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Abstract

We construct an open-economy DSGE model with a banking sector to analyse the impact of the recent credit crunch on a small open economy. In our model the banking sector operates under monopolistic competition, collects deposits and grants collateralized loans. Collateral effects amplify monetary policy actions, interest rate stickiness dampens the transmission of interest rates, and financial shocks generate non-negligible real and nominal effects. As an application we estimate the model for Poland - a typical small open economy. According to the results, financial shocks had a substantial, though not overwhelming, impact on the Polish economy during the 2008/09 crisis, lowering GDP by a little over one percent.

JEL: E32, E44, E52

Keywords: credit crunch, monetary policy, DSGE with banking sector

1 Introduction

The financial crisis affected economies worldwide. It originated from problems with subprime mortgages in the United States, but spread soon to international financial markets. Several financial institutions had to be bailed out by governments. Moreover, the disease soon started to spread to the real economy. Its impact was transmitted i.a. via negative wealth effects (housing and stock market busts), decreased consumer confidence and the crunch in credit markets. Moreover, in the case of small open economies decreased demand for exports and limited access to external funding further contributed to the slowdown[1]. As a result the world economy entered its worst recession since World War II. It is not possible, and probably never will be, to tell precisely how various channels contributed to the weakening of economic activity in various countries. In particular, it seems unlikely to measure how much of the slowdown in consumption and investment expenditure was due to widespread panic - a sort of animal instinct behaviour among households and investors. In this paper we undertake a more decent exercise: we only assess the role played in transmitting the slowdown by the banking sector. To do this we construct a general equilibrium model with a banking sector.

The literature incorporating a financial sector into macroeconomic models has been developing fast over the last two decades. A seminal position is Bernanke and Gertler (1989) where financial frictions have been incorporated into a general equilibrium model. This approach has been further developed and merged with the New-Keynesian framework by Bernanke, Gertler, and Gilchrist (1996), becoming the workhorse financial frictions model in the 2000's. In this model frictions arise because monitoring the loan applicant is costly - this generates an "external finance premium" and, hence increases the lending rate. This idea has been extensively used i.a. by Choi and Cook (2004) to analyse the balance sheet channel in emerging markets or by Christiano, Motto, and Rostagno (2007) to study business cycle implications of financial frictions. Goodfriend and McCallum (2007) provided an endogenous explanation for steady state differentials between lending and money market rates. Cúrdia and Woodford (2008) derived optimal monetary policy in the presence of time-varying interest rate spreads in a model with heterogeneous agents.

A second important direction was introduced by Iacoviello (2005), who concentrated on quantities rather than on prices of loans. In his model households accumulate housing wealth, which can be used as loan collateral. Collateral constraints capture the effects of quantitative restrictions generated by the banking sector. An important application is Gerali, Neri, Sessa, and Signoretti (2009) where a model with collateral constraints and monopolistic competition in the banking sector was used to analyse i.a. the impact of financial frictions on monetary transmission and a credit crunch scenario. The eruption of the financial crisis contributed

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[1]For a thorough analysis of the crisis see e.g BIS (2009).

to even more interest in these models and probably we will see several new studies in this field soon.

Our model is written in the spirit of Iacoviello (2005) and Gerali, Neri, Sessa, and Signoretti (2009). Apart from financial sector issues it has the standard features of new Keynesian models (e.g. Erceg, Henderson, and Levin, 2000, Smets and Wouters, 2003) including monopolistically competitive markets and nominal rigidities in goods and labour markets. We contribute to the existing financial frictions literature by incorporating the model into a small open economy framework (e.g. Galí and Monacelli (2005), Altig, Christiano, Eichenbaum, and Lindé, 2005, Christiano, Eichenbaum, and Evans, 2005, Adolfson, Laséen, Lindé, and Villani, 2005). This seems important, since contemporaneous economies can rarely be treated as closed. Our economy is populated by patient (saving) and impatient (borrowing) households as well as (borrowing) entrepreneurs. Consumers consume and accumulate housing. Entrepreneurs produce homogeneous goods that are differentiated by monopolistically competitive retailers and merged with foreign goods before they are used for consumption or investment. Monopolistically competitive banks collect deposits, grant loans and have access to domestic and international money markets. In terms of financial frictions both, collateral constraints (on housing or capital) and interest rate spreads play a role and are able to generate non-negligible real and nominal effects.

As an application we estimate the model using data for Poland - a typical small open economy. This country has been substantially (though probably somewhat less than most EU countries) affected by the crisis. GDP growth is expected to decrease from 5.0% in 2008 to 0.4% in 2009 and exports are expected to contract by almost 8% in 2009 (2009 data from NBP (2009a) projection) (Figure 1). The slowdown was deepened by the restrictive behaviour of Polish banks, who significantly increased the cost of borrowing and additionally tightened lending conditions. It should be noted that, similarly to several other small open economies, the behaviour of Polish banks was driven by external rather than internal factors. Polish banks have not invested funds in toxic assets, subprime lending was not excessive and the housing market did not crash. Nevertheless the international crisis of confidence transmitted to the Polish interbank market, reducing the volume of transactions and raising spreads. This transmitted to spreads on commercial loans and deposits. Moreover, survey evidence shows that banks drastically tightened lending standards raising i.a. collateral requirements (NBP, 2009b). As a result lending to households and enterprises broke down. Between 1q2008 and 2q2009 new loans to households decreased by a quarter and to enterprises by a third (Figure 2). Simulations based on our model show that shocks generated by the Polish banking sector in late 2008 and early 2009 indeed deepened the economic slowdown. In particular shocks to spreads and LTV ratios contributed 1.3 per cent to the slowdown of GDP.

The rest of the paper is structured as follows. Section two presents the model, section three the calibrating/ estimating procedure and section four the results. Section five

concludes.

2   The model

We model a heterogeneous agents small open economy with financial frictions. Our economy is populated by patient households, impatient households and entrepreneurs. Patient households consume, accumulate housing stock, save, and work. Impatient households consume, accumulate housing stock, borrow and work. Entrepreneurs produce homogeneous intermediate goods using capital purchased form capital good producers and labour supplied by households. Furthermore, entrepreneurs can borrow to finance capital purchases.

Both patient and impatient households supply their differentiated labour services through labour unions which set their wages to maximise the members' utility. Labour is sold to a competitive intermediary who supplies undifferentiated labour services to entrepreneurs.

There are three stages of production. First, entrepreneurs produce homogeneous intermediate goods which are sold in perfectly competitive markets to retailers. Next, retailers brand them at no cost and sell differentiated intermediate goods in monopolistically competitive markets to aggregators. Finally, aggregators aggregate domestic intermediate differentiated goods and foreign differentiated goods into one final domestic good.

There are also capital good and housing producers. Those producers use final consumption goods to produce capital or housing with a technology that is subject to an investment adjustment cost. The adjustment cost allows for price of capital and housing to differ from the price of consumption goods.

In the financial sector there are lending and saving banks as well as lending and saving financial intermediaries. A saving financial intermediary purchases differentiated deposits from saving banks and sells undifferentiated deposits to households (a convenient way is to think of a deposit or a loan as a product). Similarly, the lending financial intermediary purchases differentiated loans from lending banks and sells undifferentiated loans to households or firms. In order to produce a deposit or a loan banks need to purchase a deposit or a loan at the interbank market at the interbank interest rate. There is also a central bank that controls the interbank interest rate using open market operations and keeps it at the level set according to a standard Taylor rule.

There are two types of frictions in the financial sector. First the interest rates on loans, savings and the interbank interest rate are different. The difference is due to technological reasons and is subject to external shocks. This is a convenient modelling device that allows to capture changes in interest rate spreads which took place during the recent credit crunch. Second, borrowers need collateral to take a loan either in the form of housing or capital. The restrictiveness of this constraint is perturbed stochastically in the form of shock to the required LTV ratios. Again, this is a convenient modelling device that allows to introduce

into a DSGE model the recent change in loan granting policies in commercial banks. It should be noted that both types of financial disturbances enter our model exogeneously. This reflects the fact that financial shocks that affected Poland (as well as several other small open economies) were primarily driven by external developments.

2.1 Households and entrepreneurs.

The economy is populated by impatient households, patient households, and entrepreneurs of measure γ^I, γ^P, and γ^E, respectively (the measure of all agents in the economy is one $\gamma^I + \gamma^P + \gamma^E = 1$). The important difference between agents is the value of their discount factors. The discount factor of patient households β_P is higher than the discount factors of impatient households β_I. For simplicity we assume that entrepreneurs have the same discount factor as impatient households $\beta_E = \beta_I$.

2.1.1 Patient households.

The patient household ι chooses consumption c_t^P, the stock of housing χ_t^P and deposits D_t^H. The decision on the labour supply n_t^P is not made by the household but by a labour union, details of this decision are described later. The expected lifetime utility of a representative household is as follows

$$E_0 \sum_{t=0}^{\infty} \beta_P^t \varepsilon_{u,t} \left[\frac{\left(c_t^P\left(\iota\right) - \xi c_{t-1}^P\right)^{1-\sigma_c}}{1-\sigma_c} + \varepsilon_{\chi,t} \frac{\chi_t^P\left(\iota\right)^{1-\sigma_\chi}}{1-\sigma_\chi} - \varepsilon_{n,t} \frac{n_t^P\left(\iota\right)^{1+\sigma_n}}{1+\sigma_n} \right] \quad (1)$$

where ξ denotes the degree of external habit formation and $\varepsilon_{u,t}$, $\varepsilon_{\chi,t}$, $\varepsilon_{n,t}$ are, respectively, intertermporal, housing and labour preference shocks. These shocks have an $AR(1)$ representation with i.i.d. normal innovations[2].

The patient household uses labour income $W_t n_t^P$, dividends[3] Π_t^P and its deposits from the previous period D_{t-1} multiplied by the interest rate on household deposits $R_{D,t-1}^H$ to finance its consumption and housing expenditure, new deposits and lump sum taxes[4] T_t. The patient household faces the following budget constraint[5]

$$P_t c_t^P\left(\iota\right) + P_{\chi,t}\left(\chi_t^P\left(\iota\right) - \left(1-\delta_\chi\right)\chi_{t-1}^P\left(\iota\right)\right) + D_t^H\left(\iota\right) \leq W_t n_t^P\left(\iota\right)$$
$$+ R_{D,t-1}^H D_{t-1}^H\left(\iota\right) - T\left(\iota\right) + \Pi_t^P \quad (2)$$

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[2] The autoregressive coefficients are ρ_u, ρ_χ, and ρ_n while the standard deviations are σ_u, σ_χ, and σ_n, respectively.

[3] Patient households own all the firms in this economy.

[4] Lump sum taxes for convenience are paid only by patient households, since only for patient households Ricardian equivalence holds.

[5] The model is calibrated so that in the steady state and its neighbourhood patient households do not borrow, thus borrowing is excluded from the budget constraint.

where P_t and $P_{\chi,t}$ denote, respectively, the price of consumption good and the price of housing, δ_χ is the depreciation rate of the housing stock and $T(\iota)$ denotes taxes.

2.1.2 Impatient households.

Impatient households differently from patient households are borrowers not lenders in the neighbourhood of the steady state. A representative impatient household chooses consumption c_t^I, the stock of housing χ^I and loans L_t^H . Similarly as for patient households, labour supply decision is taken by a labour union. Impatient households maximise the following expected utility

$$E_0 \sum_{t=0}^\infty \beta_I^t \varepsilon_{u,t} \left[\frac{\left(c_t^I(\iota) - \xi c_{t-1}^I\right)^{1-\sigma_c}}{1-\sigma_c} + \varepsilon_{\chi,t} \frac{\chi_t^I(\iota)^{1-\sigma_\chi}}{1-\sigma_\chi} - \varepsilon_{n,t} \frac{n_t^I(\iota)^{1+\sigma_n}}{1+\sigma_n} \right] \tag{3}$$

Impatient households spending on consumption, accumulation of housing and debt payment $R_{L,t-1}^H L_{t-1}^H$ is financed by labour income $W_t n_t^I$, and new borrowing[6]. The budget constraint of the impatient household is

$$P_t c_t^I(\iota) + P_{\chi,t}\left(\chi_t^I(\iota) - (1-\delta_\chi)\chi_{t-1}^I(\iota)\right) + R_{L,t-1}^H L_{t-1}^H(\iota) \leq W_t n_t^I(\iota) + L_t^H(\iota) - T_t(\iota) \tag{4}$$

Furthermore impatient households face the following borrowing constraint

$$R_{L,t}^H L_t^H(\iota) \leq m_t^H E_t \left[P_{\chi,t+1}(1-\delta_\chi)\chi_t^I(\iota) \right] \tag{5}$$

where m_t^H is households loan-to-value ratio which follows an $AR(1)$ process with i.i.d. normal innovations[7].

2.1.3 Entrepreneurs.

Entrepreneurs draw utility only from their consumption c_t^E, their utility function has the following form

$$E_0 \sum_{t=0}^\infty (\beta_E)^t \left(\varepsilon_{u,t} \frac{\left(c_t^E(\iota) - \xi c_{t-1}^E\right)^{1-\sigma_c}}{1-\sigma_c} \right) \tag{6}$$

In order to finance consumption they run firms producing homogeneous intermediate goods $y_{W,t}$ with the following technology

$$y_{W,t}(\iota) = A_t \left[u_t(\iota) k_{t-1}(\iota) \right]^\alpha n_t(\iota)^{1-\alpha} \tag{7}$$

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[6]Note that impatient households do not own any firms thus they do not receive any dividends.

[7]The autoregressive coefficient is ρ_{m^H} and the standard deviation is σ_{m^H}.

where A_t is an exogenous $AR(1)$ process for the total factor productivity[8], $u_t \in [0, \infty)$ is the capital utilisation rate[9], k_t is the capital stock and n_t is the labour input. The capital utilisation rate can be changed but only at a cost $\psi(u_t) k_{t-1}$ which is expressed in terms of consumption units and the function $\psi(u)$ satisfies $\psi(1) = 0$, $\psi'(1) > 0$ and $\psi''(1) > 0$ (we assume no capital utilisation adjustment cost in the deterministic steady state). In order to finance their expenditure on consumption, labour services, capital accumulation, capital utilisation rate adjustment cost and repayment of debt $R^F_{L,t-1} L^F_{t-1}$ they use the revenue from their output sales and new loans L^F_t

$$P_t c^E_t (\iota) + W_t n_t (\iota) + P_{k,t} (k_t (\iota) - (1 - \delta_k) k_{t-1} (\iota)) + P_t \psi (u_t (\iota)) k_{t-1} (\iota)$$
$$+ R^F_{L,t-1} L^F_{t-1} (\iota) = P_{W,t} y_{W,t} (\iota) + L^F_t (\iota) - T_t (\iota) \quad (8)$$

where $P_{k,t}$ is the price of capital, $P_{W,t}$ is the price of the homogeneous intermediate good and δ_k is the depreciation rate of physical capital.

In a financial market entrepreneurs face the following borrowing constraint

$$R^F_{L,t} L^F_t (\iota) \leq m^F_t E_t \left[P_{k,t+1} (1 - \delta_k) k_t (\iota) \right] \quad (9)$$

where m^F_t is firm's loan-to-value ratio which follows an $AR(1)$ process with i.i.d. normal innovations[10].

