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Financial Variables in a Policy Rule: Does It Bring Macroeconomic Benefits?

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Abstract:
After the recent financial crisis of 2007, a connection between monetary policy and financial stability has started to be thoroughly investigated. One of the particular areas of this research field deals with the role of various financial variables in the monetary policy rules. The main purpose of this research is to find whether direct incorporation of the financial variables in the monetary policy rule can bring macroeconomic benefits in terms of lower volatility of inflation and output. So far, the main emphasis of the research has been placed on the investigation of the augmented Taylor rules in the context of a closed economy. This paper sheds light on the performance of the augmented Taylor rules in a small open economy. For this purpose, a New Keynesian DSGE model with two types of financial frictions is constructed. The model is calibrated for the Czech Republic. This work provides four conclusions. First, incorporation of the financial variables (asset prices and the volume of credit) in the monetary policy rule is beneficial for macroeconomic stabilization in terms of lower implied volatilities of inflation and output. Second, the usefulness of the augmented monetary policy rule is the most apparent in case of the shock originating abroad. Third, there is a strong link between the financial and the real side of an economy. Fourth, if the banking sector experiences a sharp drop in bank capital that brings this sector into decline, activity in the whole economy deteriorates and monetary policy is not able to achieve macroeconomic stability using its conventional tools.

Keywords: DSGE models, financial imperfections, inflation targeting, monetary policy
JEL: E31, E43, E52, E58

1. Introduction

Monetary policy has come through significant developments during the past century. The central banks all over the world tried to find the optimal choice of monetary policy arrangement perfectly suitable for their economy. The alternatives that are at hand are, among others, inflation targeting, monetary targeting, or exchange rate targeting. Among these, inflation targeting has become one of the most reliable regimes and it has been implemented in many central banks in industrialised countries. Beside the prominent goal of price stability, most central banks have implemented output stability as a secondary objective of their monetary policy. Therefore, the traditional view on monetary policy has narrowed to consideration of the two mentioned variables – inflation and output. In accordance with this, mainstream literature focusing on monetary policy operates with monetary policy rules that include deviations of inflation and output from their target values.

However, the recent financial crisis has shown that the variables pronounced by the traditional view on monetary policy may not convey sufficient amount of information. Since the financial sector plays an important role in each economy, any turmoil in this sector causes significant problems in the real side of the economy. Therefore, various financial variables have become the natural candidates for monitoring. The current research (both empirical and theoretical) regarding this topic is growing extensively. Nevertheless, there is still a lot to be explored and examined. The theoretical research is grounded on the DSGE modelling framework with the pronounced focus on the banking sector incorporation, because this sector was not a part of the models constructed before the crisis. Since this modelling framework offers somewhat flexible modelling techniques, there can be found several different models characterized by the specific features of the banking sector. The majority of these theoretical papers employ closed economy models with a limited number of shocks.

The purpose of this research is to clarify whether the financial variables convey some additional information that can be identified as useful and beneficial for monetary policy decision making. In particular, the paper focuses on the macroeconomic implications of the incorporation of the financial variables in a monetary policy rule. This problem is investigated using a New Keynesian DSGE model for a small open economy that is characterized by two types of financial frictions. The model builds on the banking sector modelling approach introduced by Gambacorta and Signoretti (2014) and it is calibrated for the Czech Republic. Four main findings stand out from this paper. First, the financial variables convey useful information that helps to stabilize macroeconomic developments in terms of lower implied volatilities. Second, shocks originating in the foreign economy have a large impact on the domestic economy and the usefulness of the augmented rules is the most apparent in these events. Third, the developments in the financial side of the economy have significant effects on the real side. Fourth, in case of a significant turmoil in the financial sector represented by a sharp contraction in bank capital, monetary policy is not able to achieve macroeconomic stability using its conventional tools.

2. Financial variables as a useful policy indicator

2.1. Potential suitable candidates

A traditional approach to augment the policy rule with some variable is based on the incorporation of exchange rates. It is generally concluded that the policy function extended by the exchange rate brings substantial benefits for emerging markets, because these economies are significantly dependent on the movements in exchange rates. This is document by Ho and McCauley (2003) or Mohanty and Klau (2004). Svensson (2000) and Batini, Harrison, and Millard (2003) show that reacting to the movements of the exchange rate can be important; however, Batini et al. (2003) stress that the weight assigned to the exchange rate should be substantially smaller than the weights placed on inflation and output.

