smets and R. Wouters (2007)). To this end, we use a framework where the real side of the economy is sufficiently rich in the number of agents and frictions. We assume two types of households, patient and impatient, and entrepreneurs. Impatient households and firms are financially constrained in their spending and investment decisions, while patient households are net savers in the economy. Agents differ in their degree of impatience, which is captured by the discount factor they apply to the stream of future utility. Two types of one-period financial instruments, deposits and loans supplied by banks, are available to agents. When taking a bank loan, impatient agents face a borrowing constraint, tied to the value of tomorrow collateral holdings: households can borrow against their stock of housing, while entrepreneurs' borrowing capacity is tied to the value of their physical capital. To introduce price rigidity in the consumption sector, we follow the framework of M. Iacoviello and S. Neri (2010) by differentiating between competitive, flexible price setting entrepreneurs that produce wholesale consumption goods and housing using two technologies, and final goods firms that operate in the consumption sector under monopolistic competition. We introduce capital goods producers to derive market prices for capital, which are necessary to determine the value of entrepreneurs' collateral against which banks give loans.

As to the financial side of the model, the banking sector is introduced following the framework by A. Gerali et al. (2010) where each bank in the model is composed of three parts: two "retail" branches and one "wholesale" unit. For many emerging economies, foreign borrowing is an important source of funding in the banking system. To account for this feature, we include foreign borrowing in bank balance sheets. The cost of foreign borrowing is equal to foreign interbank rate multiplied by risk premium, which depends on the bank's real foreign debt. The two retail branches are responsible for giving out differentiated loans to impatient households and entrepreneurs, and raising differentiated deposits from patient households respectively. These branches set rates in a monopolistic competitive fashion, subject to adjustment costs. The wholesale unit manages the capital position of the group, raises wholesale deposits from the retail unit, and obtains wholesale loans both by borrowing from abroad and in the interbank market. Another important feature of emerging countries is dollarisation (euroisation) of economy, in particular regarding the currency composition of loans and deposits. To account for it, loans issued by banks and a part of attracted deposits are denominated in euro in our framework.

The central bank is able to exactly set the interest rate prevailing in the interbank market. Monetary policy is defined by an interest rate rule so that the central bank sets its policy rate to adjust for deviations in CPI inflation, output and exchange rate from the target levels. Given the fixed exchange rate policy pursued by the Bank of Latvia, where the exchange rate of the lats against the euro is maintained within ±1% fluctuation margins, we set an adequately high prior value of exchange rate coefficient in the Taylor rule. Under the UIP condition, a fixed exchange rate implies that the domestic policy rate is determined by the foreign policy rate; thereby we limit our analysis to studying the effects of foreign interest rate shocks, while the domestic interest rate policy impact is not explicitly covered.

We estimate the model with the Bayesian techniques and data for Latvia over the period of 1999–2010. The dynamics of the model are studied using impulse responses to foreign monetary shocks, technology innovation, foreign risk premium shocks, LTV shocks for households and firms, permanent and one-off shocks to bank capital, and changes in the regulatory bank capital adequacy ratio. Our aim is to assess whether and to what extent the transmission mechanism of shocks is affected by the presence of financial frictions and financial intermediation, and how sensitive the findings are across various model specifications. At the same time, we are interested in analysing the impact of shocks to profitability and capital position of domestic banks, a task that our model is suited to accomplish.

The analysis delivers the following main results. First, monopolistic competition in the banking sector mutes the response of bank retail rates to the increase in the foreign policy rate and thus attenuates the drop in output, consumption and investment. Second, a permanent bank capital contraction subdues output, consumption, investment, domestic lending and foreign borrowing in the long run, thereby leaving banks with less capital. Third, a higher capital adequacy ratio requirement induces banks to increase capital via raising loan rates, which dampens borrowing, investment and private consumption. As the capital ratio approaches the target level, lending rates and loan-deposit interest margins are gradually reduced, which ultimately boosts private borrowing, consumption and investment at the cost of lower savings. Thereby in the long run, a tighter capital requirement leads to higher output, capital investment and domestic lending.

The rest of the paper is organised as follows. Section 1 describes the model setup. Section 2 outlines the estimation strategy, and presents the results of the estimated model and robustness analysis. Section 3 studies dynamic properties of the model covering broad range of shocks. The final section concludes.

1. MODEL SETUP

There exist two groups of households, patient and impatient, and entrepreneurs. Each of these groups has unit mass. The only difference between these agents is that patient households' discount factor (β_P) is higher than that of impatient ones (β_I) and entrepreneurs (β_E).

1.1 Patient Households

The representative patient household maximises the expected utility

$$E_0 \sum_{t=0}^{\infty} \beta_P^t \varepsilon_t^z \left[\ln(c_t^P - a^P c_{t-1}^P) + \varepsilon_t^h \ln h_t^P - \frac{(l_{pc,t}^{1+\xi^P} + l_{ph,t}^{1+\xi^P})^{\frac{1+\eta^P}{1+\xi^P}}}{1+\eta^P} \right] \quad (1),$$

which depends on current consumption c_t^P, lagged consumption c_{t-1}^P, housing services h^P, hours worked in consumption goods production sector l_{pc}, and hours in housing production sector l_{ph}. Parameter a^m measures the degree of habit formation in consumption; ε_t^h captures exogenous shocks to demand for housing, while ε_t^z is an intertemporal shock to preferences. The housing preference shock ε_t^h has at least two possible interpretations. One interpretation is that the shock captures, in a reduced form, cyclical variations in the availability of resources needed to purchase housing relative to other goods or other social and institutional changes that shift preferences towards housing. Another interpretation is that fluctuations in the shock could proxy for random changes in the factor mix required to produce home services from a given housing stock. Both ε_t^h and ε_t^z have an AR (1) representation with i.i.d. normal innovations. The autoregressive coefficients are ρ_h and ρ_z respectively, and the standard deviations are σ_h and σ_z. The specification of disutility of labour ($\xi^P, \ \eta^P \geq 0$) allows for less than perfect labour mobility across sectors. If ξ^P equals zero, hours in the two sectors are perfect substitutes, whereas positive values allow for some degree of sector specificity and imply that relative hours respond less to sectoral wage differentials.

Household decisions have to match the following budget constraint (in real terms):

$$c_t^P + q_t^h (h_t^P - (1-\delta^h) h_{t-1}^P) + d_t^{P,eu} + d_t^{P,lv} \leq \frac{w_{c,t}^P l_{pc,t}}{X_{wc,t}^P} + \frac{w_{h,t}^P l_{ph,t}}{X_{wh,t}^P} + \frac{(1+r_{t-1}^{d,eu}) d_{t-1}^{P,eu} e_t}{\pi_t e_{t-1}} + \frac{(1+r_{t-1}^{d,lv})}{\pi_t} d_{t-1}^{P,lv} + T_t^P \quad (2).$$

The flow of expenses includes current consumption, accumulation of housing at price q_t^h, and deposits to be made in this period in euro $d_t^{P,eu}$ and lats $d_t^{P,lv}$. The return on euro deposits is divided by time t-1 nominal exchange rate e_{t-1} and multiplied by e_t to account for gain (loss) due to the euro appreciation (depreciation) vis-à-vis the lats.[1] Resources are composed of wage earnings $w_{c,t}^P$ and $w_{h,t}^P$ in the consumption and housing sectors respectively (scaled by respective mark-ups

[1] The nominal exchange rate e_t stands for the amount of lats per one euro.

$X^P_{wc,t}$ and $X^P_{wh,t}$ that will be discussed below), gross interest income on last period's euro and lats deposits at interest rates $r^{d,eu}_{t-1}$ and $r^{d,lv}_{t-1}$ respectively (inflation rate π_t is gross, defined as P_t / P_{t-1}), and number of lump-sum transfers T^P_t which include dividends from retail firms J^R_t. Patient agents choose consumption, housing, hours and amount of deposits to maximise utility equation (1) subject to equation (2).

1.2 Impatient Households

Impatient households do not hold deposits and do not own retail firms. The representative impatient household maximises the expected utility:

$$E_0 \sum_{t=0}^{\infty} \beta_I^t \varepsilon_t^z \left[\ln(c_t^I - a^I c_{t-1}^I) + \varepsilon_t^h \ln h_t^I - \frac{(l_{Ic,t}^{1+\xi^I} + l_{Ih,t}^{1+\xi^I})^{\frac{1+\eta^I}{1+\xi^I}}}{1+\eta^I} \right] \tag{3},$$

which depends on consumption c_t^I, housing services h^I, hours worked in the consumption sector l_{Ic} and hours worked in the housing sector l_{Ih}. Parameter a^I measures the degree of habit formation in consumption, but ε_t^h and ε_t^z are the same shocks that affect utility of patient households. Household decisions have to match the following budget constraint (in real terms):

$$c_t^I + q_t^h(h_t^I - (1-\delta^h)h_{t-1}^I) + \frac{(1+r_{t-1}^{bH})b_{t-1}^I e_t}{\pi_t e_{t-1}} \le \frac{w_{c,t}^I l_{Ic,t}}{X_{wc,t}^I} + \frac{w_{h,t}^I l_{Ih,t}}{X_{wh,t}^I} + b_t^I \tag{4}$$

where resources spent on consumption, accumulation of housing services and reimbursement of past borrowing have to be financed with wage income and new borrowing. Since the loans issued by Latvian commercial banks to households and entrepreneurs are largely denominated in euro, borrowing is scaled by the nominal exchange rate changes.

In addition, households face a borrowing constraint: the expected value of their collateralisable housing stock in period t must be sufficient to guarantee debt repayment to lenders. The constraint is:

$$(1+r_t^{bH})b_t^I \le m_t^I E_t(q_{t+1}^h \pi_{t+1}(1-\delta^H)h_t^I) \tag{5}$$

where m_t^I is (stochastic) LTV for mortgages. Microeconomics theory allows to interpret $(1-m_t^I)$ as proportional costs for collateral repossession of banks, given default. Our assumption about household discount factors is that in the absence of uncertainty the borrowing constraint of impatient households is binding in a neighbourhood of steady state. As in M. Iacoviello (2005), we assume that the size of shocks in the model is "small enough" to remain in such a neighbourhood, and we can thus solve our model, assuming that the borrowing constraint is always binding.

Following A. Gerali et al. (2010), we assume that LTV follows the stochastic AR(1) process

$$m_t^I = (1-\rho_{mI})\overline{m}^I + \rho_{mI} m_{t-1}^I + \eta_t^{mI} \quad (6)$$

where η_t^{mI} is i.i.d. zero mean normal random variable with standard deviation equal to σ_{mI}, and $\overline{m}^I$ is (calibrated) steady state value. We introduce a stochastic LTV because we are interested in studying the effects of credit supply restrictions on the real side of the economy. At a macro-level, the value of m_t^I determines the amount of credit that banks make available to each type of households for a given (discounted) value of their housing stock.

1.3 Entrepreneurs

To introduce price rigidity in the consumption sector, we follow the framework of M. Iacoviello and S. Neri (2010) by differentiating between two types of entrepreneurs. The first type refers to competitive, flexible price setting entrepreneurs that produce wholesale consumption goods and housing using two technologies; the second type covers final goods firms (described below) that operate in the consumption sector under monopolistic competition. Entrepreneurs hire labour and capital services to produce wholesale goods Y_t and new houses IH_t. They care only about their own consumption c^E and maximise the following utility function:

$$E_0 \sum_{t=0}^{\infty} \beta_E^t \ln(c_t^E - a^E c_{t-1}^E) \quad (7)$$

where a^E measures the degree of consumption habits.

Entrepreneurs maximise their utility subject to production technologies

$$Y_t = \left(A_{c,t}\left(l_{pc,t}^{\omega} l_{Ic,t}^{1-\omega}\right)\right)^{1-\mu_c} (k_{c,t-1})^{\mu_c} \quad (8),$$

$$IH_t = \left(A_{h,t}\left(l_{ph,t}^{\omega} l_{Ih,t}^{1-\omega}\right)\right)^{1-\mu_h} (k_{h,t-1})^{\mu_h} \quad (9)$$

and the budget constraint

$$\frac{Y_t}{X_t} + q_t^h IH_t + b_t = c_t^E + \sum_{i=c,h} w_{i,t}^P l_{pi,t} + \sum_{i=c,h} w_{i,t}^I l_{Ii,t} + \sum_{i=c,h} q_t^{ki}(k_{i,t} - (1-\delta^{ki})k_{i,t-1}) + \frac{(1+r_{t-1}^{bE})b_{t-1}e_t}{\pi_t e_{t-1}} \quad (10)$$

where $k_{c,t}$ and $k_{h,t}$ are capital in the consumption sector and housing sector respectively, with the respective prices q_t^{kc} and q_t^{kh}, b_t is real borrowing (at nominal rate r_t^{bE}), whereas X_t is mark-up on final goods over wholesale goods.

In equation (8), the non-housing sector produces output, and in equation (9), new houses are produced using labour and capital. Terms $A_{c,t}$ and $A_{h,t}$ measure productivity in non-housing and housing sectors respectively.

As shown by equations (8) and (9), we let hours of the two households enter the two production functions in Cobb-Douglas's fashion. This assumption implies complementarity across labour skills of the two groups and allows obtaining closedform solutions for steady state of the model. With this formulation, parameter ω measures the labour income share of unconstrained households.

The amount of resources that banks are willing to lend to entrepreneurs is constrained by the value of their collateral, which is given by their holdings of physical capital. This assumption differs from M. Iacoviello (2005), where also entrepreneurs borrow against housing (interpretable as commercial real estate), but it seems a more realistic modelling choice, for overall balance-sheet conditions reflect soundness and creditworthiness of firms. The borrowing constraint is thus

$$(1+r_t^{bE})b_t \le m_t^E E_t \left\{\pi_{t+1}\left(q_{t+1}^{kc}(1-\delta^{kc})k_{c,t} + q_{t+1}^{kh}(1-\delta^{kh})k_{h,t}\right)\right\} \tag{11}$$

where δ^{kc} and δ^{kh} are depreciation rates of capital used in the consumption sector and housing sector respectively; m_t^E is entrepreneurs' LTV ratio, which, similarly to households, follows the stochastic process

$$m_t^E = (1-\rho_{mE})\overline{m}^E + \rho_{mE} m_{t-1}^E + \eta_t^{mE} \quad (12),$$

where η_t^{mE} is zero mean normal random i.i.d. variable with standard deviation equal to σ_{mE}. The assumption about discount factor β_E and "small uncertainty" allows us to solve the model by imposing an always binding borrowing constraint for entrepreneurs. The presence of borrowing constraint implies that the amount of capital that entrepreneurs will be able to accumulate in each period is a multiple of their net worth.[2] In particular, capital is inversely proportional to the down payment that banks require in order to make one unit of loans, which in turn is a function of LTV ratio, expected future price of capital and real interest rate on loans. It is this feature that gives rise (in a model with borrowing constraint) to financial accelerator, whereby changes in interest rates or asset prices modify the transmission of shocks, monetary policy shocks in particular, by amplifying them.

1.4 Nominal Rigidities

We allow for price rigidities in the consumption sector by assuming monopolistic competition at the retail level and implicit costs of adjusting nominal prices following Calvo-style contracts. Retailers buy wholesale goods Y_t from entrepreneurs at price P_t^w in a competitive market, differentiate the goods at no cost, and sell them at a mark-up $X_t = P_t / P_t^w$ over marginal cost. The CES aggregates of these goods are converted back into homogeneous consumption and investment goods by households. In each period, fraction $1 - \theta_\pi$ of retailers set prices optimally, while fraction θ_π cannot do so and index prices to the previous period inflation rate with an elasticity equal to ι_π. These assumptions deliver the following consumption-sector Phillips curve:

$$\ln\pi_{H,t} - \iota_\pi \ln\pi_{H,t-1} = \beta_P(E_t \ln\pi_{H,t+1} - \iota_\pi \ln\pi_{H,t}) - \varepsilon_\pi \ln(X_t / X) + u_{\pi,t} \tag{13}$$

[2] The same reasoning applies to accumulation of housing by impatient households.

where $\varepsilon_\pi = \frac{(1-\theta_\pi)(1-\beta_P\theta_\pi)}{\theta_\pi}$, and X is the steady state mark-up. Above, i.i.d. cost shocks $u_{\pi,t}$ are allowed to affect inflation independently of changes in the mark-up. These shocks have zero mean and variance σ_π^2.

We model wage setting in a way that is analogous to price setting. Patient and impatient households supply homogeneous labour services to unions. Unions differentiate labour services as in F. Smets and R. Wouters (2007), set wages subject to a Calvo scheme, and offer labour services to wholesale labour packers who reassemble these services into homogeneous labour l_{pc}, l_{ph}, l_{Ic}, l_{Ih}. Entrepreneurs hire labour from these packers.

Following M. Iacoviello and S. Neri (2010), we assume that there are four unions, one for each sector/household pair. While unions in each sector choose different wage rates, reflecting the different consumption profiles of the two household types, the probability of changing wages is assumed to be common to both patient and impatient households. Under Calvo pricing with partial indexation to past inflation, the pricing rules set by the union imply the following four wage Phillips curves that are isomorphic to the price Phillips curve:

$$\ln\omega_{c,t}^P - \iota_{wc}\ln\pi_{t-1} = \beta_P(E_t\ln\omega_{c,t+1}^P - \iota_{wc}\ln\pi_t) - \varepsilon_{wc}^p\ln(X_{wc,t}^P / X_{wc}^P) + u_{wc,t}^P,$$

$$\ln\omega_{c,t}^I - \iota_{wc}\ln\pi_{t-1} = \beta_I(E_t\ln\omega_{c,t+1}^I - \iota_{wc}\ln\pi_t) - \varepsilon_{wc}^I\ln(X_{wc,t}^I / X_{wc}^I) + u_{wc,t}^I,$$

$$\ln\omega_{h,t}^P - \iota_{wh}\ln\pi_{t-1} = \beta_P(E_t\ln\omega_{h,t+1}^P - \iota_{wh}\ln\pi_t) - \varepsilon_{wh}^p\ln(X_{wh,t}^P / X_{wh}^P) + u_{wh,t}^P,$$

$$\ln\omega_{h,t}^I - \iota_{wh}\ln\pi_{t-1} = \beta_I(E_t\ln\omega_{h,t+1}^I - \iota_{wh}\ln\pi_t) - \varepsilon_{wh}^I\ln(X_{wh,t}^I / X_{wh}^I) + u_{wh,t}^I$$

where $\omega_{i,t} = \frac{w_{n,t}^i\pi_t}{w_{n,t-1}^i}$ is nominal wage inflation for each sector/household pair, $i = P$, I stands for patient and impatient agents respectively, $n = c$, h is the consumption and housing sectors respectively, $X_{wn,t}^i$ is wage mark-up for each sector/household pair, and $\varepsilon_{wc}^p = (1-\theta_{wc})(1-\beta_P\theta_{wc})/\theta_{wc}$, $\varepsilon_{wc}^I = (1-\theta_{wc})(1-\beta_I\theta_{wc})/\theta_{wc}$, $\varepsilon_{wh}^p = (1-\theta_{wh})(1-\beta_P\theta_{wh})/\theta_{wh}$, $\varepsilon_{wh}^I = (1-\theta_{wh})(1-\beta_I\theta_{wh})/\theta_{wh}$.

1.5 Capital Goods Producers

Introducing capital goods producers (CGPs) is a modelling device to derive market prices for capital q_t^{kc} and q_t^{kh}, which are necessary to determine the value of entrepreneurs' collateral against which banks concede loans. We assume that new capital used in the consumption and housing sectors is produced in the same manner; therefore, we further focus only on one sector $n = c$, h implying the consumption and housing sector respectively. At the beginning of each period, every capital goods producer buys an amount i_t^n of final goods from retailers and the stock of old undepreciated capital $(1-\delta^{kn})k_{n,t-1}$ from entrepreneurs (at nominal price P_t). Old capital can be converted one-to-one into new capital, while the transformation of final goods is subject to quadratic adjustment cost; the amount of new capital that CGPs can produce is given by

$$k_{n,t} = (1-\delta^{kn})k_{n,t-1} + \left[1 - \frac{\kappa_{in}}{2}\left(\frac{i_t^n}{i_{t-1}^n} - 1\right)^2\right] i_t^n \tag{14}$$

where κ_{in} is parameter measuring costs for adjusting investment. The new capital stock is then sold back to entrepreneurs at the end of the period at nominal price P_t^n. CGPs thus choose the level of i_t^n that maximises profits given by

$$\max P_t^n \left[1 - \frac{\kappa_{in}}{2}\left(\frac{i_t^n}{i_{t-1}^n} - 1\right)^2\right] i_t^n - P_t i_t^n \qquad (15).$$

The market for new capital is assumed to be perfectly competitive, so it can be shown that CGPs' profit maximisation delivers a dynamic equation for the real price of capital q_t^{kn}

$$q_t^{kn} = \frac{1}{1 - \frac{\kappa_{in}}{2}\left(\frac{i_t^n}{i_{t-1}^n} - 1\right)\left(\frac{3i_t^n}{i_{t-1}^n} - 1\right)} \tag{16}$$

where $q_t^{kn} = P_t^n / P_t$ and $n = c, h$.