2.1.4 Labour supply.

We assume that each household has a continuum of labour types of measure one, $h \in [0, 1]$. Moreover, for each type h there is a labour union that sets the wage for its labour type $W_t (h)$ and each household belongs to all of the labour unions (i.e. each union includes γ^P patients and γ^I impatiens). Labour services are sold to perfectly competitive aggregators who pool all the labour types into one undifferentiated labour service with the following function

$$n_t = \left((\gamma^I + \gamma^P) \int_0^1 n_t (h)^{\frac{1}{1+\mu_w}} \, dh \right)^{1+\mu_w} \quad (10)$$

The problem of the aggregator gives the following demand for labour of type h

$$n_t(h) = \frac{1}{\gamma^I + \gamma^P} \left[\frac{W_t (h)}{W_t} \right]^{\frac{-(1+\mu_w)}{\mu_w}} n_t \quad (11)$$

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[8]The autoregressive coefficient is ρ_A and the standard deviation is σ_A.

[9]u_t is normalised, so that the deterministic steady state capacity utilisation rate is equal to one.

[10]The autoregressive coefficient is ρ_{m^F} and the standard deviation is σ_{m^F}.

where

$$W_t = \left(\int_0^1 W_t(h)^{\frac{-1}{\mu_w}} dh \right)^{-\mu_w} \tag{12}$$

is the aggregate wage in the economy.

The union's discount factor is the weighted average of those of its members $\beta = \gamma^P/\left(\gamma^P + \gamma^I\right)\beta_P + \gamma^I/\left(\gamma^P + \gamma^I\right)\beta_I$. The union sets the wage rate according the the standard Calvo scheme, i.e. with probability $(1 - \theta_w)$ it receives a signal to reoptimise and then sets its wage to maximise the utility of its average member subject to the demand for its labour services and with probability θ_w does not receive the signal and indexes its wage according to the following rule

$$W_{t+1}(h) = ((1 - \zeta_w)\bar{\pi} + \zeta_w\pi_{t-1})W_t(h) \tag{13}$$

where $\bar{\pi}$ is the steady state inflation rate and $\zeta_w \in [0, 1]$.

2.2 Producers

There are three sectors in the economy: capital goods sector, housing sector and consumption goods sector. In the capital goods sector and the housing sector we have, respectively, capital goods producers and housing producers which operate in perfectly competitive markets. In the consumption goods sector we have the entrepreneurs described earlier, who sell their undifferentiated goods to retailers who brand those goods, thus differentiating them, and sell them to aggregators at home and abroad. Aggregators combine differentiated domestic intermediate goods and differentiated foreign intermediate goods into a single final good.

2.2.1 Capital Good Producers

Capital good producers operate in a perfectly competitive market and use final consumption goods to produce capital goods. In each period a capital good producer buys $i_{k,t}$ of final consumption goods and old undepreciated capital $(1 - \delta_k)k_{t-1}$ from entrepreneurs. Next she transforms old undepreciated capital one-to-one into new capital, while the transformation of the final goods is subject to adjustment cost $S_k(i_{k,t}/i_{k,t-1})$. We adopt the specification of Christiano, Eichenbaum, and Evans (2005) and assume that in the deterministic steady state there are no capital adjustment costs $(S_k(1) = S_k'(1) = 0)$, and the function is concave in the neighbourhood of the deterministic steady state $(S_k''(1) = \frac{1}{\kappa_k} > 0)$. Thus the technology to produce new capital is given by

$$k_t = (1 - \delta)k_{t-1} + \left(1 - S_k\left(\frac{i_{k,t}}{i_{k,t-1}}\right)\right)i_{k,t} \tag{14}$$

The new capital is then sold to entrepreneurs and can be used in the next period production process. The real price of capital is denoted as $p_{k,t} = P_{k,t}/P_t$.

2.2.2 Housing Producers

Housing producers act in a similar fashion as the capital good producers. The stock of new housing follows

$$\chi_t = (1 - \delta_\chi) \chi_{t-1} + S_\chi \left(\frac{i_{\chi,t}}{i_{\chi,t-1}} \right) i_{\chi,t} \tag{15}$$

where the function describing adjustment cost $S_\chi (i_{\chi,t}/i_{\chi,t-1})$ satisfies $S_\chi(1) = S_\chi'(1) = 0$ and $S_\chi''(1) = \frac{1}{\kappa_\chi} > 0$. The real price of capital is denoted as $p_{\chi,t} = P_{\chi,t}/P_t$.

2.2.3 Final Good Producers

Final good producers play the role of aggregators. They buy differentiated product from domestic retailers $y_{H,t}(j_H)$ and importing retailers $y_{F,t}(j_F)$ and aggregate them into a single final good, which they sell in a perfectly competitive market. The final good is produced according to the following technology

$$y_t = \left[\eta^{\frac{\mu}{1+\mu}} y_{H,t}^{\frac{1}{1+\mu}} + (1 - \eta)^{\frac{\mu}{1+\mu}} y_{F,t}^{\frac{1}{1+\mu}} \right]^{1+\mu} \tag{16}$$

where

$$y_{H,t} = \left(\int_0^1 y_{H,t}(j_H)^{\frac{1}{1+\mu_H}} dj_H \right)^{1+\mu_H} \tag{17}$$

$$y_{F,t} = \left(\int_0^1 y_{F,t}(j_F)^{\frac{1}{1+\mu_F}} dj_F \right)^{1+\mu_F} \tag{18}$$

and η is the home bias parameter. The problem of the aggregator gives the following demands for differentiated goods

$$y_{H,t}(j_H) = \left(\frac{P_{H,t}(j_H)}{P_{H,t}} \right)^{\frac{-(1+\mu_H)}{\mu_H}} y_{H,t} \tag{19}$$

$$y_{F,t}(j_F) = \left(\frac{P_{F,t}(j_F)}{P_{F,t}} \right)^{\frac{-(1+\mu_F)}{\mu_F}} y_{F,t} \tag{20}$$

where

$$y_{F,t} = (1 - \eta) \left(\frac{P_{F,t}}{P_t} \right)^{\frac{-(1+\mu)}{\mu}} y_t \tag{21}$$

$$y_{H,t} = \eta \left(\frac{P_{H,t}}{P_t} \right)^{\frac{-(1+\mu)}{\mu}} y_t \tag{22}$$

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and the price aggregates are

$$P_{H,t} = \left[\int P_{H,t}\left(j_H\right)^{\frac{-1}{\mu_H}} dj_H \right]^{-\mu_H} \tag{23}$$

$$P_{F,t} = \left[\int P_{F,t}\left(j_F\right)^{\frac{-1}{\mu_F}} dj_F \right]^{-\mu_F} \tag{24}$$

2.2.4 Domestic Retailers

There is a continuum of domestic retailers of measure one denoted by j_H. They purchase undifferentiated intermediate goods from entrepreneurs, brand them, thus transforming them into differentiated goods, and sell them to aggregators. They act in a monopolistically competitive environment and set their prices according to the standard Calvo scheme. In each period each domestic retailer receives with probability $(1 - \theta_H)$ a signal to reoptimise and then sets her price to maximise the expected profits or does not receive the signal and then indexes her price according to the following rule

$$P_{H,t+1}\left(j_H\right) = P_{H,t}\left(j_H\right)\left(\left(1 - \zeta_H\right)\bar{\pi} + \zeta_H \pi_{t-1}\right) \tag{25}$$

where $\xi_F \in [0,1]$.

2.2.5 Importing Retailers

Again there is a continuum of importing retailers of measure one denoted by j_F. Similarly as the domestic retailers, they purchase undifferentiated goods abroad and brand them, thus transforming them into differentiated goods, and sell them to aggregators. They operate in a monopolistically competitive environment and set their prices according to the standard Calvo scheme. We assume that prices are sticky in domestic currency, which is consistent with incomplete pass through. Prices are reoptimised with probability $(1 - \theta_F)$ and with probability θ_F prices are indexed according to the following rule

$$P_{F,t+1}\left(j_F\right) = P_{F,t}\left(j_F\right)\left(\left(1 - \zeta_F\right)\bar{\pi} + \zeta_F \pi_{t-1}\right) \tag{26}$$

where $\xi_F \in [0,1]$.

2.2.6 Exporting Retailers

There is a continuum of exporting retailers of measure one, denoted by j_H^*. Retailers purchase domestic undifferentiated goods, brand them and sell them abroad for a price $P_{H,t}^*\left(j_H^*\right)$, which is expressed in terms of foreign currency. We assume that prices are sticky in the foreign

currency. The demand for exported goods is given by

$$y_{H,t}^*(j_H^*) = \left(\frac{P_{H,t}^*\left(j_H^*\right)}{P_{H,t}^*}\right)^{\frac{-(1+\mu_{H^*})}{\mu_{H^*}}} y_{H,t}^* \tag{27}$$

where $y_H^*\left(j_H^*\right)$ denotes the output of the retailer j_H^*, $y_{H,t}^*$ is defined as

$$y_{H,t}^* = \left(\int_0^1 y_{H,t}^*\left(j_H^*\right)^{\frac{1}{1+\mu_H^*}} dj_H^*\right)^{1+\mu_H^*} \tag{28}$$

and $P_{H,t}^*$ as

$$P_{H,t}^* = \left[\int_0^1 P_{H,t}^*\left(j_H^*\right)^{\frac{-1}{\mu_{H^*}}} dj_H^*\right]^{-\mu_H^*} \tag{29}$$

Moreover, we assume that the demand abroad is given by

$$y_{H,t}^* = (1-\eta^*)\left(\frac{P_{H,t}^*}{P_t^*}\right)^{\frac{-(1+\mu_H^*)}{\mu_H^*}} y_t^* \tag{30}$$

Additionally, we assume that foreign demand, the interest rate and inflation follow AR(1) with normal, serially uncorrelated innovations[11].

Exporting retailers reoptimise their prices with probability $(1 - \theta_H^*)$ or index them according to the following formula

$$P_{H,t+1}^*\left(j_H^*\right) = P_{H,t}^*\left(j_H^*\right)\left((1-\zeta_H^*)\,\bar{\pi}^* + \zeta_H^*\pi_{t-1}^*\right) \tag{31}$$

with probability θ_H^*, where $\xi_H^* \in [0,1]$.

2.3   The financial Sector

Similarly as in the case of the goods producers, banking activity is divided into several steps. First, saving banks purchase deposit accounts (deposit account is a product, which is sold and bought) in the interbank market, next they brand them and sell to a financial saving intermediary. The financial saving intermediary purchases differentiated saving accounts aggregates them and sells them as an undifferentiated saving account to households. Similarly, credit banks take undifferentiated loans in the interbank market, brand them and sell them to a financial lending intermediary. The financial lending intermediary aggregates all differentiated loans into a single loan that is offered to either houesholds or firms. In the loan production there is specialisation and we have two parallel branches one that produces loans

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[11]The autoregressive coefficients are ρ_{π^*}, ρ_{y^*}, and ρ_{R^*} while the standard deviations are σ_{π^*}, σ_{y^*}, and σ_{R^*}, respectively. We allow for contemporaneous correlation between shocks.

for households an the other for firms (entrepreneurs).

In our model financial sector disturbances are completely exogenous. We believe that this way of introducing them into the model is justified from the point of view of our question. We are not investigating the potential sources of the recent credit crunch, but merely check the importance of financial sector disturbances to the recent credit crunch in Poland. As it was argued in the introduction, the crunch in Poland was driven by external developments and Polish financial institutions were in good shape on the onset of the crisis. Given these factors, we believe that modelling financial sector disturbances as exogenous shocks is justified.

2.3.1 Financial intermediaries

The financial savings intermediary collects deposits from households and deposits them in saving banks. In order to understand the problem of the intermediary it is convenient to think about the deposit as a product with a price $1/R_D$, where R_D is the interest rate on a given deposit. Thus the intermediary purchases differentiated deposits $D_t^H\left(i_D^H\right)$ with the interest rate $R_{D,t}^H\left(i_D^H\right)$ from all saving banks of measure one denoted as i_D^H, and aggregates them into one undifferentiated deposit D_t^H with the interest rate $R_{D,t}^H$ which is sold to households. The technology for aggregation is

$$D_t^H = \left[\int_0^1 D_t^H\left(i_D^H\right)^{\frac{1}{1+\mu_D}} di_D^H\right]^{1+\mu_D} \tag{32}$$

Saving intermediaries operate in a competitive environment and take the interest rates as given and maximise profits given by the formula

$$\frac{1}{R_{D,t}^H}D_t^H - \int_0^1 \frac{1}{R_{D,t}^i\left(i_D^H\right)}D_t^H\left(i_D^H\right)di_D^H \tag{33}$$

subject to (32).

There are two types of lending intermediaries, one that offers loans to households and one that offers loans to firms (entrepreneurs). There is one important difference between the lending and saving intermediaries: for the lending intermediary the price of credit is the interest rate, not its inverse as in case of the saving intermediary. Next, we describe the behaviour of the lending intermediary for households. Since, the behaviour of the lending intermediary for firms is identical, one needs just to replace superscript H with F. Intermediaries for households offer loans L_t^H to households at the interest rate $R_{L,t}^H$ which are financed by loans from lending banks $L_t^H\left(i_L^H\right)$ of measure one denoted as i_L^H at the interest rate $R_t^H\left(i_L^H\right)$. The technology for aggregation is

$$L_t^H = \left[\int_0^1 L_t^H\left(i_L^H\right)^{\frac{1}{1+\mu_L^H}} di_L^H\right]^{1+\mu_L^H} \tag{34}$$

Lending intermediaries operate in a competitive market thus they take the interest rates as given and maximise profits given by

$$R_{L,t}^H L_t^H - \int_0^1 R_{L,t}^H \left(i_L^H\right) L_t^H \left(i_L^H\right) di_L^H \tag{35}$$

subject to (34).