Another category of useful financial variables consists of various asset prices. The most common are stock and house price indices. Bernanke, Gertler, and Gilchrist (1999) and Bernanke and Gertler (2001) examine the performance of a variety of policy rules. The first paper concludes that a pure inflation targeting performs better than a strategy which includes reaction to stock prices, while the second identifies a little improvement in the performance of a rule augmented with asset prices. Cecchetti, Genberg, Lipsky, and Wadhwani (2000) and Cecchetti, Genberg, and Wadhwani (2002) add to these findings and they emphasize that central banks should react to asset prices; however, they should not target them. The reaction on the policy rate to the changes in asset prices should be considered on case-by-case basis. A rule-like behaviour does not seem to be appropriate.

Since there are research articles that ascribe more prominent role to credit in creation of asset price bubbles than assets have themselves, the literature identifies another indicator – credit. Agénor, Alper, and Pereira da Silva (2013) investigate a credit expansion caused by a shock in a house market. They alter a basic Taylor rule with credit and also add a capital regulation mechanism. They find that monetary policy (i.e. without capital regulation intervention) is able to stabilize the economy in most cases. However, if the monetary authority is reluctant to change the main policy rate considerably in order to stabilize the economy sufficiently, then the capital regulation mechanism should be employed to complement monetary policy. Christiano, Ilut, Motto, and Rostagno (2010) find that inflation and credit growth react asymmetrically in times of stock market booms – inflation tends to be low while credit growth high. Therefore, a simple reaction function would suggest no change in a policy rate. They show that reacting to credit growth is beneficial and a central bank should be able to stabilize an economy. Aydin and Volkan (2011) focus on the Korean economy. They conclude that reacting to a financial variable might be useful; however, they find a different performance in case of supply and demand shocks. In the first case, a significant improvement is found whereas in the latter there is none. Gelain, Lansing, and Mendicino (2013) come to conclusion that central bank's reaction to credit improves performance of some variables, while the variances of inflation and output increase.

The last indicator suggested by the literature is spreads. This variable takes different forms – the most frequently discussed are lending/deposits, corporate, or sovereign spreads. The last

mentioned form is of particular interest due to the recent European sovereign debt crisis which has been taking place since late 2009. Since spreads have been discussed for relatively short time period, there is a limited amount of literature regarding this topic. Cúrdia and Woodford (2010) investigate the role of spreads in monetary policy. They build a New Keynesian DSGE model that has features allowing for differences between lending and deposit rates. In their setting, the monetary authority reflects the size of spreads in its reaction function. They come to the conclusion that augmenting the rule with credit spreads improves the outcome with respect to the baseline scenario without spreads. The optimal response on spreads to shocks is not uniform and it is different for each case. Teranishi (2012) elaborates on the policy function with spreads that are the results of two different loan contracts. The model suggests that the optimal policy reaction is achieved under the augmented version of a reaction function; however, the response to spreads is dependent on the characteristics of both types of loans.

2.2. Incorporating financial variable in a policy rule

A starting point of this discussion is the seminal work by Taylor (1993). In this paper, the author proposes the rule according to which a central bank sets its main policy rate i_t with respect to the developments in the equilibrium real interest rate $\bar{r}$ and the current inflation rate π_t. Moreover, the central bank takes into account the deviation of the current inflation rate from its target value π^* and the deviation of actual output y_t from its desired level y^*. This relationship is described by the following equation:

$$i_t = \bar{r} + \pi_t + \alpha(\pi_t - \pi^*) + \beta(y_t - y^*) \tag{1}$$

where α and β are the weights. As many authors have shown, in the presence of nominal wage and price rigidities the real interest rate plays a crucial role. Therefore, (1) can be rewritten as:

$$r_t = i_t - \pi_t = \bar{r} + \alpha(\pi_t - \pi^*) + \beta(y_t - y^*) \tag{2}$$