1.6 Identities between Inflation, Exchange Rates and Terms of Trade

Next, several identities linking inflation, exchange rates and terms of trade are defined. Bilateral terms of trade $S_{i,t}$ between country i and domestic economy are given by

$$S_{i,t} = \frac{P_{i,t}}{P_{H,t}}$$

where $P_{i,t}$ and $P_{H,t}$ are price indices of country i's and domestically produced (home) goods respectively.

Consequently, the effective terms of trade are defined as

$$S_t \equiv \frac{P_{F,t}}{P_{H,t}} = \left(\int_0^1 S_{i,t}^{1-\gamma} di\right)^{\frac{1}{1-\gamma}}$$

or expressed in logs as

$$s_t \equiv \log S_t = p_{F,t} - p_{H,t}\,.$$

Furthermore, it is assumed that the law of one price holds at the product level for both import and export prices, implying that $P_{i,t}(j) = \varepsilon_{i,t} P_{i,t}^i(j)$ for all $i, j \in [0, 1]$.

$\varepsilon_{i,t}$ is bilateral nominal exchange rate, i.e. the price of country *i*'s currency in terms of the domestic currency, whereas $P_{i,t}^{i}(j)$ is the price of country *i*'s goods *j* denominated in its own currency terms. Applying the law-of-one-price assumption to the definition of $P_{i,t}$ results in $P_{i,t} = \varepsilon_{i,t} P_{i,t}^{i}$ where $P_{i,t}^{i} \equiv \left(\int_0^1 P_{i,t}^{i}(j)^{1-\varepsilon} dj \right)^{\frac{1}{1-\varepsilon}}$ stands for country *i*'s domestic price index.

Substituting the same assumption into expression for $P_{F,t}$ and log-linearising around symmetric steady state gives

$$p_{F,t} = \int_0^1 (e_{i,t} + p_{i,t}^{i}) di = neer_t + p_t^{*}$$

where $p_{i,t}^{i} \equiv \int_0^1 p_{i,t}^{i}(j) dj$ denotes country *i*'s log domestic price index in terms of its own currency, $neer_t \equiv \int_0^1 e_{i,t} di$ is log nominal effective exchange rate, and $p_t^{*} \equiv \int_0^1 p_{i,t}^{i} di$ stands for log foreign price index.

Plugging the effective terms of trade definition into the last relationship yields

$$p_{H,t} = p_t^{*} + neer_t - s_t$$

or, taking differences,

$$\pi_{H,t} = \pi_t^{*} + \Delta neer_t - \Delta s_t \qquad (17).$$

The obtained equation links inflation of domestically produced goods $\pi_{H,t}$ to foreign inflation π_t^{*}, changes in nominal effective exchange rate $\Delta neer_t$ and terms of trade Δs_t.

Next, to derive relationship between CPI inflation and inflation of domestically produced goods, we use the definition of CPI:

$$P_t \equiv \left[(1-\alpha)(P_{H,t})^{1-\eta} + \alpha (P_{F,t})^{1-\eta} \right]^{\frac{1}{1-\eta}}.$$

Rearranging and dividing both sides by $P_{H,t}^{1-\eta}$ yields

$$\left(\frac{P_t}{P_{H,t}} \right)^{1-\eta} = (1-\alpha) + \alpha \left(\frac{P_{F,t}}{P_{H,t}} \right)^{1-\eta} = (1-\alpha) + \alpha S_t^{1-\eta}$$

or

$$\frac{P_t}{P_{H,t}} = [(1-\alpha) + \alpha S_t^{1-\eta}]^{\frac{1}{1-\eta}}.$$

Log-linearising the latter around symmetric steady state gives

$$\log\left(\frac{P_t}{P_{H,t}}\right) = \log P_t - \log P_{H,t} = p_t - p_{H,t} = \frac{1}{1-\eta}\log[(1-\alpha)+\alpha S_t^{1-\eta}] = \frac{1}{1-\eta}\log[1+\alpha\left(S_t^{1-\eta}-1\right)] \approx$$

$$\approx \frac{1}{1-\eta}\alpha\left(S_t^{1-\eta}-1\right) = \frac{1}{1-\eta}\alpha\left(e^{(1-\eta)\log S_t}-1\right) \approx \frac{1}{1-\eta}\alpha\left(1+(1-\eta)\log S_t-1\right) = \alpha s_t \,,$$

which results in $p_t - p_{H,t} = \alpha s_t$.

Taking differences gives

$$\pi_{H,t} = \pi_t - \alpha\Delta s_t \qquad (18).$$

Equation (18) implies that the inflation difference is proportional to the percent change in terms of trade where the coefficient of proportionality is captured by the degree of openness α.

1.7 Monetary Policy

A central bank is able to exactly set the interest rate prevailing in the interbank market r_t. Monetary policy is defined by an interest rate rule in a way that the central bank sets its policy rate to adjust for movements in CPI inflation, output, and nominal exchange rate Δe_t

$$(1+r_t) = (1+r_{t-1})^{\rho_r}(1+\bar{r})^{(1-\rho_r)}\pi_t^{(1-\rho_r)\psi_1}\left(\frac{GDP_t}{GDP_{t-1}}\right)^{(1-\rho_r)\psi_2}\left(\frac{e_t}{e_{t-1}}\right)^{(1-\rho_r)\psi_3}\exp(\varepsilon_t^r) \qquad (19)$$

where policy coefficients ψ_1, ψ_2, $\psi_3 \geq 0$, and ε_t^r stands for an exogenous policy shock. To describe the persistence in nominal interest rates, smoothing term given by $0 < \rho_r < 1$ is incorporated in the policy rule.

1.8 Banks

Banks play a central role in our model since they intermediate all financial transactions between agents in the model. The only saving instrument available to patient households is bank deposits, while the only way to borrow for impatient households and entrepreneurs is by applying for a bank loan.

The first key ingredient in modelling banks herein is the introduction of monopolistic competition at the banking retail level. Banks enjoy some market power in conducting their intermediation activity, which allows them to adjust rates on loans and rates on deposits in response to shocks or other cyclical conditions in the economy. The monopolistic competition setup allows us to study how different degrees of interest rate pass-through affect the transmission of shocks, in particular monetary policy shocks.

The second key feature of banks in this study is that they have to obey balance sheet identity

$$B_t = D_t^{lv} + D_t^{eu} + F_t + K_t^b \,,$$

stating that banks can finance their loans B_t using deposits denominated in lats D_t^{lv}, deposits denominated in euro D_t^{eu}, foreign borrowing F_t, or bank equity K_t^b (also called bank capital hereinafter). The four sources of finance are perfect substitutes from the point of view of balance sheet, and we need to introduce some non-linearity (i.e. imperfect substitutability) in order to pin down choices of the bank. We assume that there exists an (exogenously given) "optimal" capital-to-assets (i.e. leverage) ratio for banks, which can be thought of as capturing the trade-offs that, in a more structural model, would arise in the decision of how much own resources to hold, or alternatively as a shortcut for studying the implications and costs of regulatory capital requirements. Given this assumption, bank capital will have a key role in determining the conditions of credit supply, both for quantities and prices. In addition, since we assume that bank capital is accumulated from retained earnings, the model has a built-in feedback loop between the real and the financial side of the economy. As macroeconomic conditions deteriorate, bank profits are negatively hit, and this weakens the ability of banks to raise new capital; depending on the nature of the shock that hit the economy, banks might respond to the ensuing weakening of their financial position (i.e. increased leverage) by reducing the amount of loans they are willing to grant, thus exacerbating the original contraction. The model can thus potentially account for the type of "credit cycle" typically observed in recent recession episodes with weakening real economy, reduction of bank profits, weakening of bank capital positions and the ensuing credit restrictions.

The presence of both ingredients, bank capital and the ability of banks to set rates, allows us to introduce a number of shocks that originate from the credit supply side, and to study their effects and their propagation to the real economy. In particular, we can study the effects of a drastic weakening in the balance sheet position of the banking sector, or the effect of an exogenous rise in loan rates.

To better highlight the distinctive features of the banking sector and to facilitate exposition, we can think of each bank j in model ($j \in [0, 1]$) as actually composed of three parts – two "retail" branches and one "wholesale" unit. The two retail branches are responsible for giving out differentiated loans to entrepreneurs and raising differentiated deposits from households. These branches set rates in a monopolistic competitive fashion subject to adjustment costs. The wholesale unit manages capital position of the group, raises wholesale deposits from the retail unit and obtains wholesale loans both by borrowing from abroad and in the interbank market.

1.8.1 Wholesale Branch

The wholesale branch combines net worth or bank capital (K_t^b), foreign loans (F_t), and wholesale deposits (D_t) on the liability side and issues wholesale loans (B_t) on the asset side. We impose a cost on this wholesale activity related to capital position of the bank. In particular, the bank pays a quadratic cost whenever the capital-to-assets ratio (K_t^b/B_t) moves away from "optimal" value ν^b. This parameter is set equal to 0.12 in our numerical experiments, a level above the minimum regulatory capital requirement of 0.08, and is consistent with the actual data of banks operating in Latvia. This ratio tries to strike a balance between various trade-offs involved when deciding how much own resources a bank should keep. We also impose quadratic cost on the amount of deposits and foreign borrowing.

Bank capital in each period is accumulated from retained earnings according to

$$K_t^b(j) = (1-\delta^b)K_{t-1}^b(j) + \omega^b J_{t-1}^b(j) \tag{20}$$

where $K_t^b(j)$ is equity of bank j in nominal terms, $J_t^b(j)$ is overall profits made by the three branches of bank j in nominal terms, $(1 - \omega^b)$ summarises bank's dividend policy, and δ^b measures resources used in managing bank capital and conducting the overall banking intermediation activity.

The dividend policy is assumed to be exogenously fixed so that bank capital is not a choice variable for the bank. A problem for a wholesale bank is thus to choose the amount of domestic lending $B_t(j)$, foreign borrowing $F_t(j)$, deposits $D_t^{lv}(j)$ and $D_t^{eu}(j)$ so as to maximise profits subject to balance sheet constraint[3]

$$\max E_0 \sum_{t=0}^{\infty} \beta_P^t \lambda_{0,t}^P \Bigg[(1+r_t^b)B_t(j)\frac{e_{t+1}}{e_t} - (1+r_t^F)F_t(j)\frac{e_{t+1}}{e_t} - (1+r_t^{D,lv})D_t^{lv}(j) - (1+r_t^{D,eu})D_t^{eu}(j)\frac{e_{t+1}}{e_t}$$

$$- K_t^b(j) - \frac{\kappa_{Kb}}{2}\left(\frac{K_t^b(j)}{B_t(j)} - \nu^b\right)^2 K_t^b(j) - \frac{\kappa_D}{2}\left(\left(D_t^{lv}(j)\right)^2 + \left(D_t^{eu}(j)\right)^2\right) - \frac{\kappa_F}{2}F_t(j)^2 \Bigg] \tag{21}$$

subject to

$$B_t(j) = D_t^{lv}(j) + D_t^{eu}(j) + F_t(j) + K_t^b(j) \tag{22}$$

where r_t^b (net wholesale loan rate), r_t^F (foreign borrowing rate), and $r_t^{D,lv}$ and $r_t^{D,eu}$ (net deposit rates on deposits denominated in lats and euro respectively) are taken as given. It is assumed that r_t^F is equal to foreign interbank rate r_t^* multiplied by risk premium Φ, which depends on (individual) bank's real foreign debt. Individual banks thus fully internalise the fact that their individual foreign debt decision determines foreign currency interest rate they face, defined by

$$r_t^F = r_t^* \Phi \tag{23}$$

Risk premium is given by

$$\Phi(f_t, \tilde{\phi}_t) = \exp\left(\tilde{\phi}_f f_t + \tilde{\phi}_t\right) \tag{24}$$

where $f_t \equiv F_t / GDP_t$ and $\tilde{\phi}_t$ is a shock to risk premium, which has an AR(1) representation

[3] Following A. Gerali et al. (2010), we assume that banks value the future stream of profits using patient households' discount factor $\Lambda_{0,t}^P$. However, in contrast to their work where banks are owned by patient households, in our case bank dividends are disbursed to foreign banks and, therefore, do not appear in household budget constraint.

$\tilde{\phi}_t = \rho_\phi \tilde{\phi}_{t-1} + \varepsilon_t^\phi$ with i.i.d. normal innovations $\varepsilon_t^\phi \sim N\left(0, \sigma_\phi^2\right)$.

Expressing $F_t(j)$ from the balance sheet constraint and substituting it into the profit maximisation problem, we derive first order conditions. The derivatives with respect to $B_t(j)$, $D_t^{lv}(j)$ and $D_t^{eu}(j)$ yield respectively

$$r_t^b = r_t^F\left(1+\tilde{\phi}_f f_t\right) - \kappa_{Kb}\left(\frac{K_t^b(j)}{B_t(j)} - \nu^b\right)\left(\frac{K_t^b(j)}{B_t(j)}\right)^2 \frac{1}{E_t\left(\frac{e_{t+1}}{e_t}\right)} \qquad (25),$$

$$r_t^{D,lv} = r_t^F\left(1+\tilde{\phi}_f f_t\right)E_t\left(\frac{e_{t+1}}{e_t}\right) - \kappa_D D_t^{lv}(j) + \kappa_F F_t \qquad (26),$$

$$r_t^{D,eu} = r_t^F\left(1+\tilde{\phi}_f f_t\right) - \frac{1}{E_t\left(\frac{e_{t+1}}{e_t}\right)}\left(\kappa_D D_t^{eu}(j) + \kappa_F F_t\right) \qquad (27).$$

The combining of the first two equations to get rid of r_t^F delivers a condition linking the spread between wholesale rates on loans and deposits to the degree of leverage $B_t(j)/K_t^b(j)$ of bank j, accounting for the exchange rate change, i.e.:

$$r_t^b = \left[r_t^{D,lv} - \kappa_{Kb}\left(\frac{K_t^b(j)}{B_t(j)} - \nu^b\right)\left(\frac{K_t^b(j)}{B_t(j)}\right)^2 + \kappa_D D_t^{lv}(j) - \kappa_F F_t\right]\frac{1}{E_t\left(\frac{e_{t+1}}{e_t}\right)}.$$

In order to close the model, we assume that banks can invest any excess funds they have in a deposit facility with the central bank remunerated at rate r_t (or, alternatively, can purchase any amount of riskless bonds remunerated at that rate), so that $r_t^{D,lv} \equiv r_t$ in the interbank market. As the interbank market is populated by many (identical) wholesale banks, in a symmetric equilibrium the equation above states a condition that links the rate on wholesale loans prevailing in the interbank market r_t^b to the official rate r_t, on the one hand, and to the leverage of the banking sector B_t/K_t^b on the other:

$$r_t^b = \left[r_t - \kappa_{Kb}\left(\frac{K_t^b}{B_t} - \nu^b\right)\left(\frac{K_t^b}{B_t}\right)^2 + \kappa_D D_t^{lv} - \kappa_F F_t\right]\frac{1}{E_t\left(\frac{e_{t+1}}{e_t}\right)} \qquad (28).$$

The above equation highlights the role of capital in determining loan supply conditions. On the one hand, as far as there exists a spread between the loan and policy rate, the bank would like to extend as many loans as possible, increasing leverage and thereby also profit per unit of capital (or return on equity). On the other hand, when leverage increases, the capital-to-asset ratio moves away from ν^b and banks face costs, which reduce profits. The optimal choice for banks (from the first order condition) is to choose such a level of loans (and thus of leverage, given K_t^b) that the marginal cost for reducing the capital-to-asset ratio exactly equals the deposit-loan spread, accounting for the exchange rate change. Equation (28) can also be rearranged to highlight the spread between (wholesale) loan and deposit rates:

$$S_t^W \equiv r_t^b E_t\left(\frac{e_{t+1}}{e_t}\right) - r_t \;= -\kappa_{Kb}\left(\frac{K_t^b}{B_t} - \nu^b\right)\left(\frac{K_t^b}{B_t}\right)^2 + \kappa_D D_t^{lv} - \kappa_F F_t$$

The spread is inversely related to overall leverage of the banking system: in particular, when banks are scarcely capitalised and capital constraints become more binding (i.e. when leverage increases), the margins become tighter.

1.8.2 Retail Branch

The retail banking activity is carried out in a regime of monopolistic competition.

<u>Loan branch.</u> Retail loan branches obtain loans $B_t(j)$ from the wholesale unit at rate r_t^b, differentiate them at no cost, and resell them to households and firms applying two distinct mark-ups. In order to introduce stickiness and study implications of an imperfect bank interest rate pass-through, we assume that banks face quadratic adjustment costs κ_{bE} and κ_{bH} for changing the rates they charge on loans. The problem for retail loan banks is to choose $\{ r_t^{bH}(j), r_t^{bE}(j) \}$ to maximise

$$\max_{\{r_t^{bH}(j), r_t^{bE}(j)\}} E_0 \sum_{t=0}^{\infty} \beta_P^t \lambda_{0,t}^P \left\{ \left(r_t^{bH}(j) b_t^H(j) + r_t^{bE}(j) b_t^E(j) - r_t^b B_t(j) \right) \frac{e_{t+1}}{e_t} - \frac{\kappa_{bH}}{2}\left(\frac{r_t^{bH}(j)}{r_{t-1}^{bH}(j)} - 1\right)^2 r_t^{bH} b_t^H - \frac{\kappa_{bE}}{2}\left(\frac{r_t^{bE}(j)}{r_{t-1}^{bE}(j)} - 1\right)^2 r_t^{bE} b_t^E \right\} \quad (29),$$

subject to demand constraints

$$b_t^H(j) = \left(\frac{r_t^{bH}(j)}{r_t^{bH}}\right)^{-\varepsilon_t^{bH}} b_t^H \text{ and } b_t^E(j) = \left(\frac{r_t^{bE}(j)}{r_t^{bE}}\right)^{-\varepsilon_t^{bE}} b_t^E$$

with $b_t^H(j) + b_t^E(j) = B_t(j)$, whereas ε_t^{bH} and ε_t^{bE} are elasticities of substitution of loans granted to households and firms respectively.

After imposing a symmetric equilibrium, the first order conditions yield

$$1 - \varepsilon_t^{bs} + \varepsilon_t^{bs} \frac{r_t^b}{r_t^{bs}} - \kappa_{bs}\left(\frac{r_t^{bs}}{r_{t-1}^{bs}} - 1\right)\frac{r_t^{bs}}{r_{t-1}^{bs}} + \beta_P E_t\left\{\frac{\lambda_{t+1}^P}{\lambda_t^P}\kappa_{bs}\left(\frac{r_{t+1}^{bs}}{r_t^{bs}} - 1\right)\left(\frac{r_{t+1}^{bs}}{r_t^{bs}}\right)^2 \frac{b_{t+1}^s}{b_t^s}\right\} = 0 \qquad (30)$$

with $s = H, E$.

<u>Deposit branch.</u> Retail deposit branches perform a similar but reversed operation with respect to deposits. They collect deposits $d_t(j)$ from households and then pass the raised funds to the wholesale unit, which pays them at rate r_t. Deposits $d_t(j)$ are collected both in lats $d_t^{lv}(j)$ and in euro $d_t^{eu}(j)$ by paying the respective rates $r_t^{d,lv}(j)$ and $r_t^{d,eu}(j)$.