Solving the problems above we get the demand for the banks' products (deposits or loans)

$$D_t^H(i_D^H) = \left(\frac{R_{D,t}^H \left(i_D^H\right)}{R_{D,t}^H}\right)^{\frac{\left(1+\mu_D^H\right)}{\mu_D^H}} D_t^H, \tag{36}$$

$$L_t^H(i_L^H) = \left(\frac{R_{L,t}^H \left(i_L^H\right)}{R_{L,t}^H}\right)^{-\frac{\left(1+\mu_L^H\right)}{\mu_L^H}} L_t^H, \tag{37}$$

$$L_t^F(i_L^F) = \left(\frac{R_{L,t}^F \left(i_L^F\right)}{R_{L,t}^F}\right)^{-\frac{\left(1+\mu_L^F\right)}{\mu_L^F}} L_t^F, \tag{38}$$

and from the zero profit condition we get the interest rates

$$R_{D,t}^H = \left(\int_0^1 R_{D,t}^H \left(i_D^H\right)^{\frac{1}{\mu_D^H}} di_D^H\right)^{\mu_D^H}, \tag{39}$$

$$R_{L,t}^H = \left(\int_0^1 R_{L,t}^H \left(i_L^H\right)^{-\frac{1}{\mu_L^H}} di_L^H\right)^{-\mu_L^H}, \tag{40}$$

$$R_{L,t}^F = \left(\int_0^1 R_{L,t}^F \left(i_L^F\right)^{-\frac{1}{\mu_L^F}} di_L^F\right)^{-\mu_L^F}. \tag{41}$$

2.3.2 Saving banks

The saving bank i_D^H collects deposits from saving intermediaries $D_t^H \left(i_D^H\right)$ at the interest rate $R_{D,t}^H \left(i_D^H\right)$ and deposits them in the interbank market $D_{IB,t}^H \left(i_D^H\right)$ at the policy rate R_t. In order to introduce time varying spreads we assume that for each unit of deposits collected the bank can deposit at the interbank market $z_{D,t}^H$ units of deposit, where $z_{D,t}^H$ follows an $AR\left(1\right)$ process with mean one and i.i.d. normal innovations[12]. Thus

$$D_{IB,t}^H \left(i_D^H\right) = z_{D,t}^H D_t^D \left(i_D^H\right) \tag{42}$$

The bank operates in a monopolistically competitive environment with the demand function given by (36). We assume that the bank sets its interest rates according to the Calvo scheme,

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[12]The autoregressive coefficient is $\rho_{z_D^H}$ and the standard deviation is $\sigma_{z_H^D}$.

i.e. with probability $(1 - \theta_D)$ it receives a signal and reoptimises its interest rate and with probability θ_D it does not change the interest rate. Once the the bank receives the signal to reoptimise it sets its interest rate in order to maximise profits

$$E_t \sum_{s=0}^{\infty} \left(\beta_P \theta_D^{\frac{s}{s+1}} \right)^{s+1} \Lambda_{t,t+s+1}^P \left[R_{t+s} D_{IB,t+s}^H \left(i_D^H \right) - R_{D,t}^{H,new} \left(i_D^H \right) D_{t+s}^H \left(i_D^H \right) \right] \tag{43}$$

subject to the deposits demand (36) and (42). Note that $(\beta_P)^{s+1} \Lambda_{t,t+s+1}^P$ is the discount factor taken from the problem of patient households (who own the bank) between period t and $t + s + 1$. Moreover, we put the " $+ 1$" term because the payments on the deposits are made one period after the deposit is collected.

2.3.3 Lending banks

There are two types of lending banks both of measure one, one that lends to households i_L^H and one that lends to firms i_L^F. Here we describe the problem of the former, the problem of the latter is identical (it is enough to replace the superscript H with F in the formulas). The lending bank i_L^H takes loans in the interbank market $L_{IB,t}^H \left(i_L^H \right)$ at the policy rate R_t, and uses those resources to make loans to lending intermediaries $L_t^H \left(i_L^H \right)$ at the interest rate $R_{L,t}^H \left(i_L^H \right)$. In order to introduce time varying spreads, again we assume that for each unit of credit taken in the interbank market $z_{L,t}^H$ units of loans can be made, where $z_{D,t}^H$ follows an $AR(1)$ process with mean one and i.i.d. normal innovations[13]. Thus

$$L_t^H \left(i_L^H \right) = z_{L,t}^H L_{IB,t}^H \left(i_L^H \right) \tag{44}$$

The bank operates in a monopolistically competitive market with the demand function given by (37). Moreover, we assume that the interest rates are set according to the Calvo scheme. Thus, the bank receives a signal to reoptimise its interest rate with probability $(1 - \theta_L)$. If the bank receives a signal it sets its interest rate in order to maximise profits

$$E_t \sum_{s=0}^{\infty} \left(\beta_P \theta_L^{\frac{s}{s+1}} \right)^{s+1} \Lambda_{t,t+s+1}^P \left[R_{L,t}^{H,new} \left(i_L^H \right) L_{t+s}^H \left(i_L^H \right) - R_{t+s} L_{IB,t+s}^H \left(i_L^H \right) \right] \tag{45}$$

subject to the deposits demand (37) and (44), otherwise it does not change its interest rate. Again the bank is owned by patient households thus the discount $(\beta_P)^{s+1} \Lambda_{t,t+s+1}^P$ is taken from the patient household's problem.

Note that since the interbank interest rate is set by the central bank according to a Taylor rule (as described in section 2.5) the interbank market is cleared by the central bank through open market operations. Thus there is no market clearing condition in this market

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[13]The autoregressive coefficient is $\rho_{z_L^H}$ and the standard deviation is $\sigma_{z_L^D}$.

(it is replaced by a Taylor rule).

Since our economy is open banks have also access to the foreign interbank market subject to a a risk premium ρ_t that is a function of the foreign debt to GDP ratio (as in Schmitt-Grohe and Uribe, 2003)

$$\rho_t = \exp\left(-\varrho\frac{e_t L_t^*}{P_t \tilde{y}_t}\right)\varepsilon_{\rho,t} \tag{46}$$

where e_t denotes the nominal exchange rate, L_t^* foreign debt, $\tilde{y}_t$ GDP and $\varepsilon_{\rho,t}$ are i.i.d. normal innovations (the standard deviation is σ_ρ). This gives rise to the standard uncovered interest parity condition (UIP) which in loglinearised version is presented in equation (A.34).

2.4 The government

The government uses lump sum taxes to finance government expenditure. The government's budget constraint in this economy is given by

$$G_t = T_t. \tag{47}$$

Since in our framework Ricardian equivalence holds there is no need to introduce government debt. Moreover, we assume that government expenditures are driven by a simple autoregressive process

$$G_t = \rho_g \mu_g + (1 - \rho_g) G_{t-1} + \varepsilon_{g,t}. \tag{48}$$

with i.i.d. normal innovations (the standard deviation is σ_g).

2.5 The central Bank

As it is common in the new Keynesian literature, we assume that monetary policy is conducted according to a Taylor rule that targets deviations from the deterministic steady state inflation and GDP, allowing additionally for interest rate smoothing

$$R_t = \left(\frac{R_{t-1}}{\bar{R}}\right)^{\gamma_R}\left(\left(\frac{\pi_t}{\bar{\pi}}\right)^{\gamma_\pi}\left(\frac{\tilde{y}_t}{\bar{\tilde{y}}}\right)^{\gamma_y}\right)^{1-\gamma_R}e^{\varphi_t} \tag{49}$$

where $\pi_t = \frac{P_t}{P_{t-1}}$, and φ_t are i.i.d. normal innovations (the standard deviation is σ_R). It's worth noting that the Taylor rule plays a key role in bringing stability to the model and determining the reaction of the model economy to exogenous shocks[14].

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[14]For discussion see Carlstrom and Fuerst (2005).

2.6   Market Clearing, Balance of Payments and GDP.

To close the model we need the market clearing conditions for the final and intermediate goods markets and the housing market as well as the balance of payments and the GDP equations. In the final goods market we have

$$c_t + i_{k,t} + i_{\chi,t} + g_t + \psi\left(u_t\right)k_{t-1} = y_t \tag{50}$$

where

$$c_t = \gamma^I c_t^I + \gamma^P c_t^P + \gamma^E c_t^E \tag{51}$$

Next, the market clearing condition in the intermediate homogeneous goods market is

$$\int_0^1 y_{H,t}(j)dj + \int_0^1 y_{H,t}^*(j)dj = y_{W,t} \tag{52}$$

Finally, the market clearing condition in the housing market is given by

$$\gamma^P \chi_t^P + \gamma^I \chi_t^I = \chi_{t-1} \tag{53}$$

The balance of payments (in home currency) has the following form

$$\int_0^1 \left(1 + \tau_F\right) P_{F,t}\left(j_F\right) y_{F,t}(j_F)dj_F + e_t R_{t-1}^* \rho_{t-1} L_{t-1}^*$$
$$= \int_0^1 \left(1 + \tau_H^*\right) E_t P_{H,t}^*\left(j_H^*\right) y_{H,t}^*(j_H^*)dj_H^* + e_t L_t^* \tag{54}$$

GDP is defined as follows

$$P_t \tilde{y}_t = P_t y_t + \int_0^1 e_t P_{H,t}^*(j_H^*)y_{H,t}^*(j_H^*)dj_H^* - \int_0^1 P_{F,t}(j_F)y_{F,t}(j_F)dj_F \tag{55}$$

where $\tilde{y}$ denotes GDP.

3   Calibration and estimation

3.1   Calibration Procedure

Conforming to the practice of bringing DSGE models to the data (Smets and Wouters, 2003; Adolfson, Laséen, Lindé, and Villani, 2005)) we partly calibrate and partly estimate the parameters. The calibrated parameters are mainly steady state ratios, that can be relatively easily found in the data and parameters that have been well established in the literature and which have previously been found to be weakly identified in the data. Where

it applies, parameters are presented as quarterly numbers.

We calibrate the rate of time preference for patient consumers to $\beta^P = 0.995$ to match the annual real rate on deposits of 2%. The rate of time preference for impatient consumers and entrepreneurs is set to $\beta^I = \beta^E = 0.975$ to make sure that the lending constraint is binding in the steady state. Depreciation rates of capital and housing are set to $\delta^k = 0.025$ and $\delta^\chi = 0.0125$ respectively. The steady state loan to value ratios are calibrated to the long-term averages coming respectively from bank surveys (household LTV) and corporate reports (enterprise LTV), so that $\bar{m}^H = 0.7$ and $\bar{m}^F = 0.2$. The inflation targets of the NBP and ECB have been set to 0.00625 and 0.005 implying annual inflation rates of 2.5% and 2% respectively. The elasticity of production with respect to capital is set to $\alpha = 0.3$, consistent with most of the DSGE literature. Further, as in Gerali, Neri, Sessa, and Signoretti (2009) we assume equal measures γ^P, γ^I and γ^E for patient and impatient households and entrepreneurs. The parameter μ is set to 1, so that the Armington elasticity of substitution between domestic and foreign goods equals $\frac{1+\mu}{\mu} = 2$ (Ruhl, 2005), and the home bias parameter is set to $\eta = 0.45$ consistent with the export to absorption ratio in Poland in the recent years. The parameter μ_w in the labour aggregator was set to 0.1 implying a steady state markup over wages of 10%. The steady state loan to GDP ratios are set to $\frac{\bar{l}^H}{\bar{y}} = .05$ and $\frac{\bar{l}^F}{\bar{y}} = .06$, reflecting the GDP ratio of new household and enterprise loans granted during a quarter. It should be noted that this is much less than the stock of outstanding loans, but in our view this reflects better the notion of flow of credit embedded in the model. Due to the disinflation process in Poland steady state interest rate levels are set according to average values in the period of stable inflation. The steady state export, import, consumption, investment, housing investment and foreign debt to GDP ratios were calibrated for Poland consistent with long-term averages. The remaining calibrated parameters are derived from from steady state relationships. The most important calibrated parameters and the steady state ratios have been collected in Tables 1 and 2.

3.2 Data and estimation

We fit the model to the data using fourteen macroeconomic time series. These cover the period 1q1997-2q2009 giving $T = 50$ quarterly observations. Eleven time series cover the Polish economy, these are real GDP, real private consumption, real government expenditure, real investment, consumer price inflation (HICP), money market interest rate (WIBOR3M), spreads between the money market rate and household deposit, household credit and enterprise credit interest rates and real new loans to households and enterprises. Three time series cover the euro area: real GDP, HICP inflation and the money market rate (EURIBOR3M). National account variables have been taken in logs, seasonally adjusted and detrended using the HP filter. Inflation rates were seasonally adjusted. Due to the disinflation process Polish data on inflation and the interest rate were also detrended. All data comes from the Eurostat

database, except for loans which come from the NBP.

The model has been estimated using Bayesian estimators. Such approach allows for providing additional information via prior distributions, something important and common in DSGE model estimation. Choosing parameters of the prior distribution we relied on the existing DSGE literature, in particular its applications for Poland (Smets and Wouters, 2003; Kolasa, 2008; Gradzewicz and Makarski, 2008). We assumed that the elasticity of intertemporal substitution for housing is probably higher than for consumption and set their prior mean values to 4 and 2 respectively. Prior means of all Calvo probability parameters were set to 0.6, of indexation rates to 0.5 and of autocorrelation of shocks to 0.7 (government consumption shock is an exception, since its d.g.p. has been defined differently). Prior means for the monetary policy rule were set at standard (Taylor, 1993) values. Priors for standard deviations were mainly set to 0.1 as is common in the literature. In three cases the prior distributions had to be tightened, since the posterior estimates diverged substantially from our prior knowledge. First, the estimate of ϕ_y was consistently close to zero, which in our view reflected the fact that our sample contained a long period of disinflation where the central bank payed relatively less attention to output performance than under current inflation targeting policy. Second, the estimates of ρ_{m^H} and ρ_{m^F} were estimated above 0.9, which was inconsistent with the data from Senior Loan Officer Surveys.

Regarding shock processes, the prior means of standard deviations for euro area shocks as well as domestic policy shocks and shocks to interest rate spreads were set to 0.01. The prior standard deviations of several other domestic shocks were set to higher values reflecting the findings in Kolasa (2008), where the substantially higher variance of the Polish economy is attributed to stronger shocks. Finally, we allowed for the euro area shocks to be correlated, reflecting their non-structural nature. The mean of the correlation coefficients has been agnostically set to zero.

The estimation was performed as follows. First, the modes of the posterior distributions have been found using Cris Sim's csminwel procedure. Next we applied the Metropolis-Hastings algorithm with five blocks each of 200.000 replications to approximate the complete posterior distribution. Since the average acceptance rates amounted to 24-26% and diagnostic tests of Brooks and Gelman (1998) confirmed convergence of the Markov chains, we used the second half of the draws to calculate posterior distributions. These, together with the assumptions about the priors have been collected in Tables 3 and 4.

We find relatively high persistence of shocks with autocorrelation coefficients ranging from 0.5 to 0.9. This is in line with both international and Polish findings (e.g. Smets and Wouters, 2003, Grabek, Kłos, and Utzig-Lenarczyk, 2007). Regarding nominal rigidities we find relatively more price than wage stickiness, and very low indexation parameters. The estimated stickiness in retail interest rates is non-negligible and is similar for loans and deposits. The mean value of the Calvo parameter of 0.5 implies an average period of 2

quarters between interest rate adjustments. This is lower than for wages and prices and is probably related to the fact that many interest rates are automatically indexed to the money market rate in Poland. From the Taylor rule only the coefficient of inertia is clearly identified in the data while the remaining parameters are estimated very close to their prior values. This may result from a change in the monetary policy regime, which until approximately 2002 was oriented on disinflation- rather that inflation targeting. As expected the correlation coefficients between euro area shocks are correlated with mean values ranging from .29 to .84.

3.3 Impulse Response Functions

Figures 3 to 7 plot the impulse responses to various shocks together with 95% confidence intervals.

Figure 3 shows that following a positive monetary policy shock that leads to the increase in the interest rate we observe a decline in the spreads on loans (due to the stickiness of the interest rates) and a decline in loans both to households and firms. This results in a fall of consumption and investment which leads to a decline in output and inflation.

Turning to Figure 4 we can see the adjustments that take place after a positive shock to the spread on loans to households. This shock leads to an increase of the interest rate on loans to households and, consequently, to a decline in loans to households which translates into a fall in consumption. Eventually, GDP, inflation and interest rates fall. The expectations of the fall in the interest rates lead the initial increase of investments. The increase of investments initially outweights the effect of the consumption decline (which declines slowly) and GDP increases but after a while the decline in consumption brings GDP down. Inflation initially goes up and then down. The interest rate falls after the initial increase.

Figure 5 shows the response of the economy to a positive shock to the spread on loans to firms. It leads to a decline of loans to firms, and thus a drop in investment. There is also a small increase in loans to households which results in a small increase in consumption, but it is quantitatively not important since it is outweighted by the decline of investment. Thus, GDP falls. The increasing spread on loans to firms raises the cost of borrowing for producers and production costs which translates into an increase in inflation. Given the opposite direction of GDP and inflation reaction, monetary policy reacts with only a marginal tightening.