The rule described by Taylor (1993) could be explicitly augmented by a term referring to some financial variable f. Equation (1) is then extended by the term including the actual value of financial variable f_t, its target value f^* and some weight γ:

$$i_t = \bar{r} + \pi_t + \alpha(\pi_t - \pi^*) + \beta(y_t - y^*) + \gamma(f_t - f^*) \tag{3}$$

In this setting, however, it is not obvious what should be a respective target value of the financial variable f^*. For example, one cannot simply state what the tolerable level of spread is. Nevertheless, if this problem is solved, another issue arises – weight γ. Central banks may set this value to some fixed level. Central banks may conversely allow this parameter to be time-varying so that different emphasis is placed on financial indicator in different stages of the business or financial cycle.

An alternative to the "financial variable targeting" is a mere reaction to the developments in a financial indicator. For example, Cúrdia and Woodford (2010) use such approach. Then, equation (1) takes the following form:

$$i_t = \bar{r} + \pi_t + \alpha(\pi_t - \pi^*) + \beta(y_t - y^*) + \gamma f_t \tag{4}$$

where f_t is the actual value of financial variable and γ is a certain weight. The discussion about the target value is suppressed in this approach.

Nevertheless, the discussion about the appropriate weight γ still remains. Regarding the USA and spreads, Taylor (2008) proposes 100% reaction, whereas Cúrdia and Woodford (2010) argue for response of less than 100%. More specifically, they find the optimal value of γ to be 0.66 (i.e. monetary authority takes into account 66% of financial developments). The optimal value of γ might be found using welfare analysis of monetary policy rule. It is important to mention that this value will differ for each model because it will strongly depend on the model setting.

It has long been understood that a forward-looking dimension in policy decision making (and in monetary policy especially) is needed. Following this, Batini and Haldane (1998) elaborate on the original idea of the Taylor rule. The authors construct and evaluate simple forward-looking policy rules which include expected inflation – so called inflation-forecast-based rules. By adopting their approach and disregarding the output targeting part, the policy rule can be augmented by the expected future value of the financial variable f:

$$i_t = \bar{r} + \pi_t + \alpha(\mathbb{E}_t\pi_{t+j} - \pi^*) + \gamma(\mathbb{E}_t f_{t+k}) \tag{5}$$

where $E_t\pi_{t+j}$ represents the expected inflation rate in time $t+j$ and j takes value from the set $\{1, 2, 3, \dots\}$. In this case monetary authority also focuses on future financial developments and adjusts its short-term policy rate with respect to the future financial imbalances. Values j and k (where $k \in \{0, 1, 2, \dots\}$) may be different in that monetary authority can perceive a different horizon of reactions.

3. The model

The model outlined in this section is built on several models. The fundamental features are adopted from the model derived by Brzoza-Brzezina and Makarski (2011), that is updated based on a few remarks made by Svačina (2015). The banking sector is implemented according to Gambacorta and Signoretti (2014), who simplify the seminal banking sector modelling approach introduced by Gerali, Neri, Sessa, and Signoretti (2010). In this setting, banks collect deposits from households and issue loans to entrepreneurs. As a result, interest rate spread emerges. Banks also face a regulatory measure – optimal level of capital-to-asset ratio.

The model utilises two types of financial frictions: (i) entrepreneurs are constrained in borrowing from banks by the value of assets they possess; (ii) the central bank (in the role of regulatory

authority) prescribes the optimal level of leverage to commercial banks – whenever the actual level of leverage deviates from the optimal level, commercial banks pay a cost. These frictions significantly affect the propagation mechanisms of shocks. More specifically, they connect the financial side of the economy with the real side in such a way that changes, for example, in entrepreneur's net wealth or policy rate are relevant determinants of conditions in the credit market. Conversely, movements in supply of loans are influential factors in the activity in the real side of the economy. The first type of friction propagates through a collateral channel, while the second type of friction propagates through a credit supply channel.