The problem for the deposit branch is to choose retail deposit rates $r_t^{d,lv}(j)$ and $r_t^{d,eu}(j)$, applying a monopolistically competitive mark-down to policy rate r_t, in order to maximise

$$\max_{\left\{r_t^{d,lv}(j),r_t^{d,eu}(j)\right\}} E_0 \sum_{t=0}^{\infty} \beta_P^t \lambda_{0,t}^P \Bigg[r_t D_t^{lv}(j) + r_t^{D,eu} D_t^{eu}(j) \frac{e_{t+1}}{e_t} - r_t^{d,lv}(j) d_t^{lv}(j) - r_t^{d,eu}(j) d_t^{eu}(j) \frac{e_{t+1}}{e_t}$$

$$- \frac{\kappa_d^{lv}}{2} \left(\frac{r_t^{d,lv}(j)}{r_{t-1}^{d,lv}(j)} - 1 \right)^2 r_t^{d,lv} D_t^{lv} - \frac{\kappa_d^{eu}}{2} \left(\frac{r_t^{d,eu}(j)}{r_{t-1}^{d,eu}(j)} - 1 \right)^2 r_t^{d,eu} D_t^{eu} \Bigg] \tag{31},$$

subject to deposit demand functions

$$d_t^{lv}(j) = \left(\frac{r_t^{d,lv}(j)}{r_t^{d,lv}} \right)^{\varepsilon_t^{d,lv}} D_t^{lv}, \; d_t^{eu}(j) = \left(\frac{r_t^{d,eu}(j)}{r_t^{d,eu}} \right)^{\varepsilon_t^{d,eu}} D_t^{eu} \tag{32}$$

with $d_t^{lv}(j) = D_t^{lv}(j)$ and $d_t^{eu}(j) = D_t^{eu}(j)$. $\varepsilon_t^{d,lv}$ and $\varepsilon_t^{d,eu}$ are elasticities of substitution of lats and euro deposits, whereas terms containing κ_d^{lv} and κ_d^{eu} are quadratic adjustment costs for changing rates on lats and euro deposits respectively. After imposing symmetric equilibrium, the first order condition for optimal lats deposit interest rate setting is

$$\varepsilon_t^{d,lv} \frac{r_t}{r_t^{d,lv}} - 1 - \varepsilon_t^{d,lv} - \kappa_d^{lv} \left(\frac{r_t^{d,lv}}{r_{t-1}^{d,lv}} - 1 \right) \frac{r_t^{d,lv}}{r_{t-1}^{d,lv}} + \beta_P E_t \left\{ \frac{\lambda_{t+1}^P}{\lambda_t^P} \kappa_d^{lv} \left(\frac{r_{t+1}^{d,lv}}{r_t^{d,lv}} \right)^2 \left(\frac{r_{t+1}^{d,lv}}{r_t^{d,lv}} - 1 \right) \frac{d_{t+1}^{lv}}{d_t^{lv}} \right\} = 0 \tag{33}.$$

Optimal choice of $r_t^{d,eu}(j)$ yields respectively

$$\varepsilon_t^{d,eu} \frac{r_t^{D,eu}}{r_t^{d,eu}} E_t \left(\frac{e_{t+1}}{e_t} \right) - \left(1 + \varepsilon_t^{d,eu} \right) E_t \left(\frac{e_{t+1}}{e_t} \right) - \kappa_d^{eu} \left(\frac{r_t^{d,eu}}{r_{t-1}^{d,eu}} - 1 \right) \frac{r_t^{d,eu}}{r_{t-1}^{d,eu}}$$

$$+ \beta_P E_t \left\{ \frac{\lambda_{t+1}^P}{\lambda_t^P} \kappa_d^{eu} \left(\frac{r_{t+1}^{d,eu}}{r_t^{d,eu}} \right)^2 \left(\frac{r_{t+1}^{d,eu}}{r_t^{d,eu}} - 1 \right) \frac{d_{t+1}^{eu}}{d_t^{eu}} \right\} = 0 \tag{34}.$$

Elasticities of substitution of loans and deposits in the banking industry are assumed stochastic. This choice enables one to study how exogenous shocks hitting the banking sector transmit to the real economy. ε_t^{bH} and ε_t^{bE} ($\varepsilon_t^{d,lv}$, $\varepsilon_t^{d,eu}$) affect the value of mark-ups (mark-downs) that banks charge when setting interest rates and, consequently, the value of spreads between policy and retail loan (deposit) rates. Innovations to the loan (deposit) mark-up (mark-down) can thus be interpreted as innovations to bank spreads arising independently of monetary policy, and we can analyse their effects on the real economy.

Finally, profits of bank *j* are the sum of earnings from the wholesale and retail branches. After deleting intra-group transactions, profits are defined in the following form:

$$
\begin{aligned}
J_t^b(j) = {} & r_t^{bH}(j)b_t^H + r_t^{bE}(j)b_t^E - r_t^{d,lv}(j)d_t^{lv}(j) - r_t^{d,eu}(j)d_t^{eu}(j)\frac{e_{t+1}}{e_t} - \frac{\kappa_{Kb}}{2}\left(\frac{K_t^b(j)}{B_t(j)} - \nu^b\right)^2 K_t^b(j) \\
& - \frac{\kappa_D}{2}\left(\left(D_t^{lv}(j)\right)^2 + \left(D_t^{eu}(j)\right)^2\right) - \frac{\kappa_F}{2}F_t(j)^2 - \frac{\kappa_{bH}}{2}\left(\frac{r_t^{bH}(j)}{r_{t-1}^{bH}(j)} - 1\right)^2 r_t^{bH}b_t^H - \frac{\kappa_{bE}}{2}\left(\frac{r_t^{bE}(j)}{r_{t-1}^{bE}(j)} - 1\right)^2 r_t^{bE}b_t^E \\
& - \frac{\kappa_d}{2}\left(\frac{r_t^{d,lv}(j)}{r_{t-1}^{d,lv}(j)} - 1\right)^2 r_t^{d,lv}D_t^{lv} - \frac{\kappa_d}{2}\left(\frac{r_t^{d,eu}(j)}{r_{t-1}^{d,eu}(j)} - 1\right)^2 r_t^{d,eu}D_t^{eu} \qquad (35).
\end{aligned}
$$

1.9 Equilibrium

The goods market produces consumption, business investment, and exports:

$$Y_t = C_t + i_t^c + i_t^h + Y_t^x \qquad (36)$$

where $C_t = c_t^P + c_t^I + c_t^E$ is aggregate consumption, i_t^c and i_t^h are the two components of business investment, whereas Y_t^x stands for exports.

The housing market produces new homes

$$IH_t = H_t - \left(1 - \delta^H\right)H_{t-1} \qquad (37)$$

where $H_t = h_t^P + h_t^I$.

Real GDP is thus domestic output Y_t plus housing investment IH_t minus imports Y_t^m Y_t^m:

$$GDP_t = Y_t + IH_t - Y_t^m.$$

Using equation (36) and definition $Y_t^m = \alpha C_t$ yields

$$GDP_t = (1-\alpha)\left(c_t^P + c_t^I + c_t^E\right) + i_t^c + i_t^h + Y_t^x + IH_t \qquad (38).$$

We assume that exports depend on foreign demand captured by total foreign imports Y_t^* and the relative price of domestic exports

$$Y_t^x = \alpha^*\left(\frac{P_{H,t}}{P_t^*}\right)^{-\gamma} Y_t^* \qquad (39)$$

where P_t^* is foreign price level, and α^* is the share of domestic exports in Y_t^*. Foreign imports, in turn, follow the stochastic AR(1) process:

$$Y_t^* = (1-\rho_{Y^*})\overline{Y}^* + \rho_{Y^*}Y_{t-1}^* + \varepsilon_t^{Y^*} \qquad (40)$$

where $\varepsilon_t^{Y^*}$ is i.i.d. zero mean normal random shock and $\overline{Y}^*$ is (calibrated) steady-state variable.

The domestic loan market condition implies that the total borrowed funds of impatient households and entrepreneurs are equal to funds lent out by retail branches of domestic banks

$$B_t = b_t^H + b_t^E \tag{41}$$

where the nominal borrowing defined in the bank's problem and the real borrowing in the optimisation problem of households and entrepreneurs are linked as follows:

$b_t^I = \dfrac{b_t^H}{P_t}$ and $b_t = \dfrac{b_t^E}{P_t}$.

Equilibrium of deposit market implies that euro deposits collected from patient households are equal to euro deposits raised by retail banks and further passed to the wholesale branch in full amount. The same applies to deposits in lats. The two conditions are defined in the following form:

$$D_t^{eu} = d_t^{eu} = d_t^{P,eu} P_t \tag{42},$$

$$D_t^{lv} = d_t^{lv} = d_t^{P,lv} P_t \tag{43}.$$

2. MODEL ESTIMATION

2.1 Methodology and Data

We use variables in levels instead of linearising equations around steady state. We apply the Bayesian approach and estimate the model using the Metropolis-Hastings algorithm. Fourteen observables are used: real consumption, real housing prices, deposits in lats and euro, loans to households and firms, 3-month RIGIBOR, 3-month EURIBOR, interest rates on deposits and loans to firms and households, bank capital-to-loans ratio, domestic and foreign consumer price inflation. The description of data is provided in appendix. The sample runs from the first quarter of 1999 to the third quarter of 2010, covering maximum period for which all data were available at the moment of estimation.

We estimate parameters that affect the model dynamics and calibrate those that determine steady state in order to obtain reasonable values for the key steady-state values and ratios. Table 1 in Appendix C reports the values of calibrated parameters.

2.2 Calibrated Parameters and Prior Distributions

Calibrated parameters. The patient households' discount factor is set to match the steady-state annual interest rate on deposits slightly above 3%, in line with the average rate on deposits between January 1999 and September 2010. We fix the discount factors of impatient households and entrepreneurs at values close to A. Gerali et al. (2010). These values have a limited effect on the model dynamics but guarantee an impatience motive for both types of agents, large enough to be arbitrarily close to the borrowing limit, thus ensuring a desire to borrow at the respective steady-state annual interest rates of 6% and 4.5%.

Next, we set LTV ratios. These parameters are difficult to estimate without data on debt, housing and capital holdings of credit-constrained households and firms. Our calibration is meant to set feasible LTV ratios for homebuyers and firms in such a way that these values are compatible with the steady state ratios of loans to GDP and the respective steady state interest rates. Thus, we set LTV for households $\overline{m}^{I} = 0.68$ and for firms $\overline{m}^{E} = 0.47$, which are consistent with the steady state loan-to-GDP ratios of 60% and 70% respectively.

We set the labour income share of unconstrained households to 0.67. The capital share in the goods production is set to 0.36 and in the housing production sector to 0.15. We fix X = 1.20, implying a steady state mark-up of 20% in the goods market, a value commonly used in the literature. Similarly, we assume a 20% steady state mark-up in the labour market.

The degrees of habit formation in consumption are set to 0.98 and 0.85 for patient and impatient households, respectively, and to 0.5 for firms. The parameters describing disutility of labour supply and labour substitution across sectors are selected to be compatible with steady state conditions and ratios. For disutility of working, we fix $\eta^P = 2.61$ and $\eta^I = 0.91$. The values for ξ^P and ξ^I, the parameters describing the inverse elasticity of substitution across hours in the two sectors, are set to 1.3 and 1.0.

As to banking parameters, no corresponding estimates for Latvia are available in the literature. Thus, we calibrate them so as to replicate some statistical properties of bank interest rates. Equation (30) implies that the steady state rate on loans to households is determined as a static mark-up over the wholesale loan rate. To calibrate mark-up $\bar{\varepsilon}^{bH}$, we first calculate the average household borrowing rate between the first quarter of 2001 and the third quarter of 2010[4], which yields r^{bH} = 6% on an annual basis. Next, to obtain the value for wholesale rate r^b, we use the relationship linking r^b to foreign interbank rate r^* and foreign debt-to-GDP ratio f.[5] We set r^* = 4% and $\bar{f}$ = 0.34 so that the latter is compatible with the bank balance sheet condition. Setting risk premium elasticity $\tilde{\phi}_f$ to 0.01 yields steady state r^b slightly above 4%, and $\bar{\varepsilon}^{bH}$ = 1.48. Analogously, we calibrate $\bar{\varepsilon}^{bE}$. Mark-downs on deposit rates $\bar{\varepsilon}^{d,lv}$ and $\bar{\varepsilon}^{d,eu}$ are calculated by setting the policy rate r = 4% and rates on lats and euro deposits $r^{d,lv} = r^{d,eu}$ = 3.1, which correspond to the average values over the sample period. The steady state ratio of bank capital to total loans ν^b is set to 0.12, a level above the minimum regulatory capital requirement, and is consistent with the actual data for banks operating in Latvia. The fixing of bank capital share and intermediation activity management costs δ^b to 0.02 and the share of reinvested bank profit ω^b to 0.85 ensures that the ratio of bank capital to total loans is exactly 0.12.

The average deposit-to-GDP ratios are rather low in the sample period herein, both – for lats and euro deposits – amounting to 0.17. Although these ratios have increased over time, to 28% and 35% in 2010 for deposits in lats and euro respectively, their values are still rather low compared to the ratio of loans to GDP. To ensure that banks finance loans mainly from deposits and rely less on foreign borrowing, we set the steady state ratios of both lats and euro deposits to GDP to 0.4, which together with the loan shares determine the ratio of foreign debt to GDP, at 0.34. The list with steady state ratios and interest rates is provided in Table 2 of Appendix C.

Prior distributions. Priors are reported in Table 3 of Appendix C herein. Overall, they are either broadly consistent with previous studies or relatively uninformative. For persistence, we choose a beta-distribution with a prior mean of 0.8 and standard deviation of 0.1. For the monetary policy specification, we assume prior means of 2.0, 0.2 and 40 for ψ_1, ψ_2 and ψ_3 respectively, where the latter is set at such a high value to ensure the fixed exchange rate regime. As there are no previous estimates for Latvia, we set the prior mean of parameters measuring the adjustment costs for bank leverage and interest rates to 10, with standard deviation of 5, in line with posterior means reported in A. Gerali et al. (2010).

The prior means of Calvo price and wage parameters θ_π, θ_{wc} and θ_{wh} are set to 0.5, with a standard deviation of 0.05 for prices and 0.2 for wages. The priors for indexation parameters ι_π, ι_{wc} and ι_{wh} are loosely centred round 0.5, as in M. Iacoviello and S. Neri (2010).

4 We do not include historical data over 1999 and 2000 when calculating the steady state rate, since borrowing rates in this period were 12%–17%, i.e. well above the sample average.

5 Combining equations [B31], [B32], [B35] and [B36] given in Appendix B yields $r^b = r^* \exp\left(\tilde{\phi}_f f\right)\left(1 + \tilde{\phi}_f f\right)$.

2.3 Posterior Estimates

Columns 5–7 of Table 3 present estimation results for the baseline specification of the model described in Section 2. In addition to 90% posterior probability intervals, we report posterior means as point estimates. Posterior distributions are computed using a posterior sampling algorithm based on 10 Markov chains, each with 50 000 draws.

A number of estimation results are noteworthy. All shocks are quite persistent, with the estimates of AR(1) coefficients ranging between 0.73 and 0.99. As far as monetary policy is concerned, the response to inflation appears higher than reported by V. Ajevskis and K. Vītola (2009) apparently due to a longer estimation period covering years of lower inflation and deflation in 2010. Posterior mean of ψ_2 confirms the weak identification of response to the output gap, whereas the high value of exchange rate parameter ($\psi_3 = 37.8$) confirms the fixed exchange rate policy pursued by the Bank of Latvia. There is also a very high degree of interest-smoothing with estimate of $\rho_r = 0.88$. Regarding nominal rigidities, we find that wages are stickier in the consumption goods production sector, while the wages in the housing sector and domestic prices are adjusted twice a year on average. The degree of price and wage indexation in the housing sector is relatively high (the mean is 0.46), while for wages in the consumption goods production it is lower (0.31). Concerning parameters measuring the degree of stickiness in bank rates, we find that the rates on household loans adjust to changes in the policy rate more rapidly than the rates on entrepreneurial loans. At the same time, the lats deposit rates are more rigid than the euro deposit rates in response to the policy rate changes. This result is plausible given that the euro deposit rates are largely accounted for by the euro area interbank rate dynamics. The capital-to-asset ratio adjustment cost is estimated above its prior mean, implying a rather high deposit-loan spread required to offset profit loss due to deviation from equilibrium ratio. Regarding investment adjustment costs, the data appear rather uninformative, as posterior means are close to prior values.

An in-depth analysis of the model dynamics under various exogenous shocks and the role of banks in shock transmission are described in Section 3. Admittedly, the empirical results largely rely on the model framework. Hence, we check robustness of our conclusions under alternative specifications of the baseline structure. Next, we briefly outline the alternative model specifications. We then proceed with the inspection of impulse responses under the baseline structure and the two altered scenarios.

2.4 Robustness Analysis

In Table 4, we provide information on robustness of our estimation results with respect to several changes in the baseline specification. A comparison will be made both on the basis of impulse responses and marginal likelihood, which gives an indication of data coherence of each specification.

First, we modify the dynamics of NEER[6] by defining the overall index in two parts, where the first part is bilateral EUR/LVL exchange rate e_t (fixed) with share ρ_e in the index, and the second is a relatively more volatile part of NEER, which follows an AR process and is treated as exogenous. The overall index of NEER is given by equation (44), whereas equation (45) presents the exogenous part:

$$neer_t = \rho_e e_t + (1-\rho_e) neer_t^{exo} \quad (44),$$

$$\Delta neer_t^{exo} = \rho_{neer} \Delta neer_{t-1}^{exo} + u_{neer,t}^{exo} \quad (45).$$

Second, in addition to the modified NEER as defined by equations (44) and (45), we exclude the Taylor rule equation (19).

We estimate the altered structures by Bayesian approach where posterior distributions are based on 10 Markov chains, each with 50 000 draws. We use the same prior means and standard deviations for structural parameters as in the baseline case, and reduce the prior mean and standard deviation of shocks from 0.05 to 0.01 and from 1 to 0.5 respectively. The posterior mean estimates for the two alternative specifications are reported in Table 4 of Appendix C.

In the modified NEER scenario, the posterior means of structural parameters are quite comparable to the baseline framework. Overall, the exogenous shocks show high persistence, with smoothing parameters falling within the range of 0.69–0.99. As to nominal rigidities, the wages in the housing sector and domestic prices are more flexible than the wages in the consumption goods sector and are adjusted twice a year on average. The only difference from the baseline case is a relatively high degree of price indexation (0.80) and wage indexation (0.74) in the consumption goods production sector. Regarding banks, the rates on entrepreneurial loans are stickier than on household loans, while the lats deposit rates are more rigid than the rates on euro deposits. The cost of adjusting capital-to-asset ratio is above the baseline posterior mean estimate. A formal inspection of the altered structure implies that allowing for modified NEER specification is not supported by data, as is indicated by a fall of more than 130 units in marginal likelihood.

By contrast, the exclusion of Taylor rule while allowing for modified NEER is supported by data, as is implied by substantially higher marginal likelihood. Regarding parameter estimates, we see less persistence in shock processes, the most pronounced drop being observed in risk premium (from 0.81 to 0.51) and mark-down on euro deposits (from 0.95 to 0.65). A qualitative change is observed in the adjustment of bank rates: the euro deposit rates now turn out to be stickier than the rates on lats deposits in response to policy rate changes. The cost of adjusting capital-to-asset ratio is well above the prior mean and almost twice as high as in the baseline case. As to investment adjustment costs, the data appear informative, suggesting that transforming investment into new capital is more costly (slower) in the housing sector than in the consumption sector and is reflected in its relatively higher price.

[6] In the baseline model, changes in NEER were assumed to follow AR(1) process $\Delta neer_t = \rho_{neer} \Delta neer_{t-1} + u_t^{neer}$.

3. MODEL PROPERTIES

In this section we study the dynamics of the model using impulse responses to foreign monetary shocks, technology innovations, foreign risk premium shocks, loan-to-value shocks for households and firms, permanent and one-off shocks to bank capital, and changes in the regulatory bank capital adequacy ratio. Our aim is to assess whether and to what extent the transmission mechanism of these shocks is affected by the presence of financial frictions and financial intermediation and how sensitive are our findings across model specifications. At the same time, we are interested in analysing the impact of shocks on profitability and capital position of domestic banks, a task that our model is suited to accomplish.

3.1 Foreign Monetary Policy Shock

The transmission of a foreign monetary policy shock is studied by analysing the impulse responses to an unanticipated 50 basis points exogenous shock to 3-month EURIBOR (see Figure 1 in Appendix D). The benchmark framework covered in the previous sections features a number of transmission channels for monetary impulses. First, there is the traditional interest rate channel, modified by the presence of agents with a heterogeneous degree of patience. Second, there exists a borrowing constraint channel via which a policy rate shock changes the net present value of collateral and thus determines how binding the agent's constraints are. Third, there is a financial accelerator effect, by which the changes in asset prices alter the value of collateral that agents can pledge. Finally, the assumption that interest and principal payments on loans and deposits are in nominal terms introduces a nominal debt channel, whereby changes in inflation affect the ex-post distribution of resources across borrowers and lenders. The last three factors have been shown to amplify and propagate the initial impulse of monetary tightening (see, e.g. M. Iacoviello, 2005). Adding to their effects, the presence of the banking sector is supposed to affect the monetary transmission mechanism by subduing each of them. In particular, credit market power, rigidity in bank rates and the presence of bank capital might produce a gap between the rates set by policymakers and those relevant for the decisions of each agent in the economy.