Figure 6 shows the impact of a positive shock to the LTV for households. First, it increases loans to household and thus, consumption. There is also a quantitatively unimportant effect on loans to firms and investment. Rising consumption leads to an increase in GDP and inflation, which results in an increase in the interest rate.

Finally, we look at the response of the economy to a positive shock to the LTV for firms, which is shown in Figure 7. First, loosening of the credit constraint results in an increase

in loans to entrepreneurs. Since, the entrepreneurs know that the shock is temporary and they would not be able to sustain higher investment in the long run they initially mostly increase consumption and only slightly investment. Rising consumption and investment lead to higher GDP and inflation, which in turn result in a monetary policy tightening and reduces investment and consumption.

4   The crunch

As already noted in the introduction, there are reasons to suggest that shocks generated by the Polish banking sector could have contributed to the slowdown of the Polish economy during the financial crisis. In this section we use the estimated model to assess how strong this contribution was. As a first step we take a closer look at the historical decomposition of structural shocks. These have been collected in Figure 9. In our model there are five shocks that can be ascribed to the banking sector, two to loan-to-value ratios (m^H and m^F) and three to spreads (z_D^H, z_L^H and z_L^F). From eyeballing the Figure it becomes clear that during the last observed quarters, shocks to loan-to-value ratios assumed historical minima (note that the last observation on each graph is zero by construction, the last observed period (2q2009) is the last but one point). This is equivalent to a strong tightening of lending constraints by commercial banks. Regarding shocks to interest rate spreads, the evidence is less clear. We can observe some tightening in the case of deposit rates and household loans during the last few quarters, though these are not extreme compared to historical experience. It should be however noted, that the sample includes a period (late 1990's) when the competition in the Polish banking sector was relatively low, thus allowing for substantial swings in interest rate spreads. The shock decomposition does not reveal any substantial tightening in the case of spreads on enterprise loans. One more thing that is obvious from analysing the graphs are also the extremely strong negative shocks detected in the euro area. These affected all three foreign variables, output (y^*), inflation (π^*) and the interest rate (R^*). Not surprisingly, this suggests that the slowdown of the Polish economy was also caused by foreign factors.

To gain more insight into the impact of financial shocks on output we run a counterfactual scenario. To do this the model is solved in autoregressive form:

$$X_t = AX_{t-1} + Bu_t \tag{56}$$

where X_t is a vector of all endogenous variables, A and B are coefficient matrices and u_t is a vector of structural shocks. Given initial values X_0 and historical shocks (as presented in Figure 9), this allows for obtaining historical time series of all endogenous variables. Our counterfactual scenarios involve substituting zero values for selected shocks during the last four periods of our sample (3q2008-2q2009). However, since the impact of most shocks takes time to feed through to the economy (as can be observed from impulse response functions)

and the scenario involves changing most recent shocks, we extend our impact analysis for the consecutive 20 periods, running an unconditional forecast (assuming all shocks between periods $T+1$ and $T+20$ to be zero). We perform four scenarios, whose results are presented in Figures 10 - 13. The solid line shows the historical (model based smoothed estimate) time series of output and its unconditional forecast. The dashed line presents the counterfactual output series. The series deviate only from 3q2008, i.e. the point where shock histories start to differ. Finally, the dotted line shows the difference between the two previous lines which can be interpreted as the pure impact of the analysed scenario on output. The vertical line denotes the point where the historical data ends and the forecast begins.

Scenario 1 assumes the absence of shocks to interest rate spreads. It can be clearly seen that the contribution of these shocks to the slowdown was marginal. Scenario 2 assumes the absence of LTV shocks. These have a stronger contribution to the weakening of GDP. Scenario 3 adds the impact of the above scenarios to see the total contribution of shocks generated by the financial sector to the slowdown of the real economy in Poland. Obviously the impact is substantial though not overwhelming, banking sector shocks can explain approximately 1.3 percentage points of the decline in GDP. For comparison we also explore the impact of foreign shocks which intuitively played a dominant role in driving the slowdown. This hypothesis is confirmed by scenario 4 (Figure 13) which assumes the absence of foreign (output, inflation and interest rate) shocks during the period 3q2008-2q2009. Clearly these shocks had a much stronger contribution to the performance of the Polish economy than domestic banking sector shocks. According to our model the recession in the EU is responsible for a decline in Polish GDP of approximately 2.6 percentage points.

Our results differ from the finding in Gerali, Neri, Sessa, and Signoretti (2009) who report a dominating contribution of financial sector developments on euro area output. However, there are several arguments that help explain the difference. First, the role of banking intermediation in the euro area is much higher than in Poland. For instance the ratio of outstanding bank loans to GDP in 2008 was 116% in the euro area compared to 52% in Poland. This makes the Polish economy less prone to a credit crunch. Second, Poland is substantially more open to foreign trade than the euro area. For instance the ratio of exports and imports of goods to GDP in 2008 was 34% in the euro area compared to 70% in Poland. This makes Poland more prone to a fallout in external demand. Moreover, Gerali, Neri, Sessa, and Signoretti (2009) model a closed economy so the foreign channel is closed by construction there. Third, the euro area banking sector was probably to a larger extent affected by the financial crisis. While problems in Poland were mainly related to liquidity shortages on interbank markets, in the euro area several banks made huge losses on structurised assets which weakened their capital positions and lending abilities. This suggests that the tightening of lending could have been stronger in the euro area.

5 Conclusions

In this paper we construct a small open economy DSGE model with a banking sector. Both, households and firms are allowed to borrow, but their borrowing abilities are restricted by collateral requirements. The banking sector operates under monopolistic competition and is by itself generator of various shocks. These consist of shocks to interest rate margins and loan-to-value ratios. Our model is capable of generating significant and relatively persistent effects of frictions generated by the banking sector.

The model is then estimated to Polish data in order to answer the question about the role played by the banking sector in generating the slowdown during the financial crisis of 2008-09. Our findings show some role for financial shocks. A counterfactual scenario, assuming no shocks on the side of the banking sector in the period 3q2008-2q2009 shows that the Polish banking sector contributed 1.3 percentage points to the decline in real GDP. Moreover we find that the bulk of impact was generated by quantitative (LTV) rather than price (interest rate spread) shocks. Nevertheless this is still substantially less than the impact of foreign shocks, which are found to account for the major part of the slowdown.

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Tables and Figures

Table 1: Selected calibrated parameters of the model

Parameter	β^P	β^I	δ_k	δ_χ	μ	μ_w	η	α
Value	0.995	0.975	0.025	0.0125	1	0.1	0.45	0.3

Table 2: Selected steady state values of the model

Parameter	$\frac{\bar{l}^H}{\bar{y}}$	$\frac{\bar{l}^F}{\bar{y}}$	$\bar{m}^H$	$\bar{m}^F$	$\frac{\bar{c}}{\bar{y}}$	$\frac{\bar{i}}{\bar{y}}$	$\frac{\bar{i}_\chi}{\bar{y}}$	$\frac{\bar{l}}{\bar{y}}$	$\bar{R}$	$\bar{R}_L^H$	$\bar{R}_L^F$
Value	0.05	0.06	0.7	0.2	0.6	0.15	0.05	0.5	1.0125	1.025	1.017

Table 3: Prior and posterior distribution: structural parameters

Parameter	Prior distribution			Posterior distribution		
	type	Mean	St. Dev.	Mode	Mean	St. Dev.
ξ	beta	0.50	0.10	0.48	0.48	0.08
σ_χ	norm	4.00	0.50	3.87	3.92	0.51
σ_c	norm	2.00	0.50	2.34	2.39	0.41
σ_n	norm	4.00	0.50	3.91	3.95	0.50
κ_k	beta	0.10	0.05	0.31	0.32	0.05
κ_χ	beta	0.02	0.01	0.02	0.02	0.00
ψ	gamm	0.20	0.05	0.18	0.18	0.05
θ_W	beta	0.60	0.10	0.63	0.64	0.08
θ_H	beta	0.60	0.10	0.87	0.87	0.02
θ_F	beta	0.60	0.10	0.69	0.69	0.06
θ_D	beta	0.60	0.10	0.54	0.55	0.06
θ_L	beta	0.60	0.10	0.52	0.53	0.04
θ_H^*	beta	0.60	0.10	0.87	0.86	0.03
ζ_w	beta	0.50	0.10	0.55	0.54	0.10
ζ_H	beta	0.50	0.10	0.13	0.14	0.04
ζ_F	beta	0.50	0.10	0.17	0.19	0.05
ζ_H^*	beta	0.50	0.10	0.50	0.51	0.11
ϕ_R	beta	0.70	0.10	0.87	0.86	0.02
ϕ_π	norm	1.50	0.10	1.47	1.48	0.10
ϕ_y	norm	0.50	0.05	0.52	0.51	0.05

Table 4: Prior and posterior distribution: shocks

Parameter	Prior distribution			Posterior distribution		
	type	Mean	St. Dev.	Mode	Mean	St. Dev.
ρ_u	beta	0.70	0.10	0.81	0.80	0.06
ρ_χ	beta	0.70	0.10	0.72	0.71	0.11
ρ_n	beta	0.70	0.10	0.93	0.92	0.03
ρ_A	beta	0.70	0.10	0.76	0.75	0.05
ρ_ρ	beta	0.70	0.10	0.53	0.53	0.09
ρ_g	beta	0.30	0.10	0.38	0.39	0.05
ρ_{m^H}	beta	0.70	0.05	0.73	0.73	0.04
ρ_{m^F}	beta	0.70	0.05	0.74	0.74	0.04
$\rho_{z_D^H}$	beta	0.70	0.10	0.61	0.60	0.09
$\rho_{z_L^H}$	beta	0.70	0.10	0.67	0.66	0.09
$\rho_{z_L^F}$	beta	0.70	0.10	0.48	0.48	0.09
ρ_{π^*}	beta	0.70	0.10	0.51	0.52	0.10
ρ_{y^*}	beta	0.70	0.10	0.75	0.75	0.05
ρ_{R^*}	beta	0.70	0.10	0.89	0.88	0.03
σ_c	invg	0.05	Inf	0.060	0.065	0.012
σ_χ	invg	0.05	Inf	0.023	0.062	0.009
σ_n	invg	0.20	Inf	0.421	0.571	0.209
σ_A	invg	0.05	Inf	0.024	0.026	0.003
σ_ρ	invg	0.05	Inf	0.012	0.013	0.002
σ_R	invg	0.01	Inf	0.002	0.002	0.000
σ_g	invg	0.01	Inf	0.007	0.008	0.007
σ_{m^H}	invg	0.10	Inf	0.084	0.086	0.009
σ_{m^F}	invg	0.10	Inf	0.101	0.104	0.010
$\sigma_{z_D^H}$	invg	0.01	Inf	0.004	0.005	0.001
$\sigma_{z_L^H}$	invg	0.01	Inf	0.005	0.005	0.001
$\sigma_{z_L^F}$	invg	0.01	Inf	0.004	0.004	0.001
σ_{π^*}	invg	0.01	Inf	0.003	0.003	0.000
σ_{y^*}	invg	0.01	Inf	0.008	0.008	0.001
σ_{R^*}	invg	0.01	Inf	0.002	0.002	0.000
$corr_{\pi^* y^*}$	norm	0	0.5	0.39	0.33	0.16
$corr_{\pi^* R^*}$	norm	0	0.5	0.36	0.29	0.18
$corr_{R^* y^*}$	norm	0	0.5	0.88	0.84	0.04

Figure 1: Exports and GDP in Poland (y-o-y).
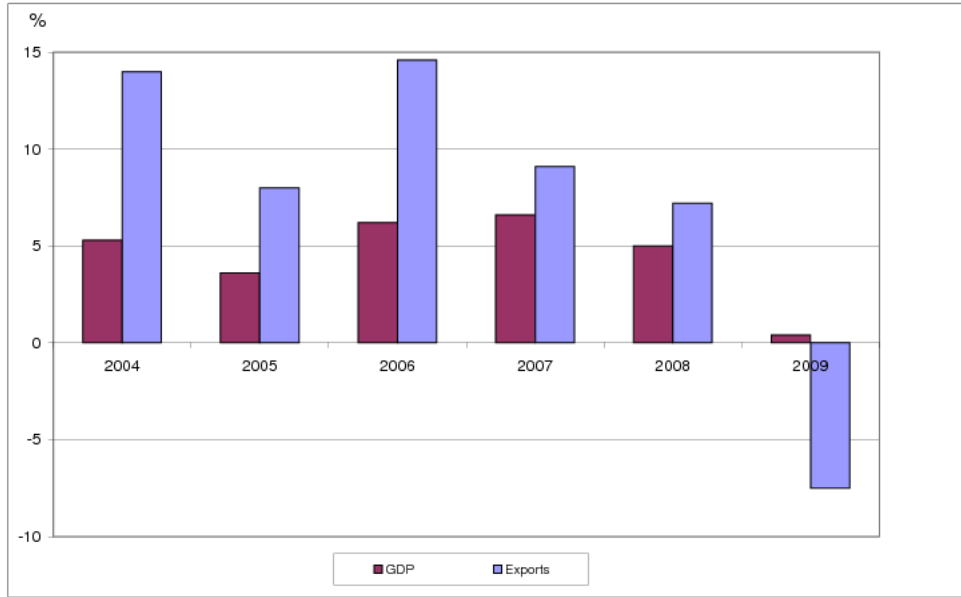
Source: Eurostat, NBP for 2009 forecast

Figure 2: New loans to households and entrepreneurs (PLN mn) and collateral requirements*.
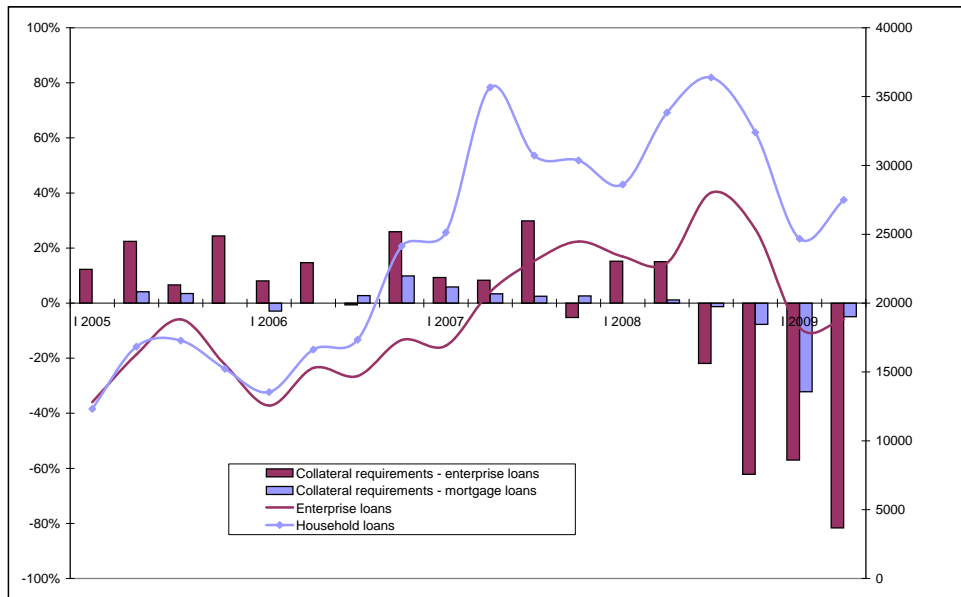
Source: NBP