The model described in this section diverts from some specific characteristics of the models mentioned above. Since the model combines features of several models, it allows for a richer structure, and therefore for additional analysis. Overall, this paper introduces a small open economy DSGE model – a stochastic growth model with monopolistic competition at the retail level and at the banking sector, capital adjustment costs, capital utilization, nominal price rigidity and financial frictions. The following paragraphs provide a description of a selected number of sectors of an economy that are central to this model. Since households, entrepreneurs, retailers and capital producers are modelled in a standard manner, these sectors of the economy are omitted from the main body and their description and subsequent derivation can be found in Appendix A.

3.1. Commercial banking sector

The banking sector is modelled according to Gambacorta and Signoretti (2014). Commercial banks (henceforth banks) posses certain market power in intermediation, which enables them to change rates on deposits and loans in response to various shocks. Banks have to obey a balance-sheet condition stating that $loans = deposits + capital$. Banks also face an "optimal" exogenous target for capital-to-asset ratio (i.e., the inverse of leverage), which can be seen as a simplified tool to study implications of capital requirements set by regulatory authorities. Additionally, the model allows for a feedback loop between financial sector and the real side of the economy. In case of subdued macroeconomic conditions, banks might respond to the situation by cutting the volume of issued loans, and therefore aggravating the original conditions.

The banking sector is composed of a continuum of banks indexed by $j \in (0, 1)$. Individual bank consists of two units – wholesale and retail. The role of the wholesale unit is to collect deposits from households and to issue wholesale loans. The retail unit purchases wholesale loans, differentiates them and resells them to entrepreneurs.

3.1.1. Wholesale branch

The wholesale unit of each bank operates under perfect competition. The wholesale unit collects deposits D_t from households at the rate set by the central bank R_t and issues wholesale loans L_t at the wholesale rate R_t^{WL}. The balance sheet of the wholesale branch consists of bank capital K_t^B and deposits D_t on the liability side, while on the asset side can be found wholesale loans L_t (all in

real terms). Bank faces an optimal value of capital-to-asset ratio ν_B. Whenever the actual capital-to-asset ratio K_t^B/L_t diverts from the target value ν_B, the bank pays a quadratic adjustment cost parametrized by κ_B. This feature implies that bank leverage ratio determines loans interest rates, which generates feedback loop between the real side of the economy and financial sector. Bank capital evolves according to:

$$K_t^B = (1-\delta_B)\frac{K_{t-1}^B}{A_t^B} + \Xi_{t-1}^B \tag{6}$$

where δ_B represents the cost for managing the bank's capital position, and Ξ_t^B are overall profits of the bank as outlined by equation (58).[1] A_t^B is a bank capital shock. Its deviation from the steady state is assumed to follow an AR(1) process with ε_t^B being normally distributed with zero mean and variance σ_B^2:

$$\hat{a}_t^B = \rho_B \hat{a}_{t-1}^B + \varepsilon_t^B \tag{7}$$

The wholesale unit of the bank chooses the optimal level of deposits and loans in order to maximize profit:

$$R_t^{WL} L_t(j) - R_t D_t(j) - \frac{\kappa_B}{2}\left(\frac{K_t^B(j)}{L_t(j)} - \nu_B\right)^2 K_t^B(j) \tag{8}$$

subject to the balance constraint $L_t = D_t + K_t^B$, while taking the interest rate R_t and the wholesale rate on loans R_t^{WL} as given. Combining the first-order conditions yields the relationship between the capital-to-asset ratio K_t^B/L_t and the spread between wholesale rates on deposits and loans:

$$R_t^{WL} - R_t = -\kappa_B\left(\frac{K_t^B(j)}{L_t(j)} - \nu_B\right)\left(\frac{K_t^B(j)}{L_t(j)}\right)^2 \tag{9}$$

The left-hand side of the above equation represents the marginal benefit from lending (i.e., an increase in profits from one loan issued), while the right-hand side represents the marginal cost from lending. Banks choose the optimal level of loans such that costs and benefits stemming from changing the leverage ratio are equalized at the margin.