In order to highlight how financial frictions and bank intermediation affect the transmission of foreign monetary shocks, in Figure 1 we compare the benchmark model with the two alternative specifications described above. The solid lines refer to the three frameworks where financial frictions are present, while the dashed lines correspond to scenarios without frictions, i.e. we remove stickiness from bank interest rates and allow for flexible rates. Operationally, the latter implies that we set the costs to change rates κ_{bH}, κ_{bE}, κ_d^{lv} and κ_d^{eu} to zero.

In the benchmark model (red solid line), the central bank raises its policy rate in the face of foreign policy tightening, as a result of which the domestic interbank rates go up but the domestic output, aggregate consumption and investment contract. Loans to both households and firms decrease, reflecting the increase in loan rates and the decline in asset, i.e. housing, prices and firm capital value that both serve as collateral for loans. Noteworthy, the bank loan rates increase less than the foreign policy rates reflected in negative spreads of household and firm loan rates.[7]

Rising loan interest rates add to marginal costs of entrepreneurial production. As marginal costs enter the Phillips curve via the mark-up component, initial upsurge in inflation is observed.

As financial activity decelerates initially reducing bank capital and profits, banks raise rates on lats deposits to attract financing. In the medium term, as the loan-deposit interest margin remains positive and contraction in loans is less pronounced than in deposits, bank profits increase, followed by growth in bank capital. Over a long term, i.e. in about 3 years, the loan portfolio returns to the initial pre-shock level, and the positive loan-deposit interest margin raises bank capital-to-asset ratio by generating profits and resulting in capital accumulation.

Introduction of financial intermediation and competition in the banking sector produces a number of differences in the model dynamics. When frictions are absent (red dashed line, baseline structure), the degree of transmission of external monetary shocks to bank rates is more pronounced, i.e. both loan and deposit rates increase to a larger extent. In essence, the banking sector serves as an attenuator in monetary transmission, i.e. monopolistic competition in banking generates an imperfect pass-through to bank rates due to adjustment costs, which, in turn, mutes the response of retail rates to the increase in the foreign policy rate. Thus, the removal of adjustment costs translates into higher borrowing rates which amplify a drop in output, consumption and investment. Asset prices decline more substantially, thus tightening borrowing constraints and producing a sharper drop in loans. Higher saving rates are insufficient to attract deposits due to pronounced decline in activity and income. However, as the loan-deposit interest margin remains positive and loans contract less than deposits, profits accrue and are subsequently accumulated into bank capital.

In the model with no Taylor rule (blue solid line), the domestic policy rate increases less than the foreign rate (on impact, the increase is around one half) and is about a quarter of the benchmark level. In this particular setting, a weaker response of domestic policy rate is due to the fact that the central bank does not respond to inflation, output and exchange rate movements. However, the effect on entrepreneurial loan rates is quite the same while just marginally lower for household loan rates than in the baseline framework, which together with a more persistent foreign interbank rate shock explains the more negative spreads on loan rates over the 4-year horizon. A positive loan-deposit interest margin and less pronounced loan contraction relative to deposits determine above-zero bank profits and capital growth, both exceeding the benchmark level (negative in the first year). Implications from zero adjustment costs in the no-Taylor-rule framework are similar to the baseline: output, consumption, loans, housing prices and investment decline at a faster pace than in the case when frictions are present.

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[7] Spreads on household (firm) rates are calculated as differences between the rate on household (firm) loans and the foreign policy rate (EURIBOR). The spread on policy rate is a difference between the domestic policy rate (RIGIBOR) and foreign policy rate (EURIBOR).

3.2 Technology Shock

Figure 2 shows simulated responses of the main macroeconomic and financial variables to a 10% technology shock in the consumption goods production sector. In the baseline model, the productivity shock translates into 2.5% output growth. Responding to a positive output gap and as the lats/euro exchange rate tends to appreciate, 3-month RIGIBOR declines by about 5 percentage points. Due to financial frictions, the loan rates do not mimic the interbank rate one-to-one: the response is lagged and more pronounced for household loan rates, which hit the below-the-steady-state bottom at –3 percentage points, while firms do it at –2 percentage points in about 1.5 years. Lower borrowing costs drive the housing demand, thereby boosting the housing price growth and investment. Via higher collateral value and relaxed borrowing constraints the increasing prices of housing and capital drive private consumption, the growth of which is most pronounced for impatient households (utmost impact of 20% in a year). Soaring housing prices amplify the wealth of savers, thereby boosting consumption, though to a much smaller degree (initial impact of 0.15% and utmost growth of 0.8% in 5 years). A positive loan-deposit interest margin and rapid loan portfolio accrual raise bank profits and capital.

The initial productivity shock reduces labour demand and drives wages in the consumption goods sector, both effects being more pronounced for impatient households (on wages partially due to a lower steady state level). The housing market expansion drives labour demand and boosts wages. While the wage growth is more pronounced for impatient agents in the housing production sector when accounting for the steady state value, the ultimate level effect is about the same for both types of households. Higher wages have different labour supply implications across households, with substitution effect dominating over income effect for patient agents and being opposite for impatient ones. Over the medium term, the wage growth effect is amplified by the borrowing constraint channel via higher collateral value, which is reflected in below-the-steady-state labour supply of impatient households in both housing and consumption goods production sectors lasting up to 1.5 years.

In the model with no Taylor rule, the initial output growth is close to baseline case while less pronounced over a longer horizon. It is due to the fact that interbank market rates are not determined by the policy rate (which would react to output gap, inflation and exchange rate movements) but rather respond to financial sector developments. As in the baseline framework, lower borrowing costs drive housing demand, prices and investment, boosting loan demand and private consumption. With less pronounced consumption growth, while housing investment is soaring, the overall output expansion is largely determined by the latter. Over short and medium terms, the wage growth in the consumption goods production sector is less pronounced for impatient and more rapid for patient agents compared to the baseline case, while labour demand contracts to a lesser extent for both household types. Strong housing market expansion drives wages, while soaring labour supply reflects substantial substitution effect for both patient and impatient households in comparison with the baseline scenario.

In all models, the presence of financial frictions weakens the response of most macro and financial indicators due to a less pronounced change in interest rates.

3.3 Foreign Risk Premium Shock

Impulse responses to 100 basis points positive foreign risk premium shock are reported in Figure 3. In all models, a higher foreign risk premium raises the domestic policy rate, bank lending and deposit rates, reduces output, consumption and loans of firms, and in the short run dampens capital and housing prices. The responses of other variables vary across specifications due to different persistence in the foreign borrowing rate and the magnitude of risk premium shock effect on the domestic policy rate. As in the case of foreign monetary shock, the loan interest rates that are rising under the impact of foreign risk premium shock amplify entrepreneurial marginal costs, thus driving inflation initially up as well.

In the baseline framework, risk premium and thus also foreign borrowing rate are both highly persistent, with a pronounced upward pressure on the policy rate (initial impact of 8 percentage points). Under financial frictions, bank lending rates increase by 2 percentage points for households and 1.5 percentage points for firms, while the effect on deposit rates is slightly above 2 percentage points. At marginally higher rates on euro savings, a part of the lats deposit outflow is reflected in the euro deposit growth. Loans to households shrink substantially (by 32%) relative to entrepreneurial lending (by 1.7%). With a negative (below-the-steady-state) loan-deposit interest margin and loan contraction by 15.8%, bank profits initially fall, reducing bank capital accordingly. Subdued housing demand accounts for declining housing prices (by 7.4%) and investment (by 8.6%). Higher borrowing costs and lower demand put downward pressure on prices of capital, the decline of which is more pronounced in the housing production sector (4.1%) than in the consumption goods production sector (3.7%). Shrinking collateral value and more expensive debt servicing constrain consumption of firms (with initial utmost downward impact of 1.3%) and households (decreasing by 3.4% in 3 quarters).

When financial frictions are removed, bank rates increase substantially, accounting for soaring profits, sharper contraction of output, consumption and loan portfolio, declining housing and capital prices as well as housing investment in the short run. Bank competition thus attenuates the negative effect of foreign risk premium shock on the domestic economy.

3.4 Loan-to-Value Shock

Further, we evaluate the implications of an increase by 10 basis points in LTV both for households and firms. We set the correlation between the two LTV shocks to 0.999 to estimate their simultaneous effect on the model. Figure 4 shows the simulation results. Higher LTV relaxes credit constraints, boosting private borrowing; the initial effect is more pronounced for household loans and more persistent for firms. Credit expansion drives the demand for housing and capital goods, which, in turn, leads to rising asset prices, collateral values and thereby eased access to credit. The output and income growth displays precautionary behaviour of patient agents, reflected in mounting household savings in the context of a rather small pickup in consumption expenditures.

The banking sector mutes the policy rate pass-through on loan and deposit rates, restraining accumulation of bank profits and capital.

3.5 Shock to Bank Capital

In light of understanding consequences of bank credit standard tightening, this section analyses what would happen if bank capital were to suffer a strong negative shock. The experiment we carry out is twofold. First, it involves implementing an unexpected and persistent contraction in bank capital. We do not attempt to construct a quantitatively realistic scenario: this would indeed be very difficult, given the uncertainty about the effects that have already occurred and those that might still be in the pipeline. We calibrate the shock so that it determines a fall of bank capital by 5 percent. Persistence of the shock is set to 0.99 to obtain a persistent fall of the capital-to-assets ratio below its steady state value. Second, we assess the impact of bank capital contraction by 20 percent, with persistence of the shock set to zero so that the effect is one-off. In the exercise, we assess the role of adjustment costs for capital-to-assets ratio by computing impulse responses under different calibrations of parameters κ_{Kb} that were estimated in the three specifications of the model.

Figure 5 shows the effect of 5% permanent negative shock on bank capital. To compensate for the loss in equity, banks raise their rates on loans to increase profits. Higher rates reduce the demand for loans by households and firms, which ultimately subdues investment and thereby output, income and consumption. The effect is more pronounced on household loans and capital investment for housing production. Contracting demand for housing and capital drives down the respective prices and thus also the collateral value, which further suppress private consumption and investment via tighter borrowing constraints. As output and income decline, banks face deposit shrinkage and are forced to raise saving rates to attract resources. However, due to economic slowdown and further deposit outflow, domestic financing is insufficient and banks are thus urged to increase their foreign liabilities.

Output contracts more substantially when the adjustment cost of capital-to-assets ratio is higher. It is observed when comparing the baseline framework and model with no Taylor rule where κ_{Kb} is 19.3 and 36.2 respectively. At a higher κ_{Kb} value, interest rates on loans (deposits) increase more (less), amplifying profits and compensating for the fall in equity, while bank capital converges faster to its new steady state. The overall long-run effect of permanent bank capital contraction is lower output, consumption, investment, domestic lending and foreign borrowing, whereas banks, while facing higher profits, are left with less capital.

The long-run implications for the economy are somewhat different when a shock to bank capital is temporary (see Figure 6). A one-off negative shock bringing down capital by 20 percent urges banks to accrue profits via higher loan rates. Such shocks also raise saving rates to attract deposits, which are insufficient and induce banks to increase borrowing from abroad. Higher rates via reduced loan demand subdue investment, output, consumption, and prices of collateral assets. Output and housing investment decline more pronouncedly at higher adjustment costs of capital ratio in the first year, rebounding faster afterwards due to more rapid decline in loan rates. Overall, asset prices and housing investment return to the initial level in 1–1.5 years, loans in about 5 years, while output, consumption and capital investment rebound at a slower pace. Banks regain the pre-shock capital level over 4–5 years via rapid short-term profit accrual; however, with loan rates declining, the profit accumulation gain fades away over a long term.

3.6 Tighter Capital Requirement

Further we assess the effect of a 2 percentage point increase in the required capital-to-assets ratio. The simulations treat the adjustment in the requirement as an unanticipated shock. As S. Roger and J. Vlček (2011) argue, to the extent that changes in regulatory requirements were anticipated, volatility of the real economy would increase, but cumulative costs in terms of output losses would remain broadly unchanged. Higher volatility of output would stem from strong consumption and investment responses to anticipated increases in borrowing costs. However, the subsequent declines in consumption and investment would also be steeper. Cumulative macroeconomic costs should be lower than in the unanticipated case, reflecting agents' better information sets. However, the gain would likely be small, as it seems unrealistic to assume that agents would be able to anticipate bank behaviour with certainty, and *vice versa*. Monetary policy is assumed to respond to regulatory changes in the first year in so far as they change the outlook for inflation and activity. However, the central bank, like the commercial banks, is not assumed to have prior knowledge of adjustments in regulatory requirements.

The magnitude of changes in required capital adequacy ratio is essentially arbitrary. Linearity of the model solution implies symmetric effects, stemming from positive and negative shocks of the same scale; thereby, implications of different capital scenarios can be obtained by simply scaling up or down the reported results.

Simulation results are reported in Figure 7. Higher capital adequacy ratio requirement induces banks to increase capital via profit accrual. To this end, they raise rates on loans, thus dampening borrowing, investment and private consumption, this being partly offset by an easing in monetary policy stance as inflation pressures diminish and output contracts. The adverse demand effects are amplified, as weaker investment and spending lead to declines in asset prices, cutting collateral values and access to credit. In the face of slowing loan demand, banks reduce their saving rates to gain profit; hence positive loan-deposit interest margins, coupled with deposits shrinking more pronouncedly than loans, result in bank profit and capital accumulation. The presence of adjustment costs attenuates the effect of interest rates on bank profitability and capital growth. At the same time, banks approach the new capital requirement at a faster pace when the capital ratio adjustment costs are higher. In the specification with no Taylor rule (where $\kappa_{Kb} = 36.2$), the new capital adequacy ratio is achieved in 1.5 years, while in the baseline case ($\kappa_{Kb} = 19.3$), the required period is 2 years. Thus, a more costly deviation from the "optimal" capital-to-assets ratio induces banks to adjust faster to the target level.

The baseline model and modified NEER framework assume that the central bank can and does respond to developments in inflation, output and exchange rate following a Taylor-rule-type monetary policy rule. Since the regulatory measures evaluated lead to tighter financing conditions for firms and households, both output and inflation tend to fall in response to a higher capital adequacy requirement.

As the capital ratio approaches the target level, lending rates and loan-deposit interest margins are gradually reduced, boosting private borrowing, consumption and investment at the cost of lower savings. Thus, in the long run, a tighter capital requirement leads to higher output, capital investment and domestic lending while reducing household deposits and foreign liabilities of banks.

CONCLUSIONS

The latest financial crisis brought to the fore the importance of financial factors and frictions for macroeconomic developments and propagation of shocks. Although the significance of financial intermediation in business cycle fluctuations has deserved appropriate attention in macro studies over the last decades, the role of banks has so far been scarcely tackled, particularly in general equilibrium frameworks.

The setup developed in this paper contributes to the strand of research by introducing demand and supply credit frictions into an estimated DSGE model for Latvia. Apart from investigating the effects of financial frictions in propagation of economic and financial shocks, our model allows us to analyse changes in regulatory regimes that the financial sector faces. In light of ever increasing linkages between macroeconomics and financial sector, our model is useful for exploring the potential of macro-prudential tools and their interaction with the other macroeconomic and monetary policy instruments.

In the model framework, we also account for two important features of financial sector which are inherent to many emerging economies. The first is related to foreign borrowing: it constitutes a significant share of liabilities in emerging countries' banking sectors and is often characterised by a subsidiary branch borrowing from its foreign headquarter. The second one refers to financial dollarisation (euroisation). Over 90% of loans granted by Latvian commercial banks and about 50% of deposits are denominated in euro. To account for these issues in our model setup, we introduce two currencies for the banking system operations.

The analysis conducted in this paper delivers several conclusions. First, the banking sector competition, by attenuating the response of bank retail rates to contractionary foreign monetary shock, mutes the negative effects on domestic real aggregates. Second, in the aftermath of enduring bank capital contraction, there is a long run slump in output, consumption, investment, domestic lending and foreign borrowing. Output contracts more substantially when adjustment costs of capital-to-assets ratio are higher. Third, when the shock to bank capital is temporary, asset prices and housing investment return to the initial level in about a year; it takes several years for loans to recover, while output, consumption and capital investment rebound at a slower pace. Banks achieve the initial capital level over the medium term via profit accrual by raising loan rates. Finally, a more stringent capital adequacy requirement prompts banks to raise capital via higher loan rates, thereby subduing domestic private sector loan demand, investment and consumption. The presence of adjustment costs attenuates effects of interest rates on bank profitability and capital growth, while banks approach the new capital requirement at a faster pace when adjustment costs of capital ratio are higher. Inasmuch as the capital ratio approaches the statutory level, bank loan rates and interest margins decrease, thus boosting borrowing, consumption and investment. As a result, a tighter capital requirement ultimately facilitates output growth, investment and domestic lending in the long run and reduces household deposits and foreign liabilities of banks.

A few caveats and directions for further research should be mentioned. First, the model does not explicitly deal with risks, i.e. there is no explicit representation of different risk classes of assets in portfolios. Second, risks of default, balance sheet consequences, and transmission of defaults or loan impairment are not represented. A third important area in which the model displays some weaknesses relates to the interaction of financial developments with the public sector fiscal accounts. As evidenced by several countries in Europe, there might be negative spillovers from sovereign risk to bank funding conditions and *vice versa*: financial stress from the financial sector can spill over into the public sector with strong feedback loops through interest rate risk premia. Finally, a more micro-founded optimisation of the policy rule to study the interaction between macro-prudential and monetary policies could be pursued.

APPENDICES

Appendix A. Model Equations

Budget constraint for patient households

$$c_t^P + q_t^h (h_t^P - (1-\delta^h) h_{t-1}^P) + d_t^{P,eu} + d_t^{P,lv} = \frac{w_{c,t}^P l_{pc,t}}{X_{wc,t}^P} + \frac{w_{h,t}^P l_{ph,t}}{X_{wh,t}^P} + \frac{(1+r_{t-1}^{d,eu}) d_{t-1}^{P,eu} e_t}{\pi_t e_{t-1}} + \frac{(1+r_{t-1}^{d,lv})}{\pi_t} d_{t-1}^{P,lv} + T_t^P \quad \text{[A1].}$$

First-order conditions for patient households

$$\lambda_t^P = \frac{\varepsilon_t^z}{c_t^P - a^P c_{t-1}^P} - \frac{\beta_P \varepsilon_{t+1}^z a^P}{c_{t+1}^P - a^P c_t^P} \quad \text{[A2],}$$

$$\frac{\varepsilon_t^z \varepsilon_t^h}{h_t^P} = \lambda_t^P q_t^h - \beta_P \lambda_{t+1}^P q_{t+1}^h (1-\delta^h) \quad \text{[A3],}$$

$$\varepsilon_t^z (l_{pc,t}^{1+\xi^P} + l_{ph,t}^{1+\xi^P})^{\frac{\eta^P - \xi^P}{1+\xi^P}} l_{pc,t}^{\xi^P} = \lambda_t^P \frac{w_{c,t}^P}{X_{wc,t}^P} \quad \text{[A4],}$$

$$\varepsilon_t^z (l_{pc,t}^{1+\xi^P} + l_{ph,t}^{1+\xi^P})^{\frac{\eta^P - \xi^P}{1+\xi^P}} l_{ph,t}^{\xi^P} = \lambda_t^P \frac{w_{h,t}^P}{X_{wh,t}^P} \quad \text{[A5],}$$

$$\lambda_t^P = \beta_P E_t \left\{ \lambda_{t+1}^P \frac{(1+r_t^{d,eu}) e_{t+1}}{\pi_{t+1} e_t} \right\} \quad \text{[A6],}$$

$$\lambda_t^P = \beta_P E_t \left\{ \lambda_{t+1}^P \frac{(1+r_t^{d,lv})}{\pi_{t+1}} \right\} \quad \text{[A7].}$$

Budget and borrowing constraint for impatient households

$$c_t^I + q_t^h (h_t^I - (1-\delta^h) h_{t-1}^I) + \frac{(1+r_{t-1}^{bH}) b_{t-1}^I e_t}{\pi_t e_{t-1}} = \frac{w_{c,t}^I l_{Ic,t}}{X_{wc,t}^I} + \frac{w_{h,t}^I l_{Ih,t}}{X_{wh,t}^I} + b_t^I \quad \text{[A8],}$$

$$(1+r_t^{bH}) b_t^I = m_t^I E_t (q_{t+1}^h \pi_{t+1} (1-\delta^H) h_t^I) \quad \text{[A9],}$$

$$m_t^I = (1-\rho_{mI}) \overline{m}^I + \rho_{mI} m_{t-1}^I + \eta_t^{mI} \quad \text{[A10].}$$