Note: collateral requirements based on Senior Loan Officer Survey. The LTV series refer to the share of officers who claim less restrictive collateral requirements minus the share of those who claim more restrictive requirements, see NBP (2009b).
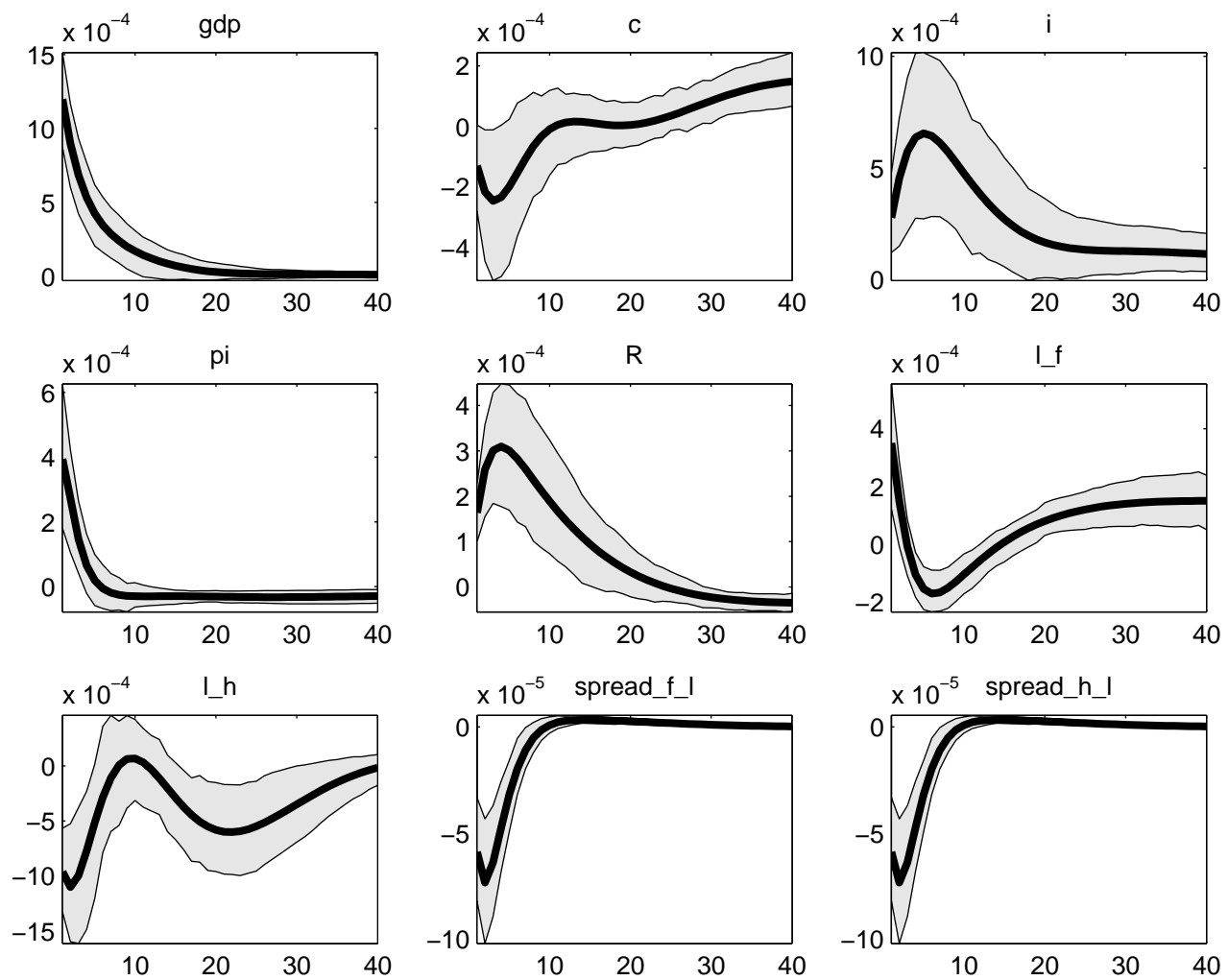
Figure 3: Impulse response to a monetary policy shock

Figure 4: Impulse response to a spread on household loans shock.
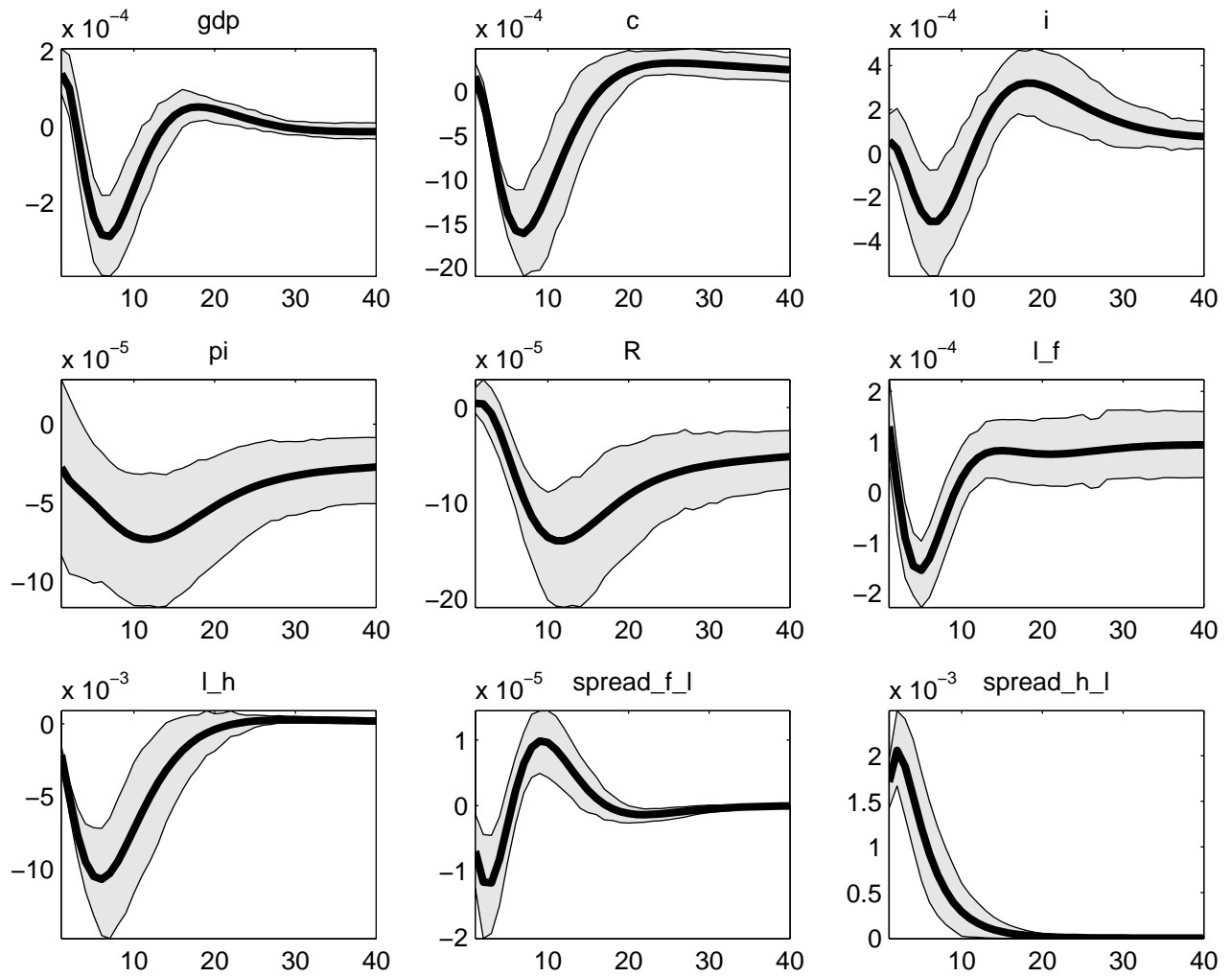
Figure 5: Impulse response to a spread on loans to firms shock.
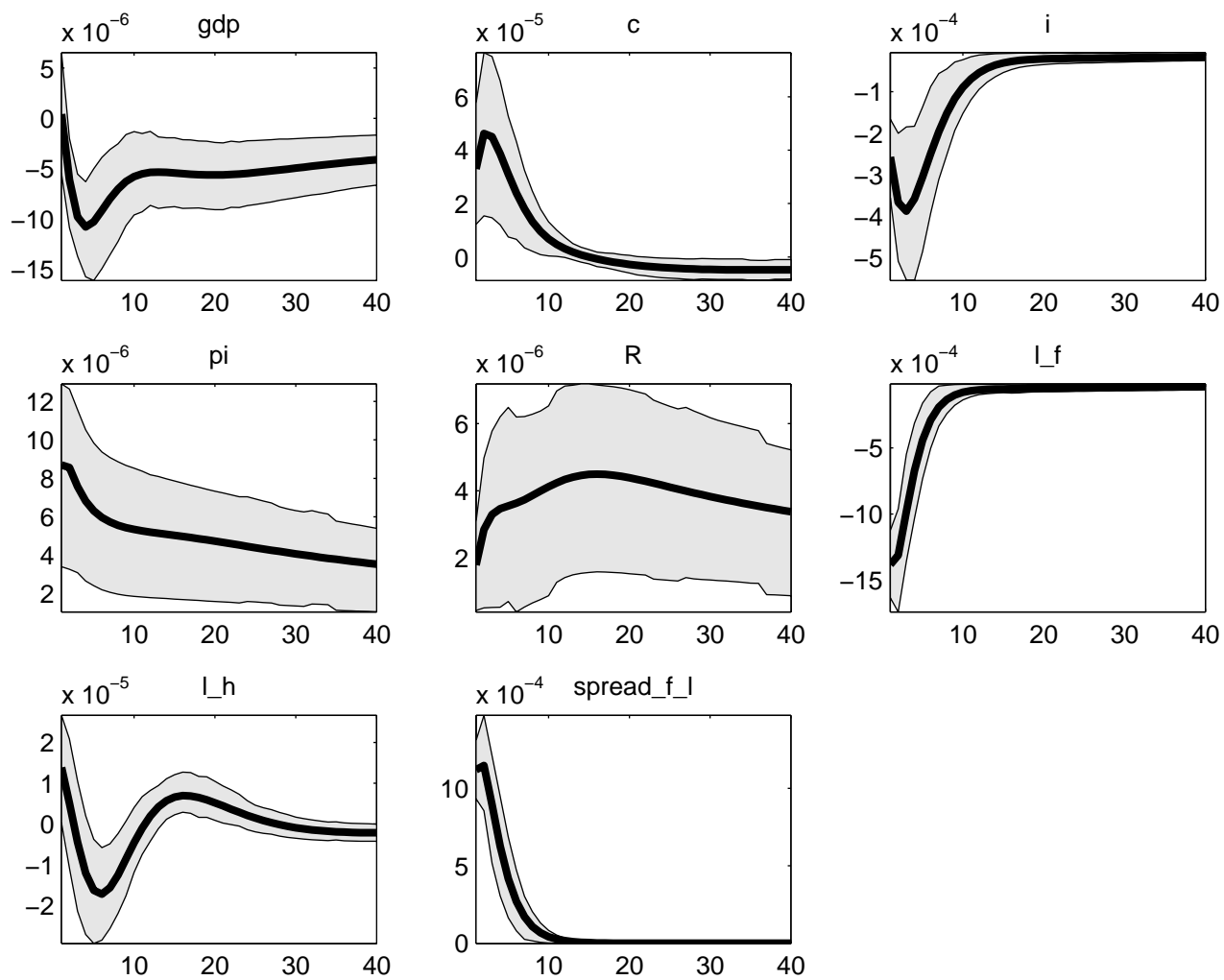
Figure 6: Impulse response to a households LTV shock
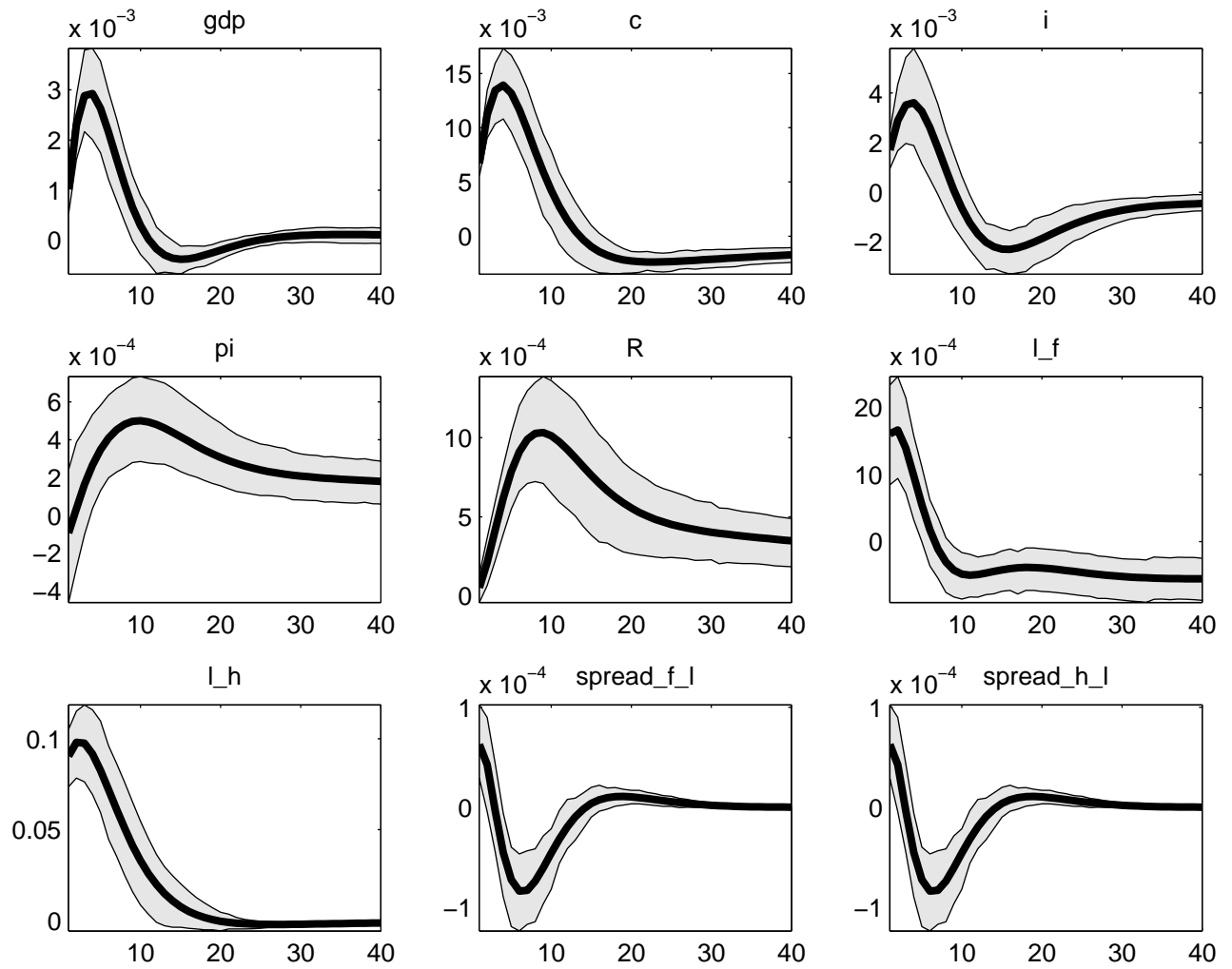
Figure 7: Impulse response to a firms LTV shock
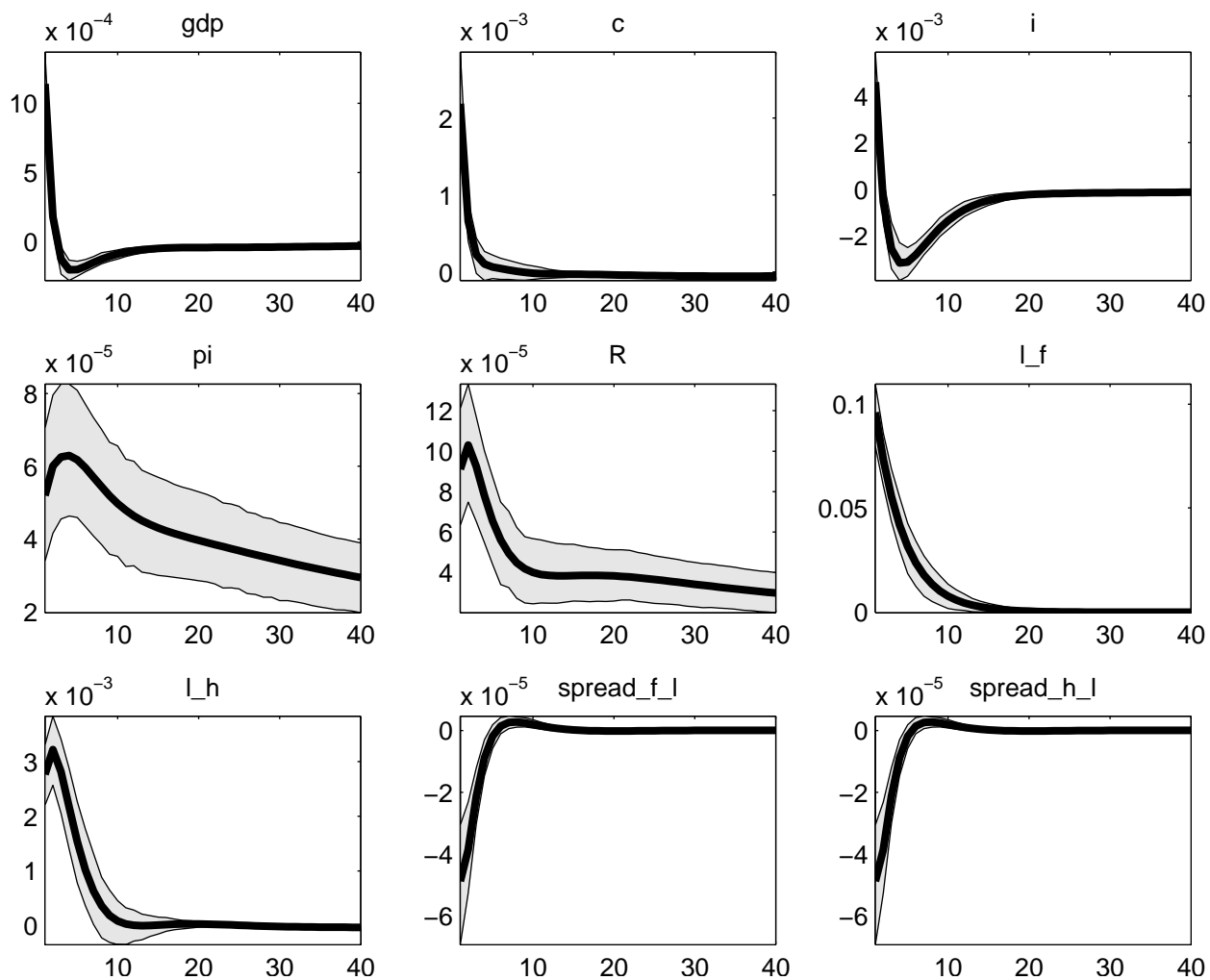
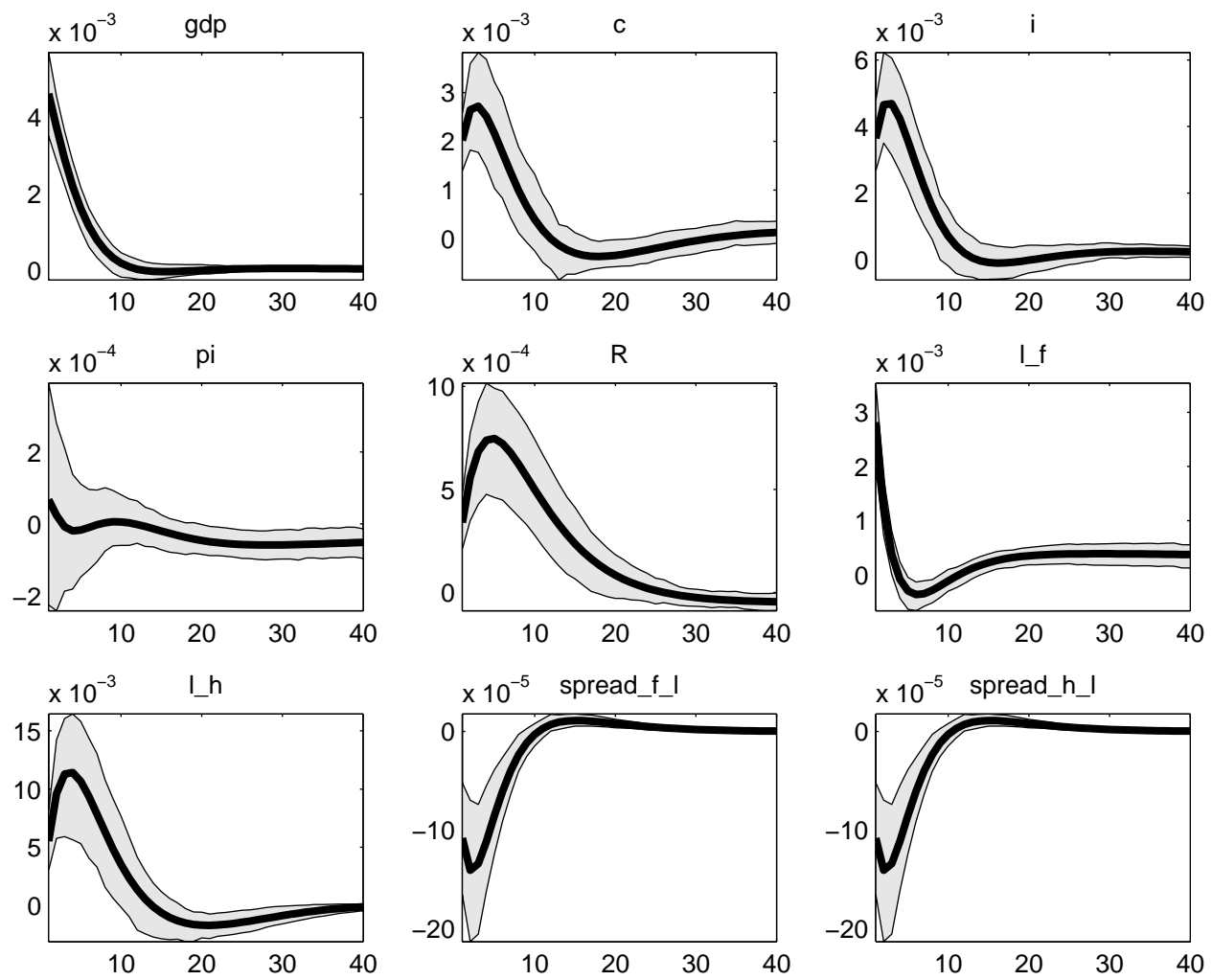Figure 8: Impulse response to a foreign demand shock.