3.1.2. Retail branch

Retail branches of banks operate in a monopolistically competitive market. The retail branch purchases wholesale loans from the wholesale branch, differentiates them at no cost and resells them to entrepreneurs. It is assumed, that retail branch applies constant mark-up μ_B on the wholesale

[1] For simplicity it is assumed that the commercial banks have no dividend policy.

loan rate R_t^{WL}. Therefore, the retail loan rate is defined as:

$$R_t^L = R_t - \kappa_B \left(\frac{K_t^B(j)}{L_t(j)} - \nu_B \right) \left(\frac{K_t^B(j)}{L_t(j)} \right)^2 + \mu_B \tag{10}$$

Bank profits combine all the partial net earnings. Aggregate bank profits (in real terms) are given by:

$$\Xi_t^B = R_t^L L_t - R_t D_t - \frac{\kappa_B}{2} \left(\frac{K_t^B}{L_t} - \nu_B \right)^2 K_t^B \tag{11}$$

3.2. Central bank

Policy of the central bank is described by a few different monetary policy rules. First, since this research focuses on the Czech Republic, a simplified version of the monetary policy rule of the Czech National Bank is outlined. Second, because financial sector significantly affects the real side of the economy, reaction functions augmented by several financial variables are introduced.

3.2.1. Conventional monetary policy rule

In the baseline model, the central bank adjusts the policy rate, R_t, in response to deviations of inflation, Π_t, from its steady-state value. This representation of policy resembles state in which the central bank does not explicitly adjust its policy rate with respect to financial disturbances. Following Andrle, Hlédik, Kameník, and Vlček (2009), the Czech National Bank implements a regime of inflation targeting with interest rate smoothing. This specific rule takes form:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R} \right)^{\rho_R} \left(\left(\frac{\Pi_t}{\Pi} \right)^{\varrho_\Pi} \right)^{1-\rho_R} \tag{12}$$

where R and Π are the steady-state values of R_t and Π_t respectively, ρ_R depicts inflation persistence, ϱ_Π is a weight characterizing the importance of inflation deviation.

3.2.2. Augmented monetary policy rules (AMPRs)

Compared to the baseline scenario, the central bank reflects developments in financial sector in its policy rule. Generally, AMPR takes the form:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R} \right)^{\rho_R} \left(\left(\frac{\Pi_t}{\Pi} \right)^{\varrho_\Pi} \left(\frac{\Psi_t}{\Psi} \right)^{\varrho_\Psi} \right)^{1-\rho_R} \tag{13}$$

where Ψ_t represents financial variable with Ψ being its steady state value and ϱ_Ψ being respective assigned weight.

Credit (AMPR I). The developments in credit market have a significant impact on the real side of the economy, because increase in credit supply encourages economic players to be more active. This augmented rule accounts for credit volume under two considerations. Since there has been

reached no agreement about the role of credit in financial stability yet, the central banks reacts: (i) by encouraging credit to firms (i.e., non-financial sector), or (ii) by discouraging credit. The AMPR I is given by:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_R} \left(\left(\frac{\Pi_t}{\Pi}\right)^{\varrho_\Pi} \left(\frac{L_t}{L}\right)^{\varrho_L}\right)^{1-\rho_R} \tag{14}$$

where L_t refers to loans granted to entrepreneurs, L is its steady state value and $\varrho_L \lessgtr 0$ is assigned weight. Following Aydin and Volkan (2011), ϱ_L is set to ± 0.3.

Asset prices (AMPR II). Following Gambacorta and Signoretti (2014), the central bank accounts for asset prices (which are represented by Q_t^K) in its monetary policy rule. To motivate this rule, assume increase in asset prices. Such movement implies a higher value of collateral that can be pledged against loan. This in turn enhances investment and spending. Therefore, rising asset prices could indicate a future inflationary pressures. The AMPR II is described by:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_R} \left(\left(\frac{\Pi_t}{\Pi}\right)^{\varrho_\Pi} \left(\frac{Q_t^K}{Q^K}\right)^{\varrho_Q}\right)^{1-\rho_R} \tag{15}$$

where Q^K is its steady state value of Q_t^K and $\varrho_Q > 0$ is assigned weight.