First-order conditions for impatient households

$$\lambda_{1,t}^I = \frac{\varepsilon_t^z}{c_t^I - a^I c_{t-1}^I} - \frac{\beta_I \varepsilon_{t+1}^z a^I}{c_{t+1}^I - a^I c_t^I} \quad \text{[A11],}$$

$$\frac{\varepsilon_t^z \varepsilon_t^h}{h_t^I} = \lambda_{1,t}^I q_t^h - \beta_I E_t \left\{ \lambda_{1,t+1}^I q_{t+1}^h (1-\delta^h) \right\} - \lambda_{2,t}^I m_t^I E_t \left\{ q_{t+1}^h \pi_{t+1} (1-\delta^H) \right\} \quad \text{[A12],}$$

$$\varepsilon_t^z (l_{Ic,t}^{1+\xi^I} + l_{Ih,t}^{1+\xi^I})^{\frac{\eta^I - \xi^I}{1+\xi^I}} l_{Ic,t}^{\xi^I} = \lambda_{1,t}^I \frac{w_{c,t}^I}{X_{wc,t}^I} \quad [A13],$$

$$\varepsilon_t^z (l_{Ic,t}^{1+\xi^I} + l_{Ih,t}^{1+\xi^I})^{\frac{\eta^I - \xi^I}{1+\xi^I}} l_{Ih,t}^{\xi^I} = \lambda_{1,t}^I \frac{w_{h,t}^I}{X_{wh,t}^I} \quad [A14],$$

$$\lambda_{1,t}^I = \beta_I E_t \left\{ \lambda_{1,t+1}^I \frac{(1+r_t^{bH})e_{t+1}}{\pi_{t+1} e_t} \right\} + \lambda_{2,t}^I (1+r_t^{bH}) \quad [A15].$$

Production technologies

$$Y_t = \left(A_{c,t}\left(l_{pc,t}^{\omega} l_{Ic,t}^{1-\omega}\right)\right)^{1-\mu_c} (k_{c,t-1})^{\mu_c} \quad [A16],$$

$$IH_t = \left(A_{h,t}\left(l_{ph,t}^{\omega} l_{Ih,t}^{1-\omega}\right)\right)^{1-\mu_h} (k_{h,t-1})^{\mu_h} \quad [A17].$$

Budget and borrowing constraint of entrepreneurs

$$\frac{Y_t}{X_t} + q_t^h IH_t + b_t = c_t^E + \sum_{i=c,h} w_{i,t}^P l_{pi,t} + \sum_{i=c,h} w_{i,t}^I l_{Ii,t} + \sum_{i=c,h} q_t^{ki} (k_{i,t} - (1-\delta^{ki}) k_{i,t-1}) + \frac{(1+r_{t-1}^{bE}) b_{t-1} e_t}{\pi_t e_{t-1}} \quad [A18],$$

$$(1+r_t^{bE}) b_t = m_t^E E_t \left\{ \pi_{t+1} \left(q_{t+1}^{kc} (1-\delta^{kc}) k_{c,t} + q_{t+1}^{kh} (1-\delta^{kh}) k_{h,t} \right) \right\} \quad [A19],$$

$$m_t^E = (1-\rho_{mE}) \overline{m}^E + \rho_{mE} m_{t-1}^E + \eta_t^{mE} \quad [A20].$$

First-order conditions for entrepreneurs

$$\lambda_{1,t}^E = \frac{1}{c_t^E - a^E c_{t-1}^E} - \frac{\beta_E a^E}{c_{t+1}^E - a^E c_t^E} \quad [A21],$$

$$(1-\mu_c)\omega Y_t = X_t w_{c,t}^P l_{pc,t} \quad [A22],$$

$$(1-\mu_c)(1-\omega) Y_t = X_t w_{c,t}^I l_{Ic,t} \quad [A23],$$

$$(1-\mu_h)\omega q_t^h IH_t = w_{h,t}^P l_{ph,t} \quad [A24],$$

$$(1-\mu_h)(1-\omega) q_t^h IH_t = w_{h,t}^I l_{Ih,t} \quad [A25],$$

$$\beta_E \mu_c E_t \left\{ \frac{\lambda_{1,t+1}^E Y_{t+1}}{X_{t+1} k_{c,t}} \right\} - \lambda_{1,t}^E q_t^{kc} + \beta_E \lambda_{1,t+1}^E (1-\delta^{kc}) q_{t+1}^{kc} + \lambda_{2,t}^E m_t^E E_t \left\{ \pi_{t+1} q_{t+1}^{kc} (1-\delta^{kc}) \right\} = 0 \quad [A26],$$

$$\beta_E \mu_h E_t \left\{ \frac{\lambda_{1,t+1}^E q_{t+1}^h IH_{t+1}}{k_{h,t}} \right\} - \lambda_{1,t}^E q_t^{kh} + \beta_E \lambda_{1,t+1}^E (1-\delta^{kh}) q_{t+1}^{kh} + \lambda_{2,t}^E m_t^E E_t \left\{ \pi_{t+1} q_{t+1}^{kh} (1-\delta^{kh}) \right\} = 0 \quad [A27],$$

$$\lambda_{1,t}^{E}-\beta_{E}E_{t}\left\{\frac{\lambda_{1,t+1}^{E}(1+r_{t}^{bE})e_{t+1}}{\pi_{t+1}e_{t}}\right\}-\lambda_{2,t}^{E}(1+r_{t}^{bE})=0 \qquad \text{[A28].}$$

Phillips curve

$$\ln\pi_{H,t}-\iota_{\pi}\ln\pi_{H,t-1}=\beta_{P}(E_{t}\ln\pi_{H,t+1}-\iota_{\pi}\ln\pi_{H,t})-\frac{(1-\theta_{\pi})(1-\beta_{P}\theta_{\pi})}{\theta_{\pi}}\ln\left(\frac{X_{t}}{X}\right)+u_{\pi,t} \qquad \text{[A29].}$$

Wage equations

$$\ln\omega_{c,t}^{P}-\iota_{wc}\ln\pi_{t-1}=\beta_{P}(E_{t}\ln\omega_{c,t+1}^{P}-\iota_{wc}\ln\pi_{t})-\frac{(1-\theta_{wc})(1-\beta_{P}\theta_{wc})}{\theta_{wc}}\ln\left(\frac{X_{wc,t}^{P}}{X_{wc}^{P}}\right) \qquad \text{[A30],}$$

$$\ln\omega_{c,t}^{I}-\iota_{wc}\ln\pi_{t-1}=\beta_{I}(E_{t}\ln\omega_{c,t+1}^{I}-\iota_{wc}\ln\pi_{t})-\frac{(1-\theta_{wc})(1-\beta_{I}\theta_{wc})}{\theta_{wc}}\ln\left(\frac{X_{wc,t}^{I}}{X_{wc}^{I}}\right) \qquad \text{[A31],}$$

$$\ln\omega_{h,t}^{P}-\iota_{wh}\ln\pi_{t-1}=\beta_{P}(E_{t}\ln\omega_{h,t+1}^{P}-\iota_{wh}\ln\pi_{t})-\frac{(1-\theta_{wh})(1-\beta_{P}\theta_{wh})}{\theta_{wh}}\ln\left(\frac{X_{wh,t}^{P}}{X_{wh}^{P}}\right) \qquad \text{[A32],}$$

$$\ln\omega_{h,t}^{I}-\iota_{wh}\ln\pi_{t-1}=\beta_{I}(E_{t}\ln\omega_{h,t+1}^{I}-\iota_{wh}\ln\pi_{t})-\frac{(1-\theta_{wh})(1-\beta_{I}\theta_{wh})}{\theta_{wh}}\ln\left(\frac{X_{wh,t}^{I}}{X_{wh}^{I}}\right) \qquad \text{[A33].}$$

Law of motion and prices of capital

$$k_{c,t}=(1-\delta^{kc})k_{c,t-1}+\left[1-\frac{\kappa_{ic}}{2}\left(\frac{i_{t}^{c}}{i_{t-1}^{c}}-1\right)^{2}\right]i_{t}^{c} \qquad \text{[A34],}$$

$$k_{h,t}=(1-\delta^{kh})k_{h,t-1}+\left[1-\frac{\kappa_{ih}}{2}\left(\frac{i_{t}^{h}}{i_{t-1}^{h}}-1\right)^{2}\right]i_{t}^{h} \qquad \text{[A35],}$$

$$q_{t}^{kc}=\frac{1}{1-\frac{\kappa_{ic}}{2}\left(\frac{i_{t}^{c}}{i_{t-1}^{c}}-1\right)\left(\frac{3i_{t}^{c}}{i_{t-1}^{c}}-1\right)} \qquad \text{[A36],}$$

$$q_{t}^{kh}=\frac{1}{1-\frac{\kappa_{ih}}{2}\left(\frac{i_{t}^{h}}{i_{t-1}^{h}}-1\right)\left(\frac{3i_{t}^{h}}{i_{t-1}^{h}}-1\right)} \qquad \text{[A37].}$$

Monetary policy rule

$$(1+r_t) = (1+r_{t-1})^{\rho_r}\,(1+\bar{r})^{(1-\rho_r)}\,\pi_t^{(1-\rho_r)\psi_1}\left(\frac{GDP_t}{GDP_{t-1}}\right)^{(1-\rho_r)\psi_2}\left(\frac{e_t}{e_{t-1}}\right)^{(1-\rho_r)\psi_3}\exp(\varepsilon_t^r) \quad \text{[A38].}$$

Identities between inflation, exchange rate and terms of trade

$$\pi_{H,t} = \pi_t^* + \Delta neer_t - \Delta s_t \quad \text{[A39],}$$

$$\pi_{H,t} = \pi_t - \alpha \Delta s_t \quad \text{[A40],}$$

Foreign interest rate and risk premium

$$r_t^F = r_t^* \Phi_t \quad \text{[A41],}$$

$$\Phi(f_t, \tilde{\phi}_t) = \exp\left(\tilde{\phi}_f\, f_t + \tilde{\phi}_t\right) \quad \text{[A42].}$$

Balance sheet constraint of the banks' wholesale branch

$$B_t = D_t^{lv} + D_t^{eu} + F_t + K_t^b \quad \text{[A43].}$$

First-order conditions of the bank wholesale branch

$$r_t^{D,eu} = r_t^F\left(1+\tilde{\phi}_f\, f_t\right) - \frac{1}{E_t\left(\frac{e_{t+1}}{e_t}\right)}\left(\kappa_D D_t^{eu} - \kappa_F F_t\right) \quad \text{[A44],}$$

$$r_t = r_t^F\left(1+\tilde{\phi}_f\, f_t\right)E_t\left(\frac{e_{t+1}}{e_t}\right) - \kappa_D D_t^{lv} + \kappa_F F_t \quad \text{[A45],}$$

$$S_t^W \equiv r_t^b E_t\left(\frac{e_{t+1}}{e_t}\right) - r_t = -\kappa_{Kb}\left(\frac{K_t^b}{B_t} - \nu^b\right)\left(\frac{K_t^b}{B_t}\right)^2 + \kappa_D D_t^{lv} - \kappa_F F_t \quad \text{[A46].}$$

First-order conditions of banks' retail branch

$$1-\varepsilon_t^{bH} + \varepsilon_t^{bH}\,\frac{r_t^b}{r_t^{bH}} - \kappa_{bH}\left(\frac{r_t^{bH}}{r_{t-1}^{bH}}-1\right)\frac{r_t^{bH}}{r_{t-1}^{bH}} + \beta_P E_t\left\{\frac{\lambda_{t+1}^P}{\lambda_t^P}\kappa_{bH}\left(\frac{r_{t+1}^{bH}}{r_t^{bH}}-1\right)\left(\frac{r_{t+1}^{bH}}{r_t^{bH}}\right)^2\frac{b_{t+1}^H}{b_t^H}\right\} = 0 \quad \text{[A47],}$$

$$1-\varepsilon_t^{bE} + \varepsilon_t^{bE}\,\frac{r_t^b}{r_t^{bE}} - \kappa_{bE}\left(\frac{r_t^{bE}}{r_{t-1}^{bE}}-1\right)\frac{r_t^{bE}}{r_{t-1}^{bE}} + \beta_P E_t\left\{\frac{\lambda_{t+1}^P}{\lambda_t^P}\kappa_{bE}\left(\frac{r_{t+1}^{bE}}{r_t^{bE}}-1\right)\left(\frac{r_{t+1}^{bE}}{r_t^{bE}}\right)^2\frac{b_{t+1}^E}{b_t^E}\right\} = 0 \quad \text{[A48],}$$

$$\varepsilon_t^{d,lv}\,\frac{r_t}{r_t^{d,lv}} - 1 - \varepsilon_t^{d,lv} - \kappa_d^{lv}\left(\frac{r_t^{d,lv}}{r_{t-1}^{d,lv}}-1\right)\frac{r_t^{d,lv}}{r_{t-1}^{d,lv}} + \beta_P E_t\left\{\frac{\lambda_{t+1}^P}{\lambda_t^P}\kappa_d^{lv}\left(\frac{r_{t+1}^{d,lv}}{r_t^{d,lv}}\right)^2\left(\frac{r_{t+1}^{d,lv}}{r_t^{d,lv}}-1\right)\frac{d_{t+1}^{lv}}{d_t^{lv}}\right\} = 0 \quad \text{[A49],}$$

$$\varepsilon_t^{d,eu}\frac{r_t^{D,eu}}{r_t^{d,eu}}E_t\left(\frac{e_{t+1}}{e_t}\right)-\left(1+\varepsilon_t^{d,eu}\right)E_t\left(\frac{e_{t+1}}{e_t}\right)-\kappa_d^{eu}\left(\frac{r_t^{d,eu}}{r_{t-1}^{d,eu}}-1\right)\frac{r_t^{d,eu}}{r_{t-1}^{d,eu}}$$

$$+\beta_P E_t\left\{\frac{\lambda_{t+1}^P}{\lambda_t^P}\kappa_d^{eu}\left(\frac{r_{t+1}^{d,eu}}{r_t^{d,eu}}\right)^2\left(\frac{r_{t+1}^{d,eu}}{r_t^{d,eu}}-1\right)\frac{d_{t+1}^{eu}}{d_t^{eu}}\right\}=0 \qquad \text{[A50].}$$

Bank capital accumulation

$$K_t^b=(1-\delta^b)K_{t-1}^b+\omega^b J_{t-1}^b \qquad \text{[A51],}$$

$$J_t^b=r_t^{bH}b_t^H+r_t^{bE}b_t^E-r_t^{d,lv}d_t^{lv}-r_t^{d,eu}d_t^{eu}-r_t^F F_t-\frac{\kappa_{Kb}}{2}\left(\frac{K_t^b}{B_t}-\nu^b\right)^2K_t^b-\frac{\kappa_D}{2}\left(\left(D_t^{lv}\right)^2+\left(D_t^{eu}\right)^2\right)-\frac{\kappa_F}{2}F_t^2$$

$$-\frac{\kappa_{bH}}{2}\left(\frac{r_t^{bH}}{r_{t-1}^{bH}}-1\right)^2r_t^{bH}b_t^H-\frac{\kappa_{bE}}{2}\left(\frac{r_t^{bE}}{r_{t-1}^{bE}}-1\right)^2r_t^{bE}b_t^E-\frac{\kappa_d^{lv}}{2}\left(\frac{r_t^{d,lv}}{r_{t-1}^{d,lv}}-1\right)^2r_t^{d,lv}D_t^{lv}-\frac{\kappa_d^{eu}}{2}\left(\frac{r_t^{d,eu}}{r_{t-1}^{d,eu}}-1\right)^2r_t^{d,eu}D_t^{eu}$$

[A52].

Market clearing conditions

$$GDP_t=(1-\alpha)\left(c_t^P+c_t^I+c_t^E\right)+i_t^c+i_t^h+IH_t+Y_t^x \qquad \text{[A53],}$$

$$IH_t=h_t^P+h_t^I-\left(1-\delta^H\right)\left(h_{t-1}^P+h_{t-1}^I\right) \qquad \text{[A54],}$$

$$B_t=b_t^H+b_t^E \qquad \text{[A55].}$$

Demand for exports

$$Y_t^x=\alpha^*\left(\frac{P_{H,t}}{P_t^*}\right)^{-\gamma}Y_t^* \qquad \text{[A56].}$$

AR(1) processes

$$\ln A_{h,t}=\rho_{Ah}\ln A_{h,t-1}+\varepsilon_t^h \qquad \text{[A57],}$$

$$\ln A_{c,t}=\rho_{Ac}\ln A_{c,t-1}+\varepsilon_t^c \qquad \text{[A58],}$$

$$\ln\varepsilon_t^z=\rho_z\ln\varepsilon_{t-1}^z+u_t^z \qquad \text{[A59],}$$

$$\ln\varepsilon_t^h=\rho_h\ln\varepsilon_{t-1}^h+u_t^h \qquad \text{[A60],}$$

$$\tilde{\phi}_t=\rho_\phi\tilde{\phi}_{t-1}+\varepsilon_t^\phi \qquad \text{[A61],}$$

$$\Delta neer_t=\rho_{neer}\Delta neer_{t-1}+u_t^{neer} \qquad \text{[A62],}$$

$$\Delta s_t=\rho_s\Delta s_{t-1}+\varepsilon_t^s \qquad \text{[A63],}$$

$$(1-\pi_t^*) = \rho_{\pi*}(1-\pi_{t-1}^*) + \varepsilon_t^{\pi*} \quad [A64],$$

$$r_t^* = (1-\rho_{r*})\bar{r}^* + \rho_{r*} r_{t-1}^* + \varepsilon_t^{r*} \quad [A65],$$

$$Y_t^* = (1-\rho_{Y^*})\bar{Y}^* + \rho_{Y^*} Y_{t-1}^* + \varepsilon_t^{Y^*} \quad [A66],$$

$$\varepsilon_t^{bH} = (1-\rho_{bH})\varepsilon^{bH} + \rho_{bH}\varepsilon_{t-1}^{bH} + u_t^{bH} \quad [A67],$$

$$\varepsilon_t^{bE} = (1-\rho_{bE})\varepsilon^{bE} + \rho_{bE}\varepsilon_{t-1}^{bE} + u_t^{bE} \quad [A68],$$

$$\varepsilon_t^{d,lv} = (1-\rho_{d,lv})\varepsilon^{d,lv} + \rho_{d,lv}\varepsilon_{t-1}^{d,lv} + u_t^{d,lv} \quad [A69],$$

$$\varepsilon_t^{d,eu} = (1-\rho_{d,eu})\varepsilon^{d,eu} + \rho_{d,eu}\varepsilon_{t-1}^{d,eu} + u_t^{d,eu} \quad [A70].$$