Figure 9: Historical shocks.

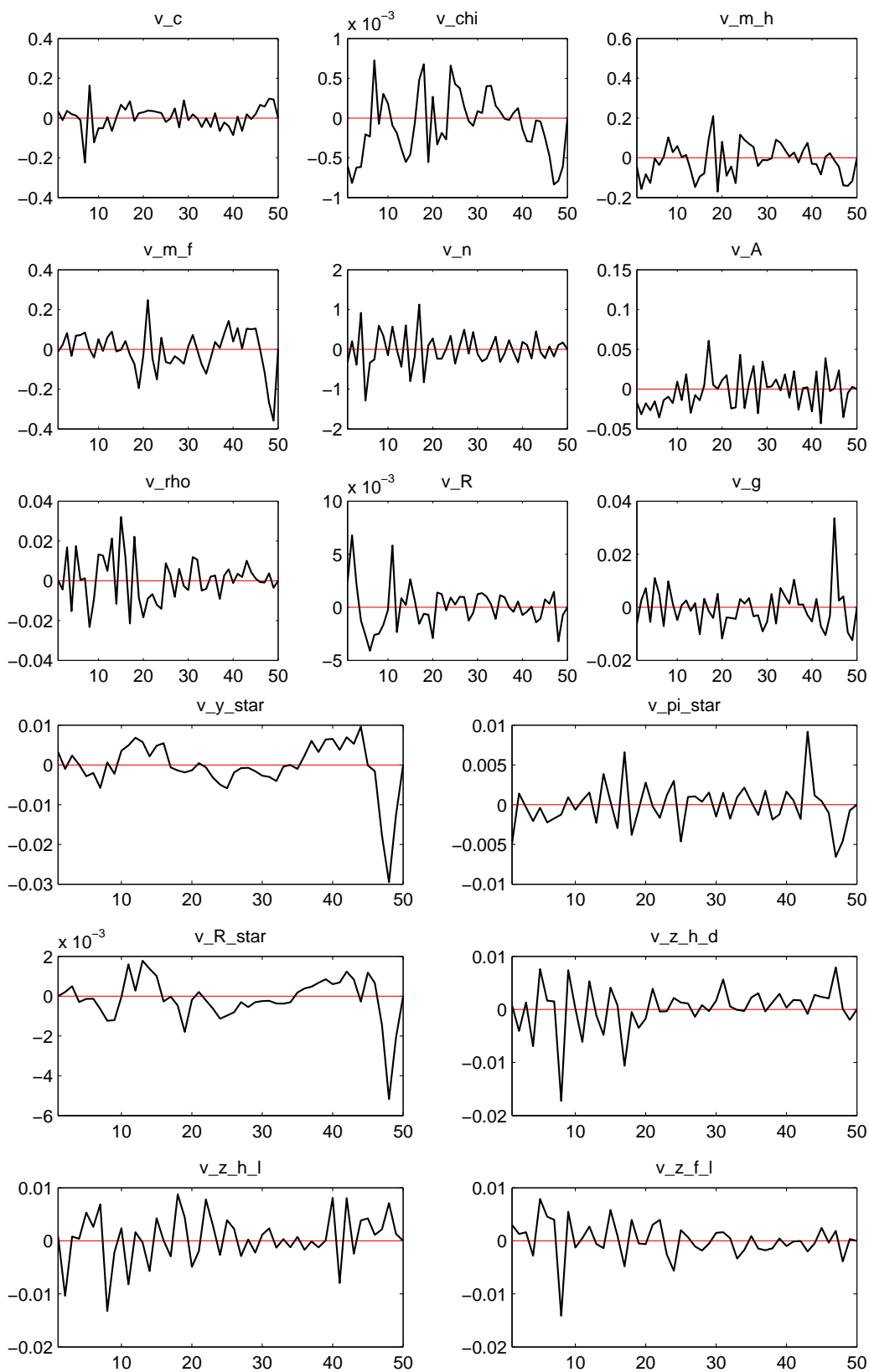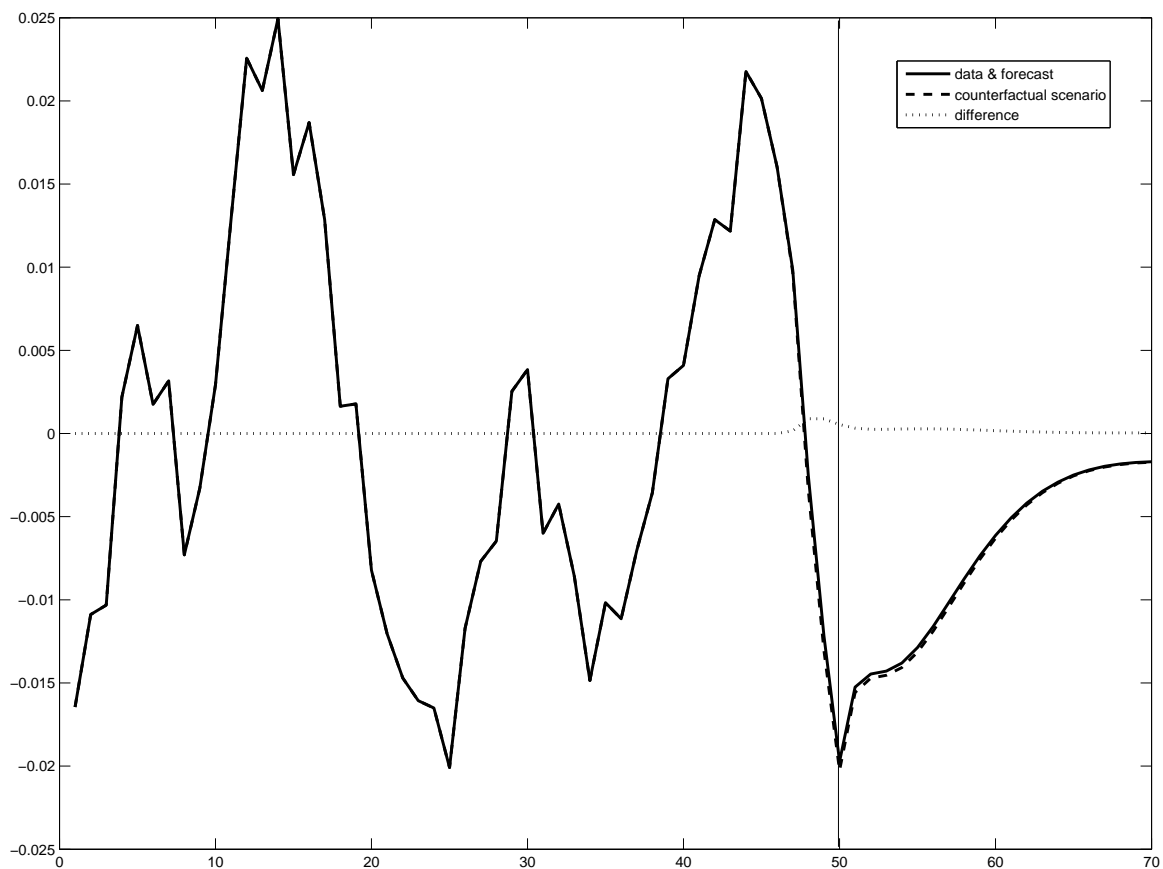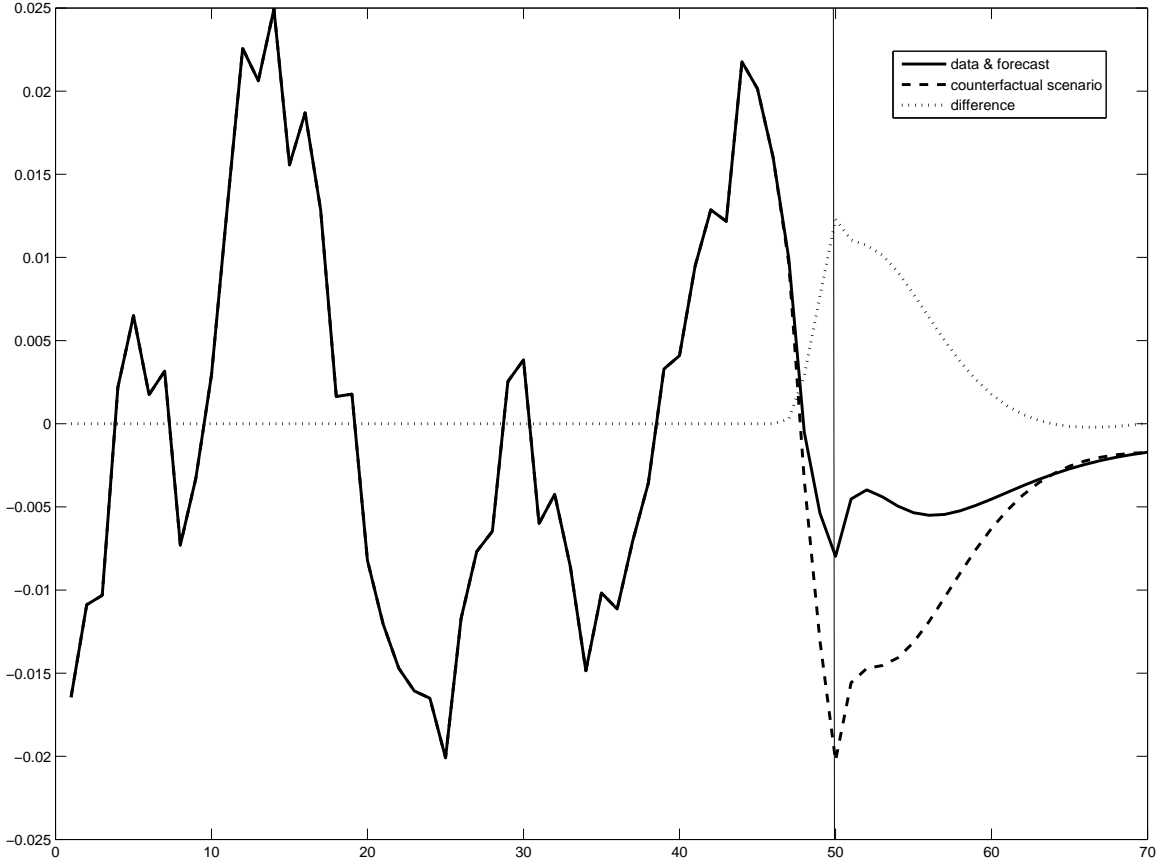Figure 10: Scenario 1. GDP with and without interest rate spread shocks after 3q 2008 (obs. 47), percentage deviations form steady state.
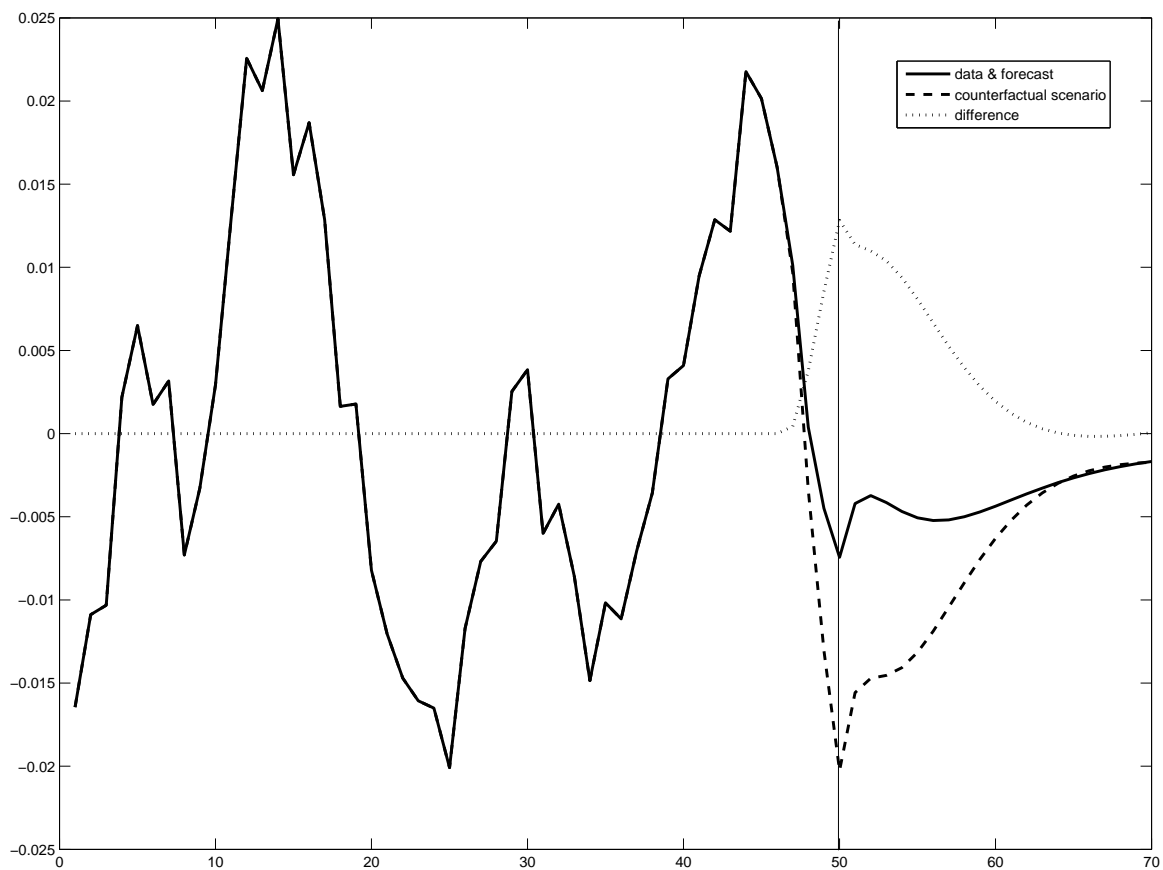