Credit and asset prices combined (AMPR III). The last augmented monetary policy rule combines both mentioned financial variables – credit and asset prices. The AMPR III is defined as:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_R} \left(\left(\frac{\Pi_t}{\Pi}\right)^{\varrho_\Pi} \left(\frac{L_t}{L}\right)^{\varrho_L} \left(\frac{Q_t^K}{Q^K}\right)^{\varrho_Q}\right)^{1-\rho_R} \tag{16}$$

where the weights are the same as in the previous augmented rules.

3.3. Foreign sector

The foreign sector is represented by simple AR(1) processes. Even though that the recent literature employs VAR models as a representation of the foreign sector (such as Christiano, Trabandt, and Walentin, 2011), this paper does not follow this approach for the following reason. The VAR model is complicated and the coefficients are estimated so as to maximize the criterion function and to fit the data. The results of the VAR estimation are not straightforward and there is no economic intuition behind the estimated values of respective coefficients. Moreover, the VAR model entails additional dynamics that cannot be described easily and it introduces unclear oscillations in the responses to the foreign shocks. Therefore, the foreign sector is represented by the following system of equations:

$$\begin{pmatrix} \hat{y}_t^* \\ \hat{\pi}_t^* \\ \hat{r}_t^* \end{pmatrix} = \begin{pmatrix} \rho_{y^*} & 0 & 0 \\ 0 & \rho_{\pi^*} & 0 \\ 0 & 0 & \rho_{r^*} \end{pmatrix} \begin{pmatrix} \hat{y}_{t-1}^* \\ \hat{\pi}_{t-1}^* \\ \hat{r}_{t-1}^* \end{pmatrix} + \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \varepsilon_t^{y^*} \\ \varepsilon_t^{\pi^*} \\ \varepsilon_t^{r^*} \end{pmatrix} \tag{17}$$

where $\varepsilon_t^{y^*} \sim iid(0, \sigma_{y^*}^2)$, $\varepsilon_t^{\pi^*} \sim iid(0, \sigma_{\pi^*}^2)$, $\varepsilon_t^{r^*} \sim iid(0, \sigma_{r^*}^2)$, and the autocorrelation coefficients ρ_{y^*}, ρ_{π^*}, $\rho_{r^*} \in (0, 1)$.

4. Calibration and properties of the model

4.1. Calibration for the Czech Republic

The whole model is calibrated. The parameters are calibrated based on studies focusing on the Czech Republic or studies employing similar model mechanisms (when Czech studies not available), and own computations using data from ARAD database. The sample period used for the computations ranges from 2000Q1 to 2014Q4. Table 4 summarizes calibration. There is a block of parameters that is calibrated directly, while the rest of the parameters are computed based on the steady-states relationships.

Based on own computations, the following steady-states ratios are calibrated such that $\frac{C}{Y_G} = 0.5177$, $\frac{I}{Y_G} = 0.1538$, $\frac{L}{Y_G} = 0.6139$, $\frac{p_F Y_F}{Y_G} = 0.2107$, and $\frac{p_H^* Y_H^* \mathcal{Q}}{Y_G} = 0.243$.[2] Steady state ratio of derivatives of capital utilization is set arbitrarily (in line with other studies) to 0.2, while the rate of capital adjustment costs κ_K is calibrated to 3. Capital share in production (α) and the depreciation rate of capital (δ_K) are set standardly to 0.3 and 0.035 respectively. Exogenous discount factors of households and entrepreneurs are calibrated such that entrepreneurs and foreign households are more impatient than domestic households – $\beta_H = 0.9900$, $\beta_E = 0.9800$ and $\beta_H^* = 0.9850$. These values are in line with DSGE literature and also with the studies related to the Czech Republic (e.g. Malovaná, 2015). It is assumed that the economy is covered by 75% of households, which makes the coverage of entrepreneurs to be 25%. The steady state of inflation is expected to be 2% (which corresponds to the average of the Czech inflation level across the investigated time period and it also corresponds to the inflation target of the Czech National Bank) which leads to the steady state value of home policy interest rate 2.0202. The foreign counterparts to these two variables are calibrated to slightly lower values. The steady state ratio of foreign debt to GDP is assumed to be 1.[3]