Definitions

$$f_t = F_t / GDP_t \quad [A71],$$

$$\pi_t = P_t / P_{t-1} \quad [A72],$$

$$\pi_{H,t} = P_{H,t} / P_{H,t-1} \quad [A73],$$

$$\pi_t^* = P_t^* / P_{t-1}^* \quad [A74],$$

$$d_t^{P,lv} = D_t^{lv} / P_t \quad [A75],$$

$$d_t^{P,eu} = D_t^{eu} / P_t \quad [A76],$$

$$b_t^I = b_t^H / P_t \quad [A77],$$

$$b_t = b_t^E / P_t \quad [A78],$$

$$\omega_{c,t}^P = \frac{w_{c,t}^P \pi_t}{w_{c,t-1}^P} \quad [A79],$$

$$\omega_{c,t}^I = \frac{w_{c,t}^I \pi_t}{w_{c,t-1}^I} \quad [A80],$$

$$\omega_{h,t}^P = \frac{w_{h,t}^P \pi_t}{w_{h,t-1}^P} \quad [A81],$$

$$\omega_{h,t}^I = \frac{w_{h,t}^I \pi_t}{w_{h,t-1}^I} \quad [A82].$$

Appendix B. Steady State

$$c^P + q^h \delta^h h^P = \frac{w_c^P l_{pc}}{X_{wc}^P} + \frac{w_h^P l_{ph}}{X_{wh}^P} + r^{d,eu} d^{P,eu} + r^{d,lv} d^{P,lv} \quad \text{[B1],}$$

$$\lambda^P = \frac{(1-\beta_P a^P)}{c^P (1-a^P)} \quad \text{[B2],}$$

$$\frac{1}{h^P} = \lambda^P q^h (1-\beta_P (1-\delta^h)) \quad \text{[B3],}$$

$$(l_{pc}^{1+\xi^P} + l_{ph}^{1+\xi^P})^{\frac{\eta^P-\xi^P}{1+\xi^P}} l_{pc}^{\xi^P} = \lambda^P \frac{w_c^P}{X_{wc}^P} \quad \text{[B4],}$$

$$(l_{pc}^{1+\xi^P} + l_{ph}^{1+\xi^P})^{\frac{\eta^P-\xi^P}{1+\xi^P}} l_{ph}^{\xi^P} = \lambda^P \frac{w_h^P}{X_{wh}^P} \quad \text{[B5],}$$

$$\beta_P = \frac{1}{1+r^{d,eu}} \quad \text{[B6],}$$

$$\beta_P = \frac{1}{1+r^{d,lv}} \quad \text{[B7],}$$

$$c^I + q^h \delta^h h^I + r^{bH} b^I = \frac{w_c^I l_{Ic}}{X_{wc}^I} + \frac{w_h^I l_{Ih}}{X_{wh}^I} \quad \text{[B8],}$$

$$(1+r^{bH}) b^I = m^I q^h (1-\delta^H) h^I \quad \text{[B9],}$$

$$m^I = \overline{m}^I \quad \text{[B10],}$$

$$\lambda_1^I = \frac{1-\beta_I a^I}{c^I (1-a^I)} \quad \text{[B11],}$$

$$\frac{1}{h^I} = \lambda_1^I q^h - q^h (1-\delta^h)(\beta_I \lambda_1^I + \lambda_2^I m^I) \quad \text{[B12],}$$

$$(l_{Ic}^{1+\xi^I} + l_{Ih}^{1+\xi^I})^{\frac{\eta^I-\xi^I}{1+\xi^I}} l_{Ic}^{\xi^I} = \lambda_1^I \frac{w_c^I}{X_{wc}^I} \quad \text{[B13],}$$

$$(l_{Ic}^{1+\xi^I} + l_{Ih}^{1+\xi^I})^{\frac{\eta^I-\xi^I}{1+\xi^I}} l_{Ih}^{\xi^I} = \lambda_1^I \frac{w_h^I}{X_{wh}^I} \quad \text{[B14],}$$

$$\lambda_1^I = (1+r^{bH})(\beta_I \lambda_1^I + \lambda_2^I) \quad \text{[B15],}$$

$$Y = \left(l_{pc}^{\omega} l_{Ic}^{1-\omega}\right)^{1-\mu_c} (k_c)^{\mu_c} \quad \text{[B16],}$$

$$IH = \left(l_{ph}^{\omega} l_{Ih}^{1-\omega}\right)^{1-\mu_h} (k_h)^{\mu_h} \quad \text{[B17],}$$

$$\frac{Y}{X} + q^h IH = c^E + \sum_{i=c,h} w_i^P l_{pi} + \sum_{i=c,h} w_i^I l_{Ii} + \sum_{i=c,h} \delta^{ki} k_i + r^{bE} b \quad \text{[B18],}$$

$$(1+r^{bE})b = m^E\left((1-\delta^{kc})k_c + (1-\delta^{kh})k_h\right) \quad \text{[B19],}$$

$$m^E = \overline{m}^E \quad \text{[B20],}$$

$$\lambda_1^E = \frac{1-\beta_E a^E}{c^E(1-a^E)} \quad \text{[B21],}$$

$$(1-\mu_c)\omega Y = X w_c^P l_{pc} \quad \text{[B22],}$$

$$(1-\mu_c)(1-\omega)Y = X w_c^I l_{Ic} \quad \text{[B23],}$$

$$(1-\mu_h)\omega q^h IH = w_h^P l_{ph} \quad \text{[B24],}$$

$$(1-\mu_h)(1-\omega)q^h IH = w_h^I l_{Ih} \quad \text{[B25],}$$

$$\beta_E \mu_c \frac{\lambda_1^E Y}{X k_c} - \lambda_1^E + (1-\delta^{kc})(\beta_E \lambda_1^E + \lambda_2^E m^E) = 0 \quad \text{[B26],}$$

$$\beta_E \mu_h \frac{\lambda_1^E q^h IH}{k_h} - \lambda_1^E + (1-\delta^{kh})(\beta_E \lambda_1^E + \lambda_2^E m^E) = 0 \quad \text{[B27],}$$

$$\lambda_1^E - (1+r^{bE})(\beta_E \lambda_1^E + \lambda_2^E) = 0 \quad \text{[B28],}$$

$$i^c = \delta^{kc} k_c \quad \text{[B29],}$$

$$i^h = \delta^{kh} k_h \quad \text{[B30],}$$

$$r^F = r^* \Phi \quad \text{[B31],}$$

$$\Phi = \exp\left(\tilde{\phi}_f f\right) \quad \text{[B32],}$$

$$B = D^{lv} + D^{eu} + F + K^b \quad \text{[B33],}$$

$$r^{D,eu} = r^F\left(1+\tilde{\phi}_f f\right) - \kappa_D D^{eu} + \kappa_F F \quad \text{[B34],}$$

$$r = r^F\left(1+\tilde{\phi}_f f\right) - \kappa_D D^{lv} + \kappa_F F \quad \text{[B35],}$$

$$r = r^b - \kappa_D D^{lv} + \kappa_F F \quad \text{[B36],}$$

$$\varepsilon^{bH}\left(1-\frac{r^{b}}{r^{bH}}\right)=1 \qquad \text{[B37],}$$

$$\varepsilon^{bE}\left(1-\frac{r^{b}}{r^{bE}}\right)=1 \qquad \text{[B38],}$$

$$\varepsilon^{d,lv}\left(\frac{r}{r^{d,lv}}-1\right)=1 \qquad \text{[B39],}$$

$$\varepsilon^{d,eu}\left(\frac{r^{D,eu}}{r^{d,eu}}-1\right)=1 \qquad \text{[B40],}$$

$$\delta^{b}K^{b}=\omega^{b}J^{b} \qquad \text{[B41],}$$

$$J^{b}=r^{bH}b^{H}+r^{bE}b^{E}-r^{d,lv}d^{lv}-r^{d,eu}d^{eu}-r^{F}F-\frac{\kappa_{D}}{2}\left(\left(D^{lv}\right)^{2}+\left(D^{eu}\right)^{2}\right)-\frac{\kappa_{F}}{2}F^{2} \qquad \text{[B42],}$$

$$GDP=(1-\alpha)\left(c^{P}+c^{I}+c^{E}\right)+i^{c}+i^{h}+IH+Y^{x} \qquad \text{[B43],}$$

$$IH=\delta^{H}(h^{P}+h^{I}) \qquad \text{[B44],}$$

$$B=b^{H}+b^{E} \qquad \text{[B45],}$$

$$Y^{x}=\alpha^{*}\left(\frac{P_{H}}{P^{*}}\right)^{-\gamma}Y^{*} \qquad \text{[B46],}$$

$$f=F/GDP \qquad \text{[B47],}$$

$$d^{P,lv}=D^{lv}/P=d^{lv}/P \qquad \text{[B48],}$$

$$d^{P,eu}=D^{eu}/P=d^{eu}/P \qquad \text{[B49],}$$

$$b^{I}=b^{H}/P \qquad \text{[B50],}$$

$$b=b^{E}/P \qquad \text{[B51],}$$

Appendix C

Table 1

Calibrated parameters

Parameter	Description	Value
δ^h	Housing depreciation rate	0.02
a^P	Degree of patient households' habit formation in consumption	0.98
ξ^P	Degree of patient households' labour substitution across sectors	1.30
η^P	Disutility of patient households' labour supply	2.61
$\overline{m}^I$	Loan-to-value of households	0.68
a^I	Degree of impatient households' habit formation in consumption	0.85
ξ^I	Degree of impatient households' labour substitution across sectors	1.00
η^I	Disutility of impatient households' labour supply	0.91
ω	Labour income share of unconstrained households	0.67
μ_c	Capital share in the goods production function	0.36
μ_h	Capital share in the housing production function	0.15
δ^{kc}	Depreciation rate of capital used in the consumption sector	0.16
δ^{kh}	Depreciation rate of capital used in the housing sector	0.02
$\overline{m}^E$	Loan-to-value of entrepreneurs	0.47
a^E	Degree of entrepreneurial habit formation in consumption	0.50
α	Openness, imports share in GDP	0.40
κ_D	Adjustment cost of wholesale deposits	0.11
ν^b	Capital-to-loans ratio in steady state	0.12
X	Mark-up in the goods market	1.20
δ^b	Share of bank capital and intermediation activity management costs	0.02
ω^b	Share of reinvested bank profit	0.85
$\tilde{\phi}_f$	Risk premium elasticity	0.01
$\bar{f}$	Foreign debt-to-GDP ratio	0.34
κ_F	Adjustment cost of foreign borrowing	0.12
α^*	Share of domestic exports in foreign imports	0.001
γ	Degree of substitution between domestic and import goods	1.00
X_{wc}^P	Wage mark-up of patient households employed in consumption sector	1.20
X_{wc}^I	Wage mark-up of impatient households employed in consumption sector	1.20
X_{wh}^P	Wage mark-up of patient households employed in housing sector	1.20
X_{wh}^I	Wage mark-up of impatient households employed in housing sector	1.20
$\bar{\varepsilon}^{bH}$	$\frac{\varepsilon^{bH}}{\varepsilon^{bH}-1}$ mark-up on rate on loans to households	1.48
$\bar{\varepsilon}^{bE}$	$\frac{\varepsilon^{bE}}{\varepsilon^{bE}-1}$ mark-up on rate on loans to households	1.12
$\bar{\varepsilon}^{d,lv}$	$\frac{\varepsilon^{d,lv}}{\varepsilon^{d,lv}+1}$ mark-down on lats deposits	0.78
$\bar{\varepsilon}^{d,eu}$	$\frac{\varepsilon^{d,eu}}{\varepsilon^{d,eu}+1}$ mark-down on euro deposits	0.78

Table 2
Steady-state ratios

Variable	**Interpretation**	**Value**
C / GDP	Ratio of consumption to GDP	0.74
B / GDP	Ratio of loans to GDP	1.30
B^H / B	Share of loans to households over total loans	0.46
B^E / B	Share of loans to firms over total loans	0.54
K^b / B	Ratio of bank capital to loans	0.12
D^{lv} / GDP	Ratio of deposits denominated in lats to GDP	0.40
D^{eu} / GDP	Ratio of deposits denominated in euro to GDP	0.40
F / GDP	Ratio of foreign debt to GDP	0.34
r	Annualised policy rate (per cent)	4.0
r^*	Annualised foreign interbank rate (per cent)	4.0
$r^{d,lv}$	Annualised bank rate on lats deposits (per cent)	3.1
$r^{d,eu}$	Annualised bank rate on euro deposits (per cent)	3.1
r^{bH}	Annualised bank rate on loans to households (per cent)	6.0
r^{bE}	Annualised bank rate on loans to firms (per cent)	4.5

Table 3
Prior and posterior distribution of structural parameters

Para-meter	**Prior distribution**			**Posterior distribution**		
	Density	**Mean**	**St. dev.**	**Mean**	**90% interval**	
κ_{Kb}	Gamma	10	5	19.31	18.55	19.97
κ_{bH}	Gamma	10	5	4.42	3.44	5.32
κ_{bE}	Gamma	10	5	19.41	17.27	21.30
κ_{d}^{lv}	Gamma	10	5	11.40	9.55	13.24
κ_{d}^{eu}	Gamma	10	5	0.28	0.20	0.36
κ_{ic}	Gamma	2.5	1	2.65	2.20	3.24
κ_{ih}	Gamma	2.5	1	2.39	2.10	2.72
ψ_1	Gamma	2.0	0.5	2.38	2.16	2.52
ψ_2	Gamma	0.2	0.1	0.19	0.15	0.23
ψ_3	Gamma	40	5	37.78	36.11	40.06
θ_{π}	Beta	0.5	0.05	0.53	0.51	0.54
ι_{π}	Beta	0.5	0.2	0.46	0.40	0.51
ι_{wc}	Beta	0.5	0.2	0.31	0.21	0.40
θ_{wc}	Beta	0.5	0.2	0.76	0.73	0.78
ι_{wh}	Beta	0.5	0.2	0.46	0.39	0.51
θ_{wh}	Beta	0.5	0.2	0.56	0.47	0.67
ρ_r	Beta	0.8	0.1	0.88	0.87	0.90
ρ_{mI}	Beta	0.8	0.1	0.89	0.85	0.93
ρ_{mE}	Beta	0.8	0.1	0.81	0.77	0.84
ρ_{Ac}	Beta	0.8	0.1	0.87	0.84	0.90
ρ_{Ah}	Beta	0.8	0.1	0.85	0.81	0.88
ρ_z	Beta	0.8	0.1	0.74	0.71	0.76
ρ_h	Beta	0.8	0.1	0.98	0.96	0.99
ρ_s	Beta	0.8	0.1	0.77	0.74	0.79
$\rho_{\pi*}$	Beta	0.8	0.1	0.89	0.85	0.92
ρ_{r*}	Beta	0.8	0.1	0.73	0.69	0.76
ρ_{ϕ}	Beta	0.8	0.1	0.81	0.78	0.84
ρ_{Y^*}	Beta	0.8	0.1	0.73	0.69	0.76
ρ_{bH}	Beta	0.8	0.1	0.83	0.80	0.86
ρ_{bE}	Beta	0.8	0.1	0.87	0.83	0.92
$\rho_{d,lv}$	Beta	0.8	0.1	0.85	0.81	0.89
$\rho_{d,eu}$	Beta	0.8	0.1	0.95	0.92	0.98

Table 3 (cont.)

Para-meter	Prior distribution			Posterior distribution		
	Density	Mean	St. dev.	Mean	90% interval	
ρ_{neer}	Beta	0.8	0.1	0.993	0.987	0.999
σ_{mI}	InvGamma	0.05	1.0	0.613	0.505	0.716
σ_{mE}	InvGamma	0.05	1.0	0.059	0.044	0.074
σ_{π}	InvGamma	0.05	1.0	0.476	0.373	0.574
σ_{r}	InvGamma	0.05	1.0	0.084	0.010	0.223
σ_{s}	InvGamma	0.05	1.0	0.723	0.610	0.835
σ_{Ac}	InvGamma	0.05	1.0	0.665	0.516	0.841
σ_{Ah}	InvGamma	0.05	1.0	0.044	0.011	0.079
σ_{z}	InvGamma	0.05	1.0	5.838	5.321	6.360
σ_{h}	InvGamma	0.05	1.0	0.036	0.012	0.063
σ_{r*}	InvGamma	0.05	1.0	0.009	0.008	0.011
σ_{ϕ}	InvGamma	0.05	1.0	0.420	0.349	0.489
σ_{Y^*}	InvGamma	0.05	1.0	0.046	0.012	0.090
$\sigma_{\pi*}$	InvGamma	0.05	1.0	0.009	0.008	0.011
σ_{bH}	InvGamma	0.05	1.0	2.780	2.465	3.105
σ_{bE}	InvGamma	0.05	1.0	0.045	0.012	0.086
$\sigma_{d,lv}$	InvGamma	0.05	1.0	0.046	0.012	0.086
$\sigma_{d,eu}$	InvGamma	0.05	1.0	4.583	4.165	5.012
σ_{wc}^{P}	InvGamma	0.05	1.0	0.820	0.650	0.990
σ_{wc}^{I}	InvGamma	0.05	1.0	2.680	2.335	3.085
σ_{wh}^{P}	InvGamma	0.05	1.0	0.040	0.012	0.072
σ_{wh}^{I}	InvGamma	0.05	1.0	0.517	0.193	0.926
σ_{neer}	InvGamma	0.05	1.0	0.434	0.356	0.514

Table 4
Robustness of parameter estimates and marginal likelihood comparison

Parameter	**Baseline**	**Modified NEER**	**No Taylor rule**
κ_{Kb}	19.31	25.73	36.20
κ_{bH}	4.42	3.45	2.30
κ_{bE}	19.41	19.30	15.92
κ_{d}^{lv}	11.40	16.34	0.33
κ_{d}^{eu}	0.28	1.13	23.97
κ_{ic}	2.65	2.95	0.60
κ_{ih}	2.39	3.71	3.55
ψ_1	2.38	2.78	–
ψ_2	0.19	0.19	–
ψ_3	37.78	31.75	–
θ_π	0.53	0.47	0.53
ι_π	0.46	0.80	0.34
ι_{wc}	0.31	0.74	0.12
θ_{wc}	0.76	0.80	0.69
ι_{wh}	0.46	0.43	0.77
θ_{wh}	0.56	0.49	0.86
ρ_R	0.88	0.93	–
ρ_{mI}	0.89	0.69	0.69
ρ_{mE}	0.81	0.96	0.87
ρ_{Ac}	0.87	0.88	0.86
ρ_{Ah}	0.85	0.86	0.81
ρ_z	0.74	0.83	0.89
ρ_h	0.98	0.99	0.83
ρ_s	0.77	0.99	0.73
$\rho_{\pi*}$	0.89	0.88	0.81
ρ_{r*}	0.73	0.91	0.83
ρ_ϕ	0.81	0.71	0.51
ρ_{Y^*}	0.73	0.86	0.83
ρ_{bH}	0.83	0.78	0.87
ρ_{bE}	0.87	0.84	0.86
$\rho_{d,lv}$	0.85	0.76	0.86
$\rho_{d,eu}$	0.95	0.78	0.65

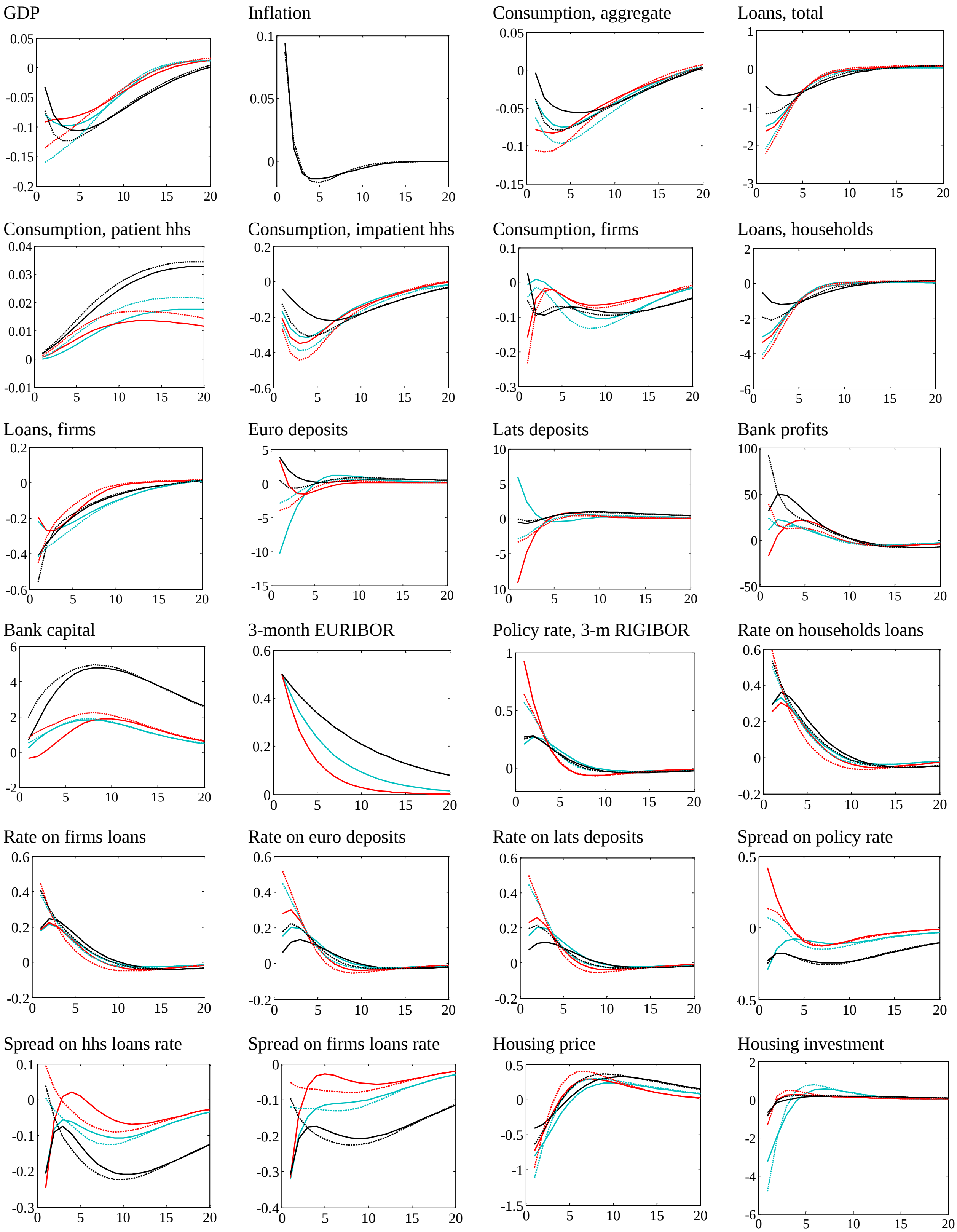
Table 4 (cont.)