Note: vertical line denotes the end of sample and beginning of unconditional forecast.

Figure 11: Scenario 2. GDP with and without LTV ratios shocks after 3q 2008 (obs. 47), percentage deviations form steady state.
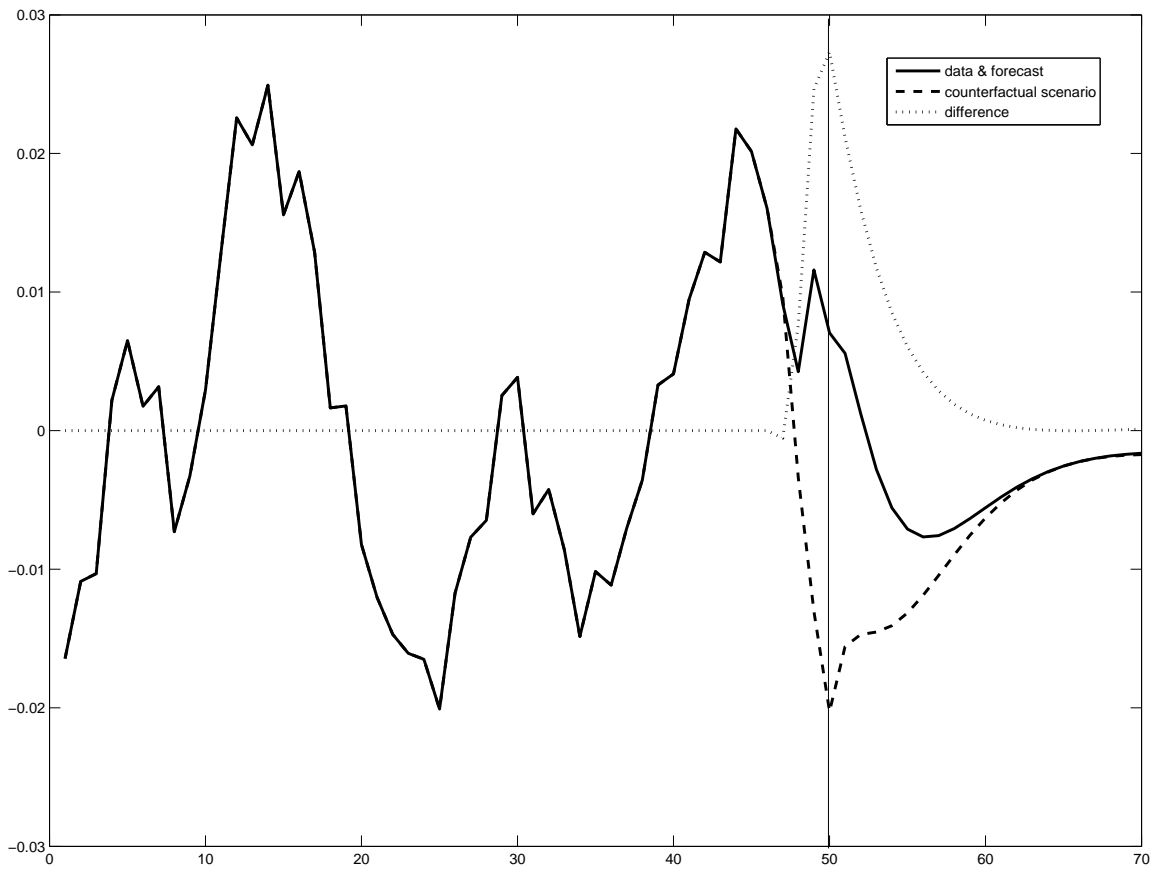

Note: vertical line denotes the end of sample and beginning of unconditional forecast.

Figure 12: Scenario 3. GDP with and without financial sector shocks (LTV ratios and spread shocks) after 3q 2008 (obs. 47), percentage deviations form steady state.

Note: vertical line denotes the end of sample and beginning of unconditional forecast.

Figure 13: Scenario 4. GDP with and without external shocks (foreign demand, int. rate and inflation shocks) after 3q 2008 (obs. 47), percentage deviations form steady state.

Note: vertical line denotes the end of sample and beginning of unconditional forecast.

A The log-linearised model

The bar above a variable denotes the deterministic steady state of the variable, while a hat denotes the log deviation from the the deterministic steady state i.e. $\hat{x}_t = \log x_t - \log \bar{x}$.

A.1 Households and entrepreneurs

Define marginal utilities for patient households, impatient households and entrepreneurs

$$\hat{u}^P_{c,t} = \frac{-\sigma}{1-\xi}\left(\hat{c}^P_t - \xi\hat{c}^P_{t-1}\right) + \hat{\varepsilon}_t \tag{A.1}$$

$$\hat{u}^I_{c,t} = \frac{-\sigma}{1-\xi}\left(\hat{c}^I_t - \xi\hat{c}^I_{t-1}\right) + \hat{\varepsilon}_t \tag{A.2}$$

$$\hat{u}^E_{c,t} = \frac{-\sigma}{1-\xi}\left(\hat{c}^E_t - \xi\hat{c}^E_{t-1}\right) + \hat{\varepsilon}_t \tag{A.3}$$

A.1.1 Patient households

From the patient households problem we obtain:

Euler equation

$$\hat{u}^P_{c,t} = E_t\left[\hat{u}^P_{c,t+1} + \hat{R}^H_{D,t} - \hat{\pi}_{t+1}\right] \tag{A.4}$$

Housing

$$\sigma_\chi\hat{\chi}^P_t = -\hat{u}^P_{c,t} - \hat{p}_{\chi,t} + \frac{\beta_P\left(1-\delta_\chi\right)}{1-\beta_P\left(1-\delta_\chi\right)}E_t\left[\hat{\pi}_{\chi,t+1} - \hat{R}^H_{D,t}\right] + \hat{\varepsilon}_{\chi,t} \tag{A.5}$$

A.1.2 Impatient households

Housing

$$\left(1 - \beta_I\left(1-\delta_\chi\right) + \left(\beta_I - \frac{\bar{\pi}}{\bar{R}^H_L}\right)\bar{m}^H\right)\left(\hat{\varepsilon}_{\chi,t} - \sigma_\chi\hat{\chi}^I_t\right) = \hat{u}_{c,t} + \hat{p}_{\chi,t} + \bar{m}^H\beta_I\left(E_t\hat{u}_{c,t+1}\right)$$

$$+ \left(\beta_I - \frac{\bar{\pi}}{\bar{R}^H_L}\right)\bar{m}^H\left(E_t\hat{p}_{\chi,t+1} + \hat{m}^H_t\right) - \bar{m}^H\frac{\bar{\pi}}{\bar{R}^H_L}\left(E_t\hat{\pi}_{t+1} + \hat{u}_{c,t} - \hat{R}^H_{L,t}\right)$$

$$- \left(1-\delta_\chi\right)\beta_I\left(E_t\hat{u}_{c,t+1} + E_t\hat{p}_{\chi,t+1}\right) \tag{A.6}$$

Borrowing Constraint

$$\hat{R}^H_{L,t} + \hat{l}^I_t = \hat{m}^H_t + E_t\left[\hat{p}_{\chi,t+1} + \hat{\pi}_{t+1}\right] + \hat{\chi}^I_t \tag{A.7}$$

Flow of funds (Budget Constraint)

$$\frac{\gamma^I \bar{c}^I}{\bar{\bar{y}}}\hat{c}_t^I + \frac{\gamma^I \bar{\chi}^I}{\bar{\chi}}\frac{\bar{i}_\chi}{\bar{\bar{y}}}\left(\hat{p}_{\chi,t} + \frac{1}{\delta_\chi}\hat{\chi}_t^I - \frac{1-\delta_\chi}{\delta_\chi}\hat{\chi}_{t-1}^I\right) + \frac{\bar{R}_L^H}{\bar{\pi}}\frac{\bar{l}^H}{\bar{\bar{y}}}\left(\hat{R}_{L,t-1}^H + \hat{l}_{t-1}^H - \hat{\pi}_t\right)$$
$$= \frac{\gamma^I \bar{w}\bar{n}}{\bar{\bar{y}}}\left(\hat{w}_t + \hat{n}_t^I\right) + \frac{\bar{l}^H}{\bar{\bar{y}}}\hat{l}_t^H - \gamma^I \frac{\bar{T}}{\bar{\bar{y}}}\hat{T}_t \quad \text{(A.8)}$$

A.1.3 Entrepreneurs

Labour demand
$$\hat{w}_t = \hat{p}_{W,t} + \hat{A}_t + \alpha\hat{u}_t + \alpha\left(\hat{k}_{t-1} - \hat{n}_t\right) \quad \text{(A.9)}$$

Capital utilisation
$$\hat{u}_t = \Psi^{-1}\left(\hat{p}_{W,t} + \hat{A}_t + (1-\alpha)\left(\hat{n}_t - \hat{u}_t - \hat{k}_{t-1}\right)\right) \quad \text{(A.10)}$$

where $\Psi = \frac{\psi''(1)}{\psi'(1)}$.