External habit persistence parameter ι equals 0.7, which is in line with the recent study of Havránek, Horváth, Iršová, and Rusnák (2015). Based on Babecký, Galuščák, and Lízal (2012), wage elasticity ϕ is calibrated to 1.88. Adopting estimations of Tvrz (2012) and Svačina (2015), Calvo parameters are calibrated as follows: home goods parameter ($\theta_H = 0.4$), imported goods parameter ($\theta_F = 0.5$), exported goods parameter ($\theta_H^* = 0.5$). Using estimations of Svačina (2015), inflation indexation parameters are calibrated such that $\varsigma_H = 0.3233$, $\varsigma_H^* = 0.4949$ and $\varsigma_F = 0.3428$. Elasticities of substitution for domestic and foreign goods are set at $\mu = 1.87$ and $\mu^* = 1.923$ based on Ryšánek, Tonner, and Vašíček (2011).

Regarding the commercial banking sector, the optimal level of capital-to-asset ratio (ν_B) is set

[2] The last two values take into account only final consumption (the intermediate goods are not considered).

[3] The ratio of foreign debt to GDP does not resemble the reality well. This particular value is selected due to the fast convergence.

at 9% according to Basel II Accord.[4] Following Gambacorta and Signoretti (2014), the rate of bank capital adjustment costs, share of bank capital used in capital maintenance and mark-up on loans are set at 11.49, 0.059 and 0.1 respectively. Based on Ryšánek et al. (2011), interest rate persistence $\rho_M = 0.83$ and weight put on inflation $\varrho_\Pi = 1.7$. Lastly, the autocorrelations coefficients of the exogenous processes are calibrated based on Svačina (2015) and Brzoza-Brzezina and Makarski (2011): $\rho_{y^*} = 0.8024$, $\rho_{\pi^*} = 0.6256$, $\rho_{r^*} = 0.7570$, $\rho_{UIP} = 0.4798$, $\rho_M = 0.1040$, $\rho_Y = 0.3642$, $\rho_B = 0.4138$, and $\rho_C = 0.6980$.

4.2. Properties of the model

The performance of the baseline monetary policy rule and its augmented versions is investigated using two approaches. First, the properties of the model under different monetary policy rules are assessed based on implied volatilities. Second, the qualitative assessment is done via the impulse response functions.

4.2.1. Variability

As it was mentioned earlier, the ultimate goal of the CNB is to maintain the price stability. Beside this prominent goal, the CNB also maintains stable economic growth unless the primary goal of price stability is not harmed. Therefore, the following analysis also focuses on GDP in addition to inflation as the most prominent indicator. Moreover, the traditional approach is to investigate implications of different monetary policy rules for both variables.

Volatility of two selected variables is measured by implied standard deviations which is the common approach to the measurement of variability. This approach is chosen because the standard errors of the shocks are small in their magnitude which implies that the second central moments of simulated series are negligible. Each monetary policy rule is characterised by different variables, and therefore each variable is represented by a different weight. The values of the respective weights on the financial variables are chosen based on Gambacorta and Signoretti (2014), and Aydin and Volkan (2011). Table 1 recapitulates calibration of the monetary policy rules.

Rule	**Weights**
Baseline	$\varrho_\Pi = 1.7$
AMPR I +	$\varrho_\Pi = 1.7$, $\varrho_L = 0.3$
AMPR I −	$\varrho_\Pi = 1.7$, $\varrho_L = -0.3$
AMPR II	$\varrho_\Pi = 1.7$, $\varrho_Q = 0.5$
AMPR III	$\varrho_\Pi = 1.7$, $\varrho_L = -0.3$, $\varrho_Q = 0.5$

Table 1: **Monetary policy rules and the weights.**

The results of the analysis are summarized in table 2. The table includes the results for inflation

[4]In particular, Basel II Accord refers to risk-weighted assets. Thus, the overall ratio of capital and assets is lower in reality. Nevertheless, as section 5 shows, the results are robust to changes in this particular parameter.

and GDP and it also provides an overall effect represented by the weighted sum. The weighted sum is defined as:

$$\mathrm{SD}(\Pi) + \omega \cdot \mathrm{SD}(GDP) \tag{18}$$

where the value of the weight ω is set at 0.09, since Ryšánek et al. (2011) estimate this value to represent the weight ascribed to output in their Taylor rule.[5] The table contains implied volatilities caused by all the shocks that were discussed in the section devoted to the model construction.