Parameter	Baseline	Modified NEER	No Taylor rule
ρ_{neer}	0.99	0.82	0.83
σ_{mI}	0.613	0.495	0.394
σ_{mE}	0.059	0.320	0.040
σ_{π}	0.476	1.003	0.098
σ_{r}	0.084	1.300	0.120
σ_{s}	0.723	0.528	0.016
σ_{Ac}	0.665	1.136	0.490
σ_{Ah}	0.044	0.007	0.009
σ_{z}	5.838	0.008	2.993
σ_{h}	0.036	2.026	0.108
σ_{r*}	0.009	0.005	0.006
σ_{ϕ}	0.420	0.398	1.701
σ_{Y^*}	0.046	0.009	0.009
$\sigma_{\pi*}$	0.009	0.007	0.007
σ_{bH}	2.780	2.053	2.068
σ_{bE}	0.045	0.008	0.009
$\sigma_{d,lv}$	0.046	0.009	0.008
$\sigma_{d,eu}$	4.583	1.089	0.009
σ_{wc}^{P}	0.820	0.773	0.710
σ_{wc}^{I}	2.680	1.773	1.071
σ_{wh}^{P}	0.040	0.012	0.009
σ_{wh}^{I}	0.517	0.008	0.009
σ_{neer}	0.434	0.209	0.013
Marginal likelihood	–145.092	–2 281.046	–1 859.248

Appendix D. Impulse responses

Figure 1

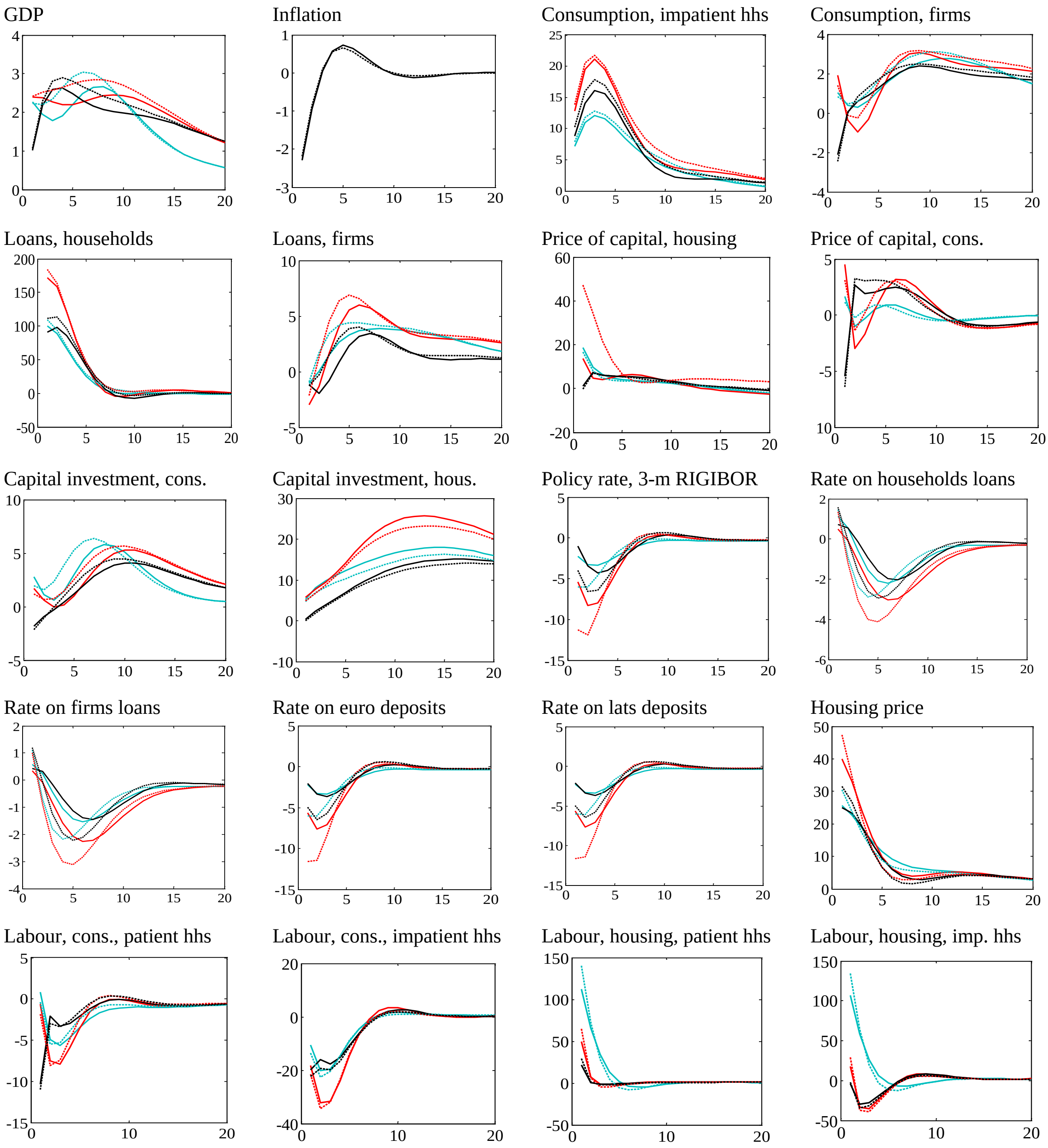
Impulse responses to 50 basis points contractionary foreign monetary shock

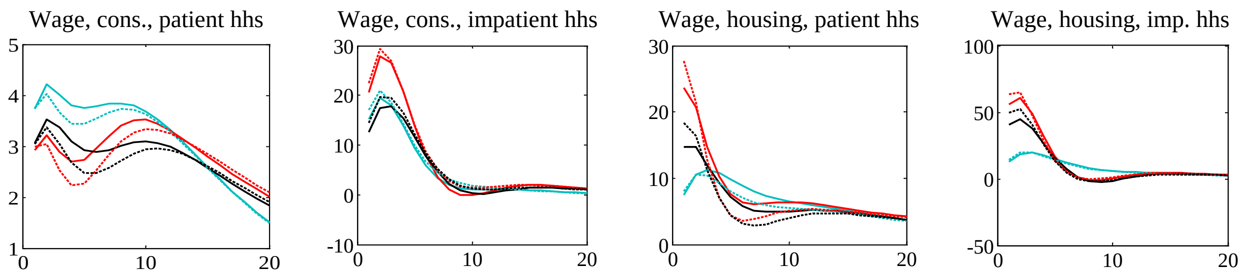


Notes: The impulse responses are computed using the mean of the posterior distribution. Interest rates and bank spreads are absolute deviations from steady state, in percentage points. All others are percentage deviations from steady state. The solid lines refer to the three specifications with financial frictions, while the dashed lines correspond to scenarios without frictions, i.e. the costs to change rates κ_{bH}, κ_{bE}, κ_d^{lv} and κ_d^{eu} are set to zero. The red line is the baseline model, the black line is the modified NEER framework, and the blue line is the model with modified NEER but no Taylor rule.

Figure 2

Impulse responses to 10% positive technology shock

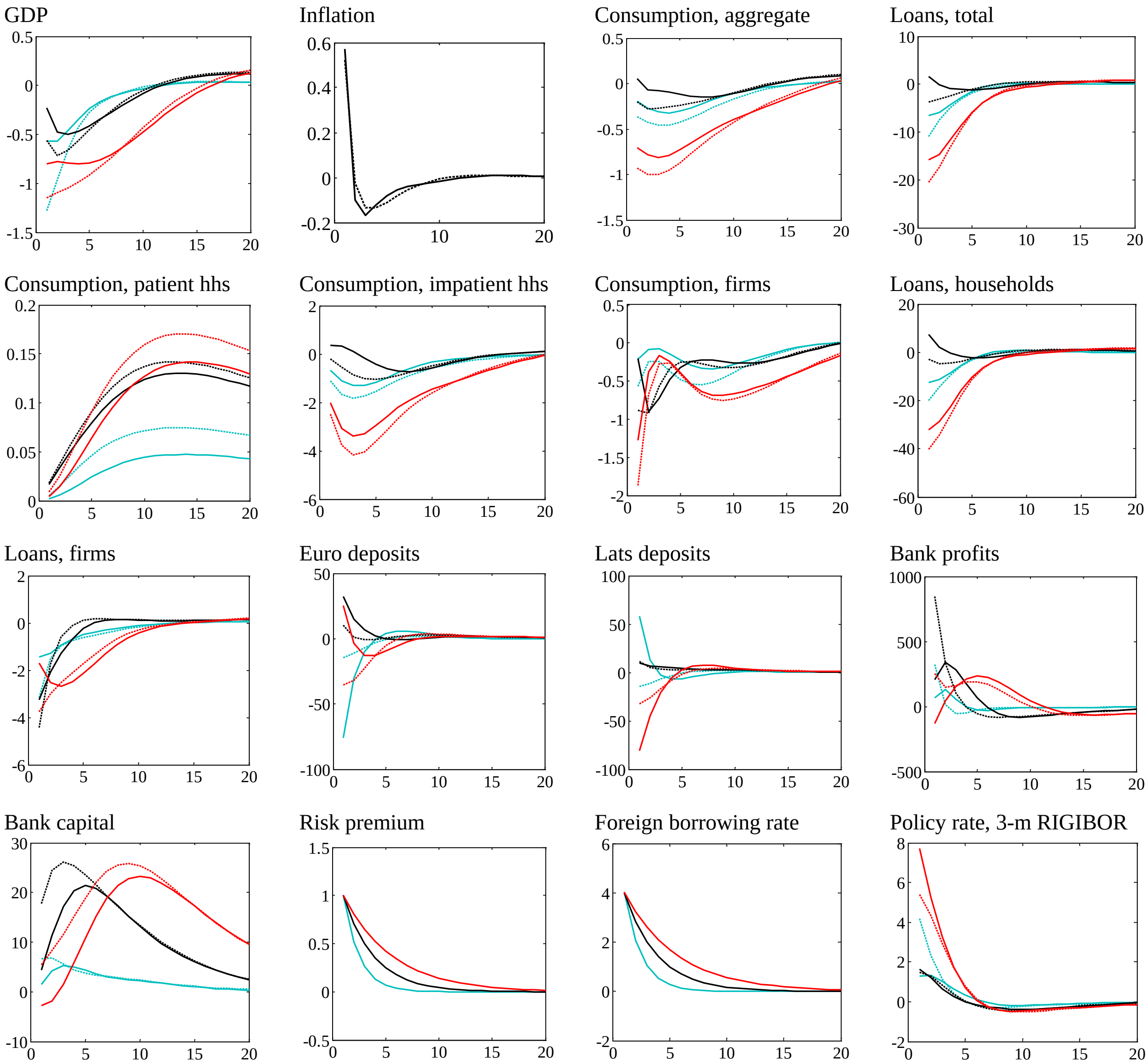


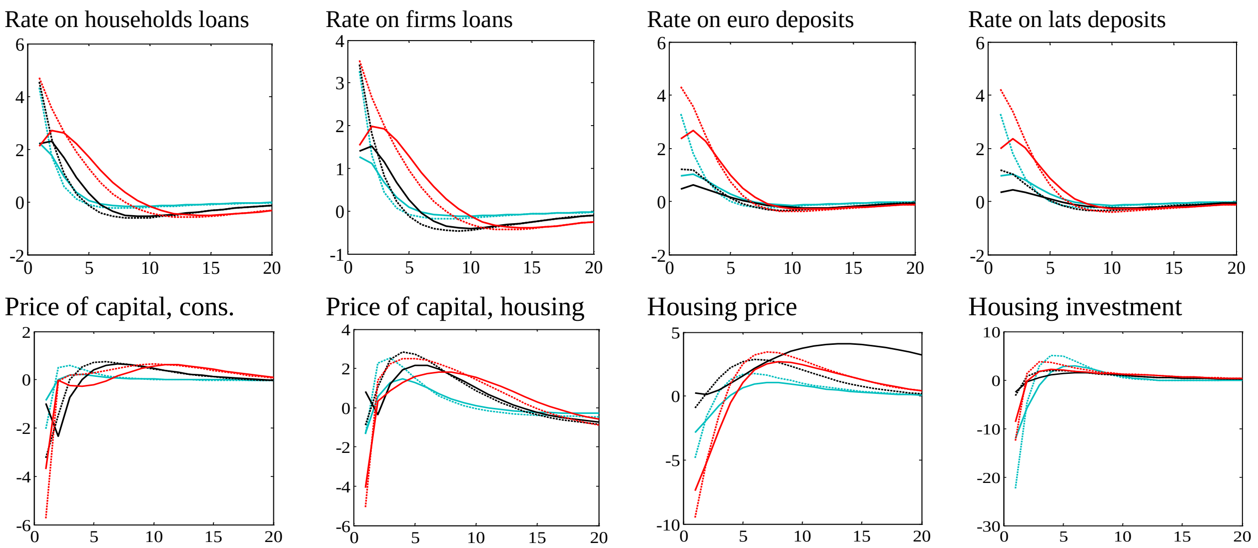


Notes: The impulse responses are computed using the mean of the posterior distribution. Interest rates and bank spreads are absolute deviations from steady state, in percentage points. All others are percentage deviations from steady state. The solid lines refer to the three specifications with financial frictions, while the dashed lines correspond to scenarios without frictions, i.e. the costs to change rates κ_{bH}, κ_{bE}, κ_d^{lv} and κ_d^{eu} are set to zero. The red line is the baseline model, the black line is the modified NEER framework, and the blue line is the model with modified NEER but no Taylor rule.

Figure 3

Impulse responses to 100 basis points positive foreign risk premium shock

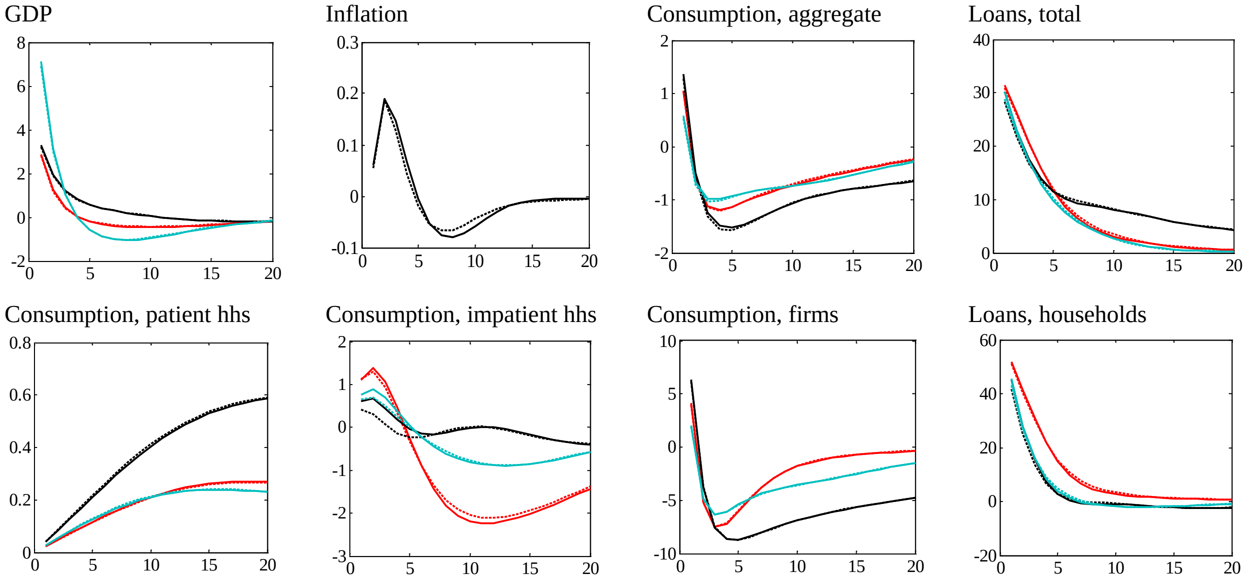


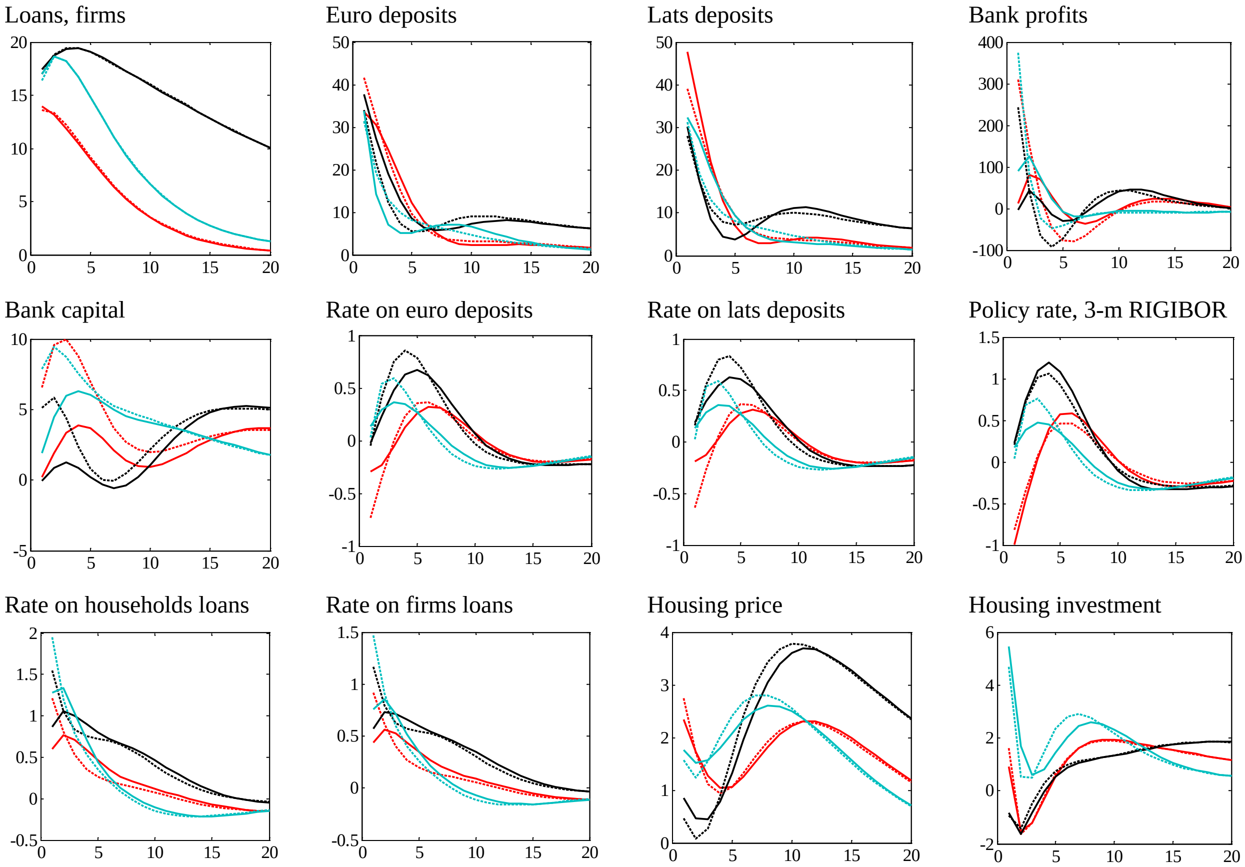


Notes: The impulse responses are computed using the mean of the posterior distribution. Interest rates and bank spreads are absolute deviations from steady state, in percentage points. All others are percentage deviations from steady state. The solid lines refer to the three specifications with financial frictions, while the dashed lines correspond to scenarios without frictions, i.e. the costs to change rates κ_{bH}, κ_{bE}, κ_{d}^{lv} and κ_{d}^{eu} are set to zero. The red line is the baseline model, the black line is the modified NEER framework, and the blue line is the model with modified NEER but no Taylor rule.