Euler

$$\hat{p}_{k,t} = (1-\delta_k)\beta_I E_t\left[\hat{p}_{k,t+1} + \left(\hat{u}_{c,t+1}^E - \hat{u}_{c,t}^E\right)\right] + \beta_I \psi'(1) E_t\left[\hat{u}_{c,t+1}^E - \hat{u}_{c,t}^E + \Psi\hat{u}_{t+1}\right]$$
$$+ \bar{m}^F(1-\delta_k)\bar{\pi}\left(\left(\frac{1}{\bar{R}_L^F} - \frac{\beta_I}{\bar{\pi}}\right)E_t\left[\hat{m}_t^F + \hat{p}_{k,t+1}\right]\right.$$
$$\left. - \frac{1}{\bar{R}_L^F}E_t\left[\hat{R}_{L,t}^F - \hat{\pi}_{t+1}\right] - \frac{\beta_I}{\bar{\pi}}E_t\left[\hat{u}_{c,t+1}^E - \hat{u}_{c,t}^E\right]\right) \quad \text{(A.11)}$$

Borrowing Constraint

$$\hat{R}_{L,t}^F + \hat{l}_t^F = \hat{m}_t^F + E_t\left[\hat{p}_{k,t+1}\right] + E_t\left[\hat{\pi}_{t+1}\right] + \hat{k}_t \quad \text{(A.12)}$$

Production Function

$$\hat{y}_{W,t} = \hat{A}_t + \alpha\left(\hat{u}_t + \hat{k}_{t-1}\right) + (1-\alpha)\hat{n}_t \quad \text{(A.13)}$$

Flow of funds

$$\frac{\gamma^E \bar{c}^E}{\bar{c}}\frac{\bar{c}}{\bar{\bar{y}}}\hat{c}_t^E = \frac{\bar{p}_W \bar{y}_W}{\bar{\bar{y}}}\left(\hat{p}_{W,t} + \hat{y}_{W,t}\right) + \frac{1-\delta_k}{\delta_k}\frac{\bar{i}}{\bar{\bar{y}}}\left(\hat{p}_{k,t} + \hat{k}_{t-1}\right) + \frac{\bar{l}^F}{\bar{\bar{y}}}\hat{l}_t^F - \frac{\bar{w}\bar{n}}{G\bar{D}P}\left(\hat{w}_t + \hat{n}_t\right)$$
$$- \frac{1}{\delta_k}\frac{\bar{i}}{\bar{\bar{y}}}\left(\hat{p}_{k,t} + \hat{k}_t\right) - \frac{\psi'(1)}{\delta_k}\frac{\bar{i}}{\bar{\bar{y}}}\hat{u}_t - \frac{\bar{R}_L^F}{\bar{\pi}}\frac{\bar{l}^F}{\bar{\bar{y}}}\left(\hat{R}_{L,t-1}^F + \hat{l}_{t-1}^F - \hat{\pi}_t\right) - \gamma^E \frac{\bar{T}}{\bar{\bar{y}}}\hat{T}_t \quad \text{(A.14)}$$

A.1.4 Labour supply

Wages

$$\frac{\theta_w}{1-\theta_w}\left(\hat{w}_t - \hat{w}_{t-1} + \hat{\pi}_t - \zeta_w\hat{\pi}_{t-1}\right) = \frac{1-\bar{\beta}\theta_w}{1+\sigma_n\frac{1+\mu_w}{\mu_w}}\left[-\hat{U}_{c,t} + \sigma_n\hat{n}_t + \hat{\varepsilon}_{n,t} - \hat{w}_t\right]$$

$$+ \frac{\bar{\beta}\theta_w}{1-\theta_w}E_t\left[\hat{w}_{t+1} - \hat{w}_t + \hat{\pi}_{t+1} - \zeta_w\hat{\pi}_t\right] \quad (A.15)$$

A.2 Producers

Denote $p_{H,t} = \frac{P_{H,t}}{P_t}$, $p_{F,t} = \frac{P_{F,t}}{P_t}$, $p_{H,t} = \frac{P_{H,t}^*}{P_t^*}$,

A.2.1 Capital Good Producers

Price of capital

$$\hat{i}_t = \frac{\kappa_k}{1+\beta}\hat{p}_{k,t} + \frac{\beta}{1+\beta}E_t\hat{i}_{t+1} + \frac{1}{1+\beta}\hat{i}_{t-1} \quad (A.16)$$

Capital accumulation

$$\hat{k}_t = (1-\delta_k)\,\hat{k}_{t-1} + \delta_k\hat{i}_{k,t} \quad (A.17)$$

A.2.2 Housing Producers

Price of housing

$$\hat{i}_{\chi,t} = \frac{\kappa_\chi}{1+\beta_P}\hat{p}_{k,t} + \frac{\beta_P}{1+\beta_P}E_t\hat{i}_{\chi,t+1} + \frac{1}{1+\beta_P}\hat{i}_{\chi,t-1} \quad (A.18)$$

Housing accumulation

$$\hat{\chi}_t = (1-\delta_\chi)\,\hat{\chi}_{t-1} + \delta_\chi\hat{\chi}_t \quad (A.19)$$

A.2.3 Final Good Producers

Production function

$$\hat{y}_t = \eta^{\frac{\mu}{1+\mu}}\left(\frac{\bar{y}_H}{\bar{y}}\right)^{\frac{1}{1+\mu}}\hat{y}_{H,t} + (1-\eta)^{\frac{\mu}{1+\mu}}\left(\frac{\bar{y}_F}{\bar{y}}\right)^{\frac{1}{1+\mu}}\hat{y}_{F,t} \quad (A.20)$$

Demand for domestic and imported intermediate goods.

$$\hat{y}_{H,t} = -\frac{1+\mu}{\mu}\left(\hat{p}_{H,t}\right) + \hat{y}_t \qquad \text{(A.21)}$$

$$\hat{y}_{F,t} = -\frac{1+\mu}{\mu}\left(\hat{p}_{F,t}\right) + \hat{y}_t \qquad \text{(A.22)}$$

Inflation.

$$\hat{\pi}_t = (1-\eta)\left(\bar{p}_F\right)^{\frac{-1}{\mu}}\left(\hat{\pi}_{F,t} + \hat{p}_{F,t-1}\right) + \eta\left(\bar{p}_H\right)^{\frac{-1}{\mu}}\left(\hat{\pi}_{H,t} + \hat{p}_{H,t-1}\right) \qquad \text{(A.23)}$$

A.2.4   Domestic Retailers

Domestic goods inflation

$$\hat{\pi}_{H,t} = \hat{\pi}_t + \hat{p}_{H,t} - \hat{p}_{H,t-1} \qquad \text{(A.24)}$$

Domestic goods prices

$$\frac{\theta_H}{1-\theta_H}\left(\hat{p}_{H,t} + \hat{\pi}_t - \hat{p}_{H,t-1} - \zeta_H\hat{\pi}_{t-1}\right) = (1-\beta_P\theta_H)\left(\hat{p}_{W,t} - \hat{p}_{H,t}\right)$$
$$+ \frac{\beta_P\theta_H}{1-\theta_H}E_t\left[\hat{p}_{H,t+1} - \hat{p}_{H,t} + \hat{\pi}_{t+1} - \zeta_H\hat{\pi}_t\right] \quad \text{(A.25)}$$

A.2.5   Importing Retailers

Imported goods inflation

$$\hat{\pi}_{F,t} = \hat{\pi}_t + \hat{p}_{F,t} - \hat{p}_{F,t-1} \qquad \text{(A.26)}$$

Imported goods prices

$$\frac{\theta_F}{1-\theta_F}\left(\hat{p}_{F,t} + \hat{\pi}_t - \hat{p}_{F,t-1} - \zeta_F\hat{\pi}_{t-1}\right) = (1-\beta_P\theta_F)\left(\hat{q}_t - \hat{p}_{F,t}\right)$$
$$+ \frac{\beta_P\theta_F}{1-\theta_F}E_t\left[\hat{p}_{F,t+1} - \hat{p}_{F,t} + \hat{\pi}_{t+1} - \zeta_F\hat{\pi}_t\right] \quad \text{(A.27)}$$

A.2.6   Exporting Retailers

Demand for exported intermediate goods

$$\hat{y}_{H,t}^* = -\frac{1+\mu_H^*}{\mu_H^*}\left(\hat{p}_{H,t}^*\right) + \hat{y}_t^* \qquad \text{(A.28)}$$

Exported goods inflation

$$\hat{\pi}^*_{H,t} = \hat{p}^*_{H,t} + \hat{\pi}^*_t - \hat{p}^*_{H,t-1} \tag{A.29}$$

Exported goods prices

$$\frac{\theta^*_H}{1-\theta^*_H}\left(\hat{p}^*_{H,t} + \hat{\pi}^*_t - \hat{p}^*_{H,t-1} - \zeta^*_H\hat{\pi}^*_{t-1}\right) = (1-\beta_P\theta^*_H)\left(\hat{p}_{W,t} - \hat{q}_t - \hat{p}^*_{H,t}\right)$$
$$+ \frac{\beta_P\theta^*_H}{1-\theta^*_H}E_t\left[\hat{p}^*_{H,t+1} - \hat{p}^*_{H,t} + \hat{\pi}^*_{t+1} - \zeta^*_H\hat{\pi}^*_t\right] \tag{A.30}$$

A.3 Banking

A.3.1 Financial intermediaries

No equations after loglinearisation.

A.3.2 Saving bank

Interest rates

$$\frac{\theta_D}{1-\theta_D}\left(\hat{R}^H_{D,t} - \hat{R}^H_{D,t-1}\right) = \frac{\beta_P\theta_D}{1-\theta_D}E_t\left[\hat{R}^H_{D,t+1} - \hat{R}^H_{D,t}\right] + (1-\beta_P\theta_D)\left(\hat{R}_t + \hat{z}^H_{D,t} - \hat{R}^H_{D,t}\right) \tag{A.31}$$

A.3.3 Lending bank

Interest rates for households

$$\frac{\theta_L}{1-\theta_L}\left(\hat{R}^H_{L,t} - \hat{R}^H_{L,t-1}\right) = \frac{\beta_P\theta_L}{1-\theta_L}E_t\left[\hat{R}^H_{L,t+1} - \hat{R}^H_{L,t}\right] + (1-\beta_P\theta_L)\left(\hat{R}_t - \hat{z}^H_{L,t} - \hat{R}^H_{L,t}\right) \tag{A.32}$$

Interest rates for firms

$$\frac{\theta_L}{1-\theta_L}\left(\hat{R}^F_{L,t} - \hat{R}^F_{L,t-1}\right) = \frac{\beta_P\theta_L}{1-\theta_L}E_t\left[\hat{R}^F_{L,t+1} - \hat{R}^F_{L,t}\right] + (1-\beta_P\theta_L)\left(\hat{R}_t - \hat{z}^F_{L,t} - \hat{R}^F_{L,t}\right) \tag{A.33}$$

Uncovered interest parity (UIP)

$$\hat{R}_t - \hat{R}^*_t = E_t\left[\left(\hat{q}_{t+1} - \hat{q}_t\right) + \left(\hat{\pi}_{t+1} - \hat{\pi}^*_{t+1}\right)\right] + \hat{\rho}_t \tag{A.34}$$

Risk premium. From (46) we obtain

$$\hat{\rho}_t = \varrho \frac{\bar{l}}{\bar{\bar{y}}} \left(\hat{l}_t^* - \hat{\bar{y}}_t \right) + \varepsilon_{\kappa,t} \tag{A.35}$$

A.4 Government

Government expenditures. From (48) we obtain

$$\hat{G}_t = (1 - \rho_g) \hat{G}_{t-1} + \hat{\varepsilon}_{g,t} \tag{A.36}$$

Government budget. From (47) we obtain

$$\hat{G}_t = \hat{T}_t \tag{A.37}$$

A.5 Central Bank

Taylor rule. From (49) we obtain

$$\hat{R}_t = \gamma_R \hat{R}_{t-1} + (1 - \gamma_R) \left(\gamma_\pi \hat{\pi}_t + \gamma_y \hat{\bar{y}}_t \right) + \varphi_t \tag{A.38}$$

A.6 Market clearing, Balance of Payments and GDP

Denote $l_t^* = \frac{e_t L_t^*}{P_t}$ and $q_t = \frac{E_t P_t^*}{p_t}$.

Final goods. From (50) we obtain

$$\frac{\bar{c}}{\bar{\bar{y}}} \hat{c}_t + \frac{\bar{i}_k}{\bar{\bar{y}}} \hat{i}_{k,t} + \frac{\bar{i}_\chi}{\bar{\bar{y}}} \hat{i}_{\chi,t} + \frac{\bar{g}}{\bar{\bar{y}}} \hat{g}_t + \frac{\psi'(1)}{\delta_k} \frac{\bar{i}}{\bar{\bar{y}}} \hat{u}_t = \frac{\bar{y}}{\bar{\bar{y}}} \hat{y}_t \tag{A.39}$$

and from (51) we obtain

$$\gamma^I \frac{\bar{c}^I}{\bar{c}} \hat{c}_t^I + \gamma^P \frac{\bar{c}^P}{\bar{c}} \hat{c}_t^P + \gamma^E \frac{\bar{c}^E}{\bar{c}} \hat{c}_t^E = \hat{c}_t \tag{A.40}$$

Intermediate homogeneous goods. From (52) we obtain

$$\frac{\bar{y}_H}{\bar{y}_H + \bar{y}_H^*} \hat{y}_{H,t} + \frac{\bar{y}_H^*}{\bar{y}_H + \bar{y}_H^*} \hat{y}_{H,t}^* = \hat{y}_{W,t} \tag{A.41}$$

Housing. From (53) we obtain

$$\gamma^P \frac{\bar{\chi}^P}{\bar{\chi}} \hat{\chi}_t^P + \gamma^I \frac{\bar{\chi}^I}{\bar{\chi}} \hat{\chi}_t^I = \hat{\chi}_{t-1} \tag{A.42}$$

Balance of Payments. From (54) we obtain

$$(1 + \tau_F) \frac{\bar{p}_F \bar{y}_F}{\bar{\tilde{y}}} \left(\hat{p}_{F,t} + \hat{y}_{F,t} \right) + \frac{\bar{l}^*}{\bar{\tilde{y}}} \frac{\bar{R}^* \bar{\rho}}{\bar{\pi}^*} \left(\hat{q}_t - \hat{q}_{t-1} - \hat{\pi}_t^* + \hat{l}_{t-1}^* + \hat{R}_{t-1}^* + \hat{\rho}_{t-1} \right) =$$

$$= (1 + \tau_H^*) \frac{\bar{q}\bar{p}_H^* \bar{y}_H^*}{\bar{\tilde{y}}} \left(\hat{q}_t + \hat{p}_{H,t}^* + \hat{y}_{H,t}^* \right) + \frac{\bar{l}^*}{\bar{\tilde{y}}} \cdot \hat{l}_t^* \quad (A.43)$$

GDP. From (55) we obtain

$$\hat{\tilde{y}}_t = \frac{\bar{y}}{\bar{\tilde{y}}} \hat{y}_t + \frac{\bar{q}\bar{p}_H^* \bar{y}_H^*}{\bar{\tilde{y}}} (\hat{p}_H^* + \hat{y}_H^* + \hat{q}_t) - \frac{\bar{p}_F \bar{y}_F}{\bar{\tilde{y}}} (\hat{p}_F + \hat{y}_F) \quad (A.44)$$