The simulations lead to the following conclusions. First, the most obvious is that reacting to any kind of shock by discouraging credit (AMPR I +) does not seem to be beneficial for inflation stability. The results regarding the stability of GDP are mixed in this case and they are shock-dependent. On the other hand, monetary policy under the AMPR I with a negative coefficient delivers significantly favourable results in inflation stabilization than the baseline rule and such augmented rule proves to be a good stabilizer. The only exception is the shock that originates in the financial sector (shock into bank capital). These results are in line with the finding of Aydin and Volkan (2011) who implement the similar policy rule, however, in the different model setting with a significantly lower amount of shocks. This suggests that credit could be a useful source of information for monetary authorities. Moreover, the results show that reacting negatively on policy rate to the developments of the credit volume in the economy outperforms significantly the latter possibility with the positive coefficient.

Second, using asset prices as the only financial variable in the policy rule does not seem to be optimal. On the other hand, combining asset prices with the credit volume delivers the best results under investigated options. This suggests that asset prices and credit volume are interconnected and if they are considered to be implemented, than only jointly. This finding is consistent with the result of Gambacorta and Signoretti (2014) who report the combined rule to be the most appropriate. Considering weighted volatility, table 2 shows that reacting to the financial developments by adjusting policy rate based on movements in asset prices and the credit volume delivers significant improvements in all the cases except for the bank capital shock. The results are plausible in case of inflation stabilization, while the simulations does not give a clear message in case of stability of GDP.

4.2.2. Impulse response functions

This subsection includes description of the reactions of the model to various shocks using the impulse response functions. Each figure depicts responses under two monetary policy rules out of five alternatives discussed in the previous paragraphs. These are the baseline rule and the AMPR III. The AMPR III was chosen in that it is identified to be the most beneficial for monetary policy based on the volatility analysis. All figures presented in this section depict percentage deviations from the steady state values of the respective variables. The IRFs of the baseline scenario are

[5] The robustness of the results to different values of ω is verified in section 5.

Shock to	Rule	Inflation	GDP	Weighted sum
Productivity	Baseline	0.0106	0.0080	0.0113
	AMPR I +	0.0124	0.0070	0.0130
	AMPR I −	0.0086	0.0095	0.0095
	AMPR II	0.0107	0.0079	0.0114
	AMPR III	0.0088	0.0093	0.0096
Bank capital	Baseline	0.0010	0.0025	0.0012
	AMPR I +	0.0016	0.0026	0.0018
	AMPR I −	0.0013	0.0024	0.0015
	AMPR II	0.0011	0.0025	0.0013
	AMPR III	0.0012	0.0024	0.0014
Consumption preference	Baseline	0.0042	0.0096	0.0051
	AMPR I +	0.0040	0.0096	0.0049
	AMPR I −	0.0040	0.0096	0.0049
	AMPR II	0.0046	0.0098	0.0055
	AMPR III	0.0029	0.0092	0.0037
Foreign inflation	Baseline	0.0010	0.0017	0.0012
	AMPR I +	0.0013	0.0019	0.0015
	AMPR I −	0.0007	0.0016	0.0008
	AMPR II	0.0011	0.0018	0.0013
	AMPR III	0.0007	0.0015	0.0008
Foreign interest rate	Baseline	0.0021	0.0026	0.0023
	AMPR I +	0.0026	0.0028	0.0029
	AMPR I −	0.0014	0.0022	0.0016
	AMPR II	0.0022	0.0027	0.0024
	AMPR III	0.0013	0.0021	0.0015
Foreign output	Baseline	0.0007	0.0010	0.0008
	AMPR I +	0.0007	0.0011	0.0008
	AMPR I −	0.0006	0.0010	0.0007
	AMPR II	0.0007	0.0011	0.0008
	AMPR III	0.0005	0.0009	0.0006

Table 2: **Variability under different monetary policy rules.