Figure 4

Impulse responses to 10 basis points positive LTV shock

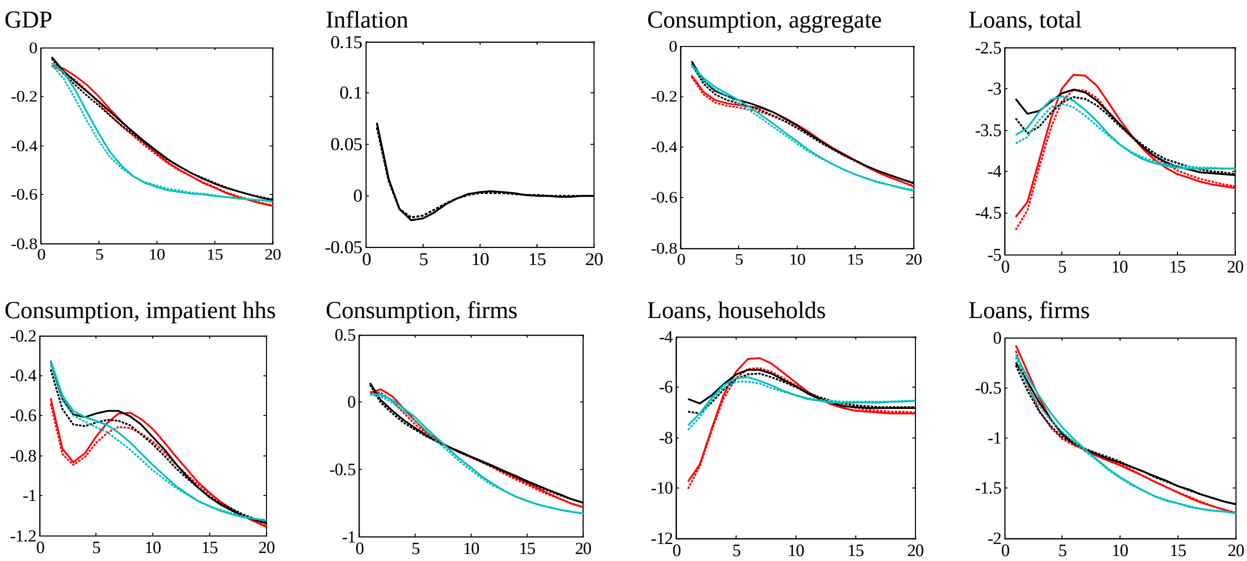


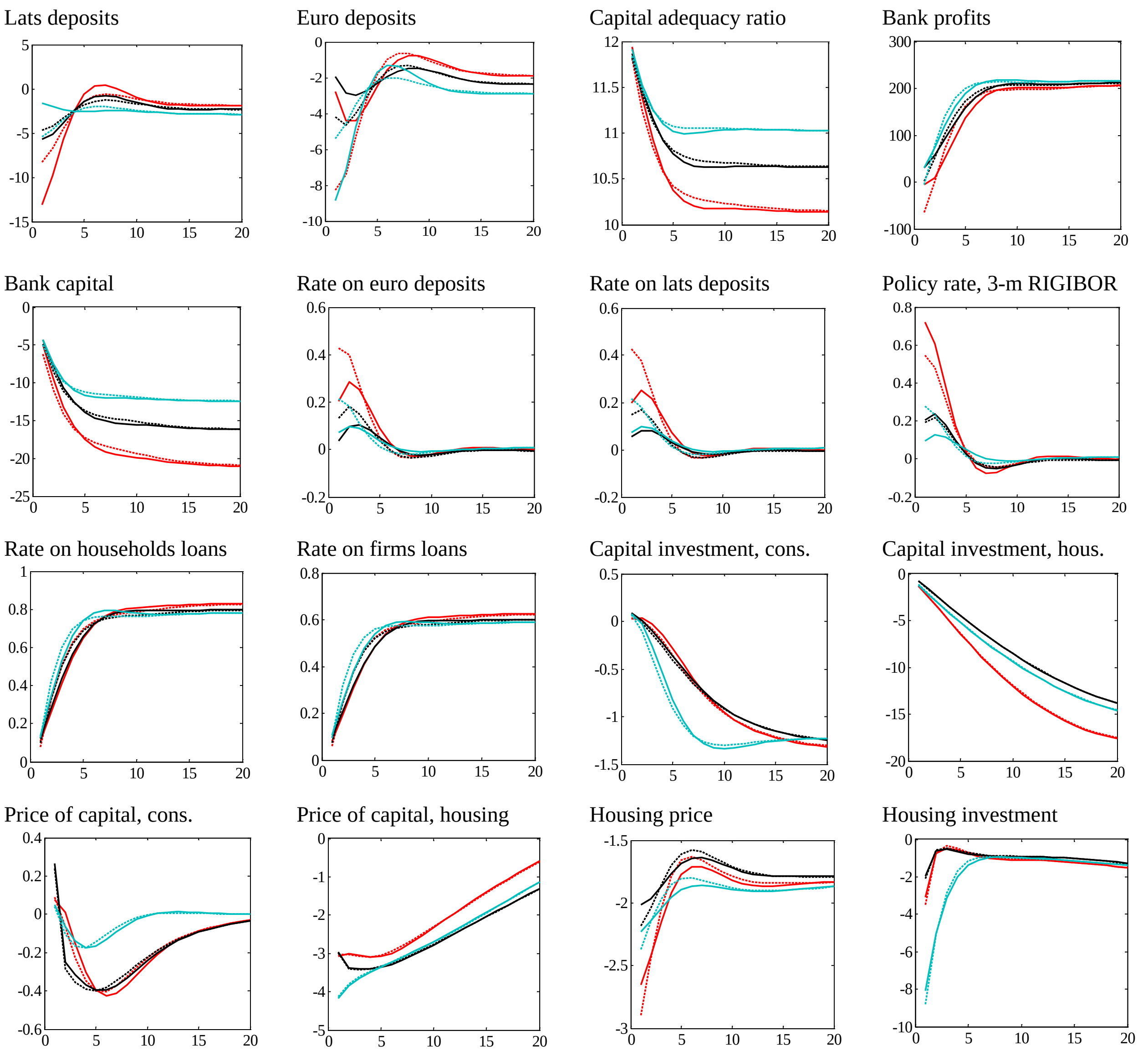


Notes: The impulse responses are computed using the mean of the posterior distribution. Interest rates and bank spreads are absolute deviations from steady state, in percentage points. All others are percentage deviations from steady state. The solid lines refer to the three specifications with financial frictions, while the dashed lines correspond to scenarios without frictions, i.e. the costs to change rates κ_{bH}, κ_{bE}, κ_d^{lv} and κ_d^{eu} are set to zero. The red line is the baseline model, the black line is the modified NEER framework, and the blue line is the model with modified NEER but no Taylor rule.

Figure 5

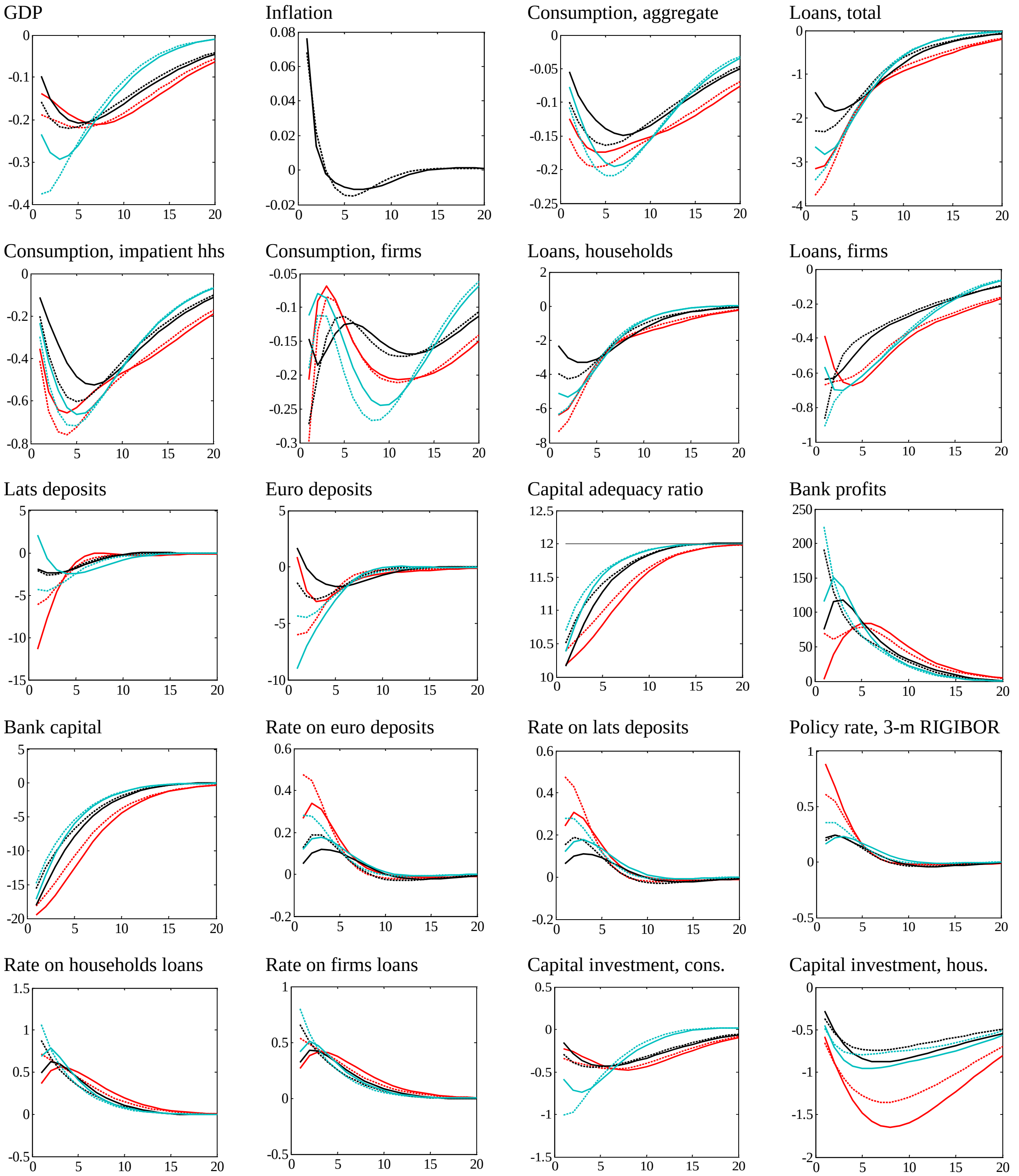
Impulse responses to 5% permanent negative shock to bank capital

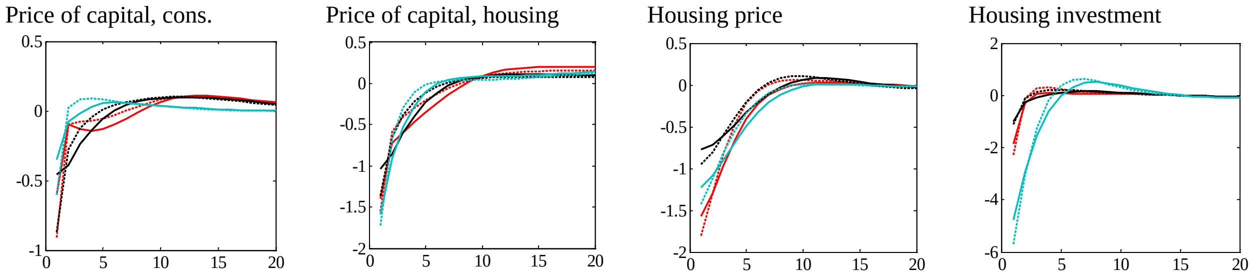




Notes: The impulse responses are computed using the mean of the posterior distribution. Interest rates and bank spreads are absolute deviations from steady state, in percentage points. All others are percentage deviations from steady state. The solid lines refer to the three specifications with financial frictions, while the dashed lines correspond to scenarios without frictions, i.e. the costs to change rates κ_{bH}, κ_{bE}, κ_d^{lv} and κ_d^{eu} are set to zero. The red line is the baseline model, the black line is the modified NEER framework, and the blue line is the model with modified NEER but no Taylor rule.

Figure 6
Impulse responses to 20% one-off negative shock to bank capital

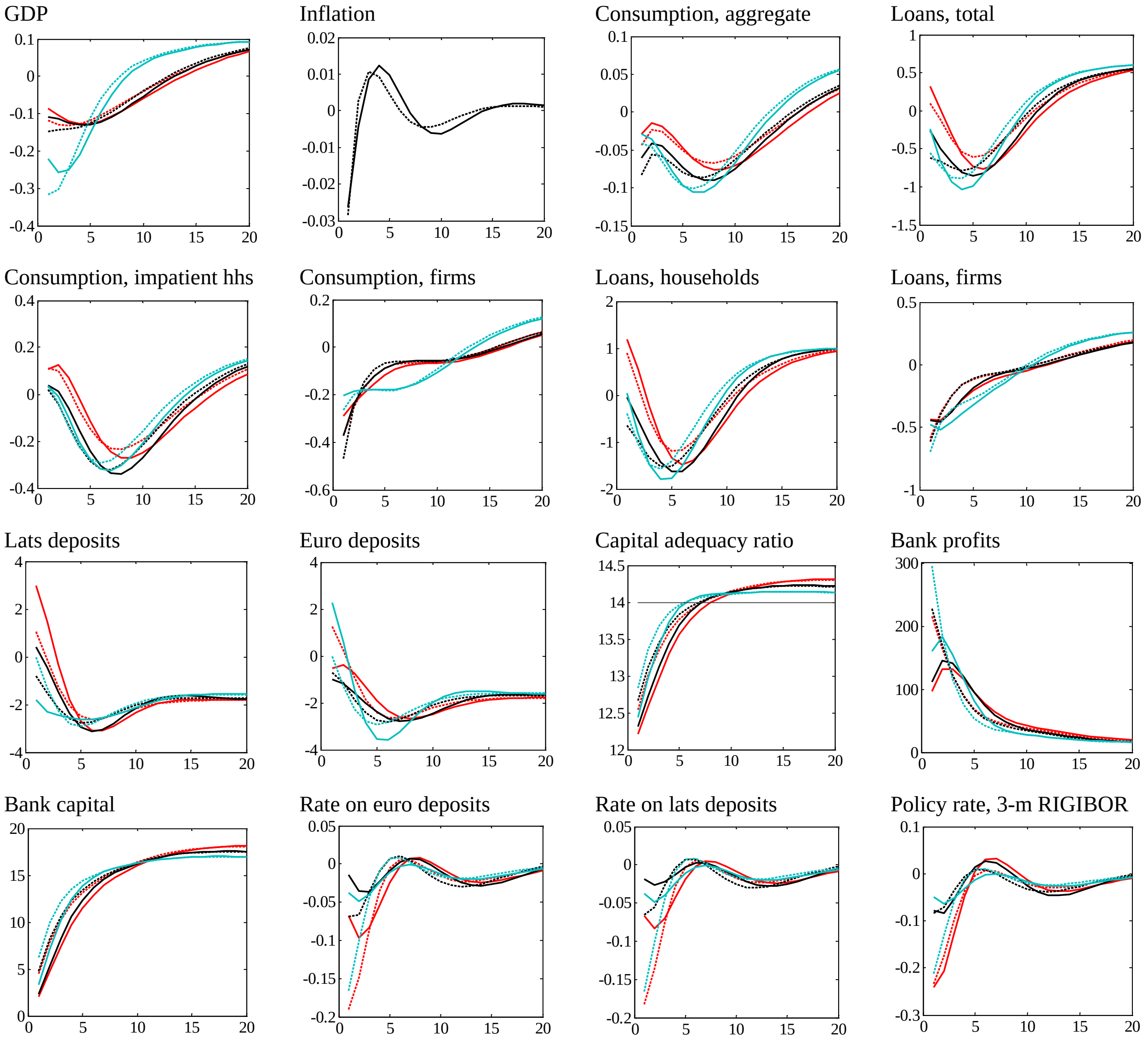


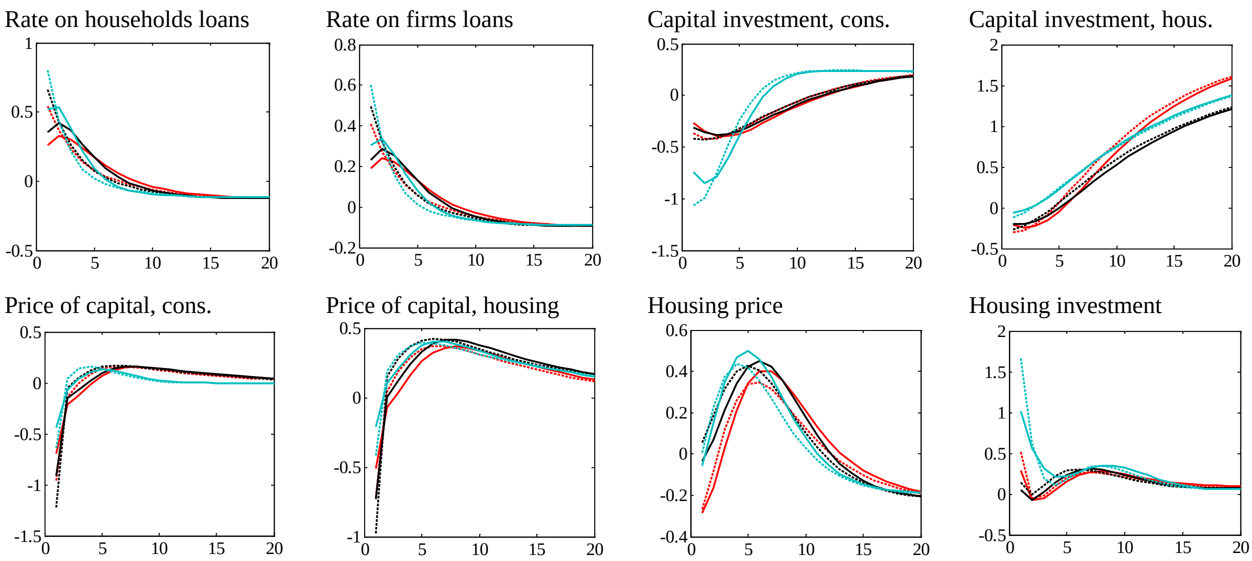


Notes: The impulse responses are computed using the mean of the posterior distribution. Interest rates and bank spreads are absolute deviations from steady state, in percentage points. All others are percentage deviations from steady state. The solid lines refer to the three specifications with financial frictions, while the dashed lines correspond to scenarios without frictions, i.e. the costs to change rates κ_{bH}, κ_{bE}, κ_d^{lv} and κ_d^{eu} are set to zero. The red line is the baseline model, the black line is the modified NEER framework, and the blue line is the model with modified NEER but no Taylor rule.

Figure 7

Impulse responses to increase in capital adequacy ratio by 2 percentage points





Notes: The impulse responses are computed using the mean of the posterior distribution. Interest rates and bank spreads are absolute deviations from steady state, in percentage points. All others are percentage deviations from steady state. The solid lines refer to the three specifications with financial frictions, while the dashed lines correspond to scenarios without frictions, i.e. the costs to change rates κ_{bH}, κ_{bE}, κ_d^{lv} and κ_d^{eu} are set to zero. The red line is the baseline model, the black line is the modified NEER framework, and the blue line is the model with modified NEER but no Taylor rule.

Appendix E. Data and sources

Real consumption: Final consumption expenditure of households and non-profit institutions serving households, constant prices, seasonally adjusted. Source: CSB.

Real housing prices: Prices per square meter of standard type apartments in the suburbs of Riga, deflated with the HICP. Sources: Latio, CSB.

Deposits in lats: Outstanding amounts of deposits of households and private non-financial corporations, in lats. Source: FCMC.

Deposits in euro: Outstanding amounts of deposits of households and private non-financial corporations, in OECD currencies. Source: FCMC.

Loans to households: Outstanding amounts of loans for house purchasing, OECD currencies. Source: FCMC.

Loans to firms: Outstanding amounts of loans to private non-financial corporations, OECD currencies. Source: FCMC.

Nominal d**omestic policy rate**: 3-month RIGIBOR, quarter average. Source: Bank of Latvia.

Nominal f**oreign policy rate**: 3-month EURIBOR, quarter average. Source: Bloomberg.

Nominal interest rates on deposits: Interest rates on new deposits of households and private non-financial corporations, OECD currencies. Source: FCMC.

Nominal interest rates on loans to firms: Interest rates on new loans to private non-financial corporations, OECD currencies. Source: FCMC.

Nominal interest rates on loans to households: Interest rates on new loans for house purchasing, OECD currencies (up to end-2003 total loans, as of 2004 loans for house purchasing). Source: FCMC.

Bank capital-to-loans ratio: Paid-up share capital (stock) divided by stock of loans to private non-financial corporations and loans for house purchasing. Source: FCMC.

Domestic inflation: Quarter on quarter growth rate in the HICP. Overall index, seasonally adjusted, Latvia. Source: CSB.

Foreign inflation: Quarter on quarter growth rate in the HICP. Overall index, seasonally adjusted, EU-25. Source: Eurostat.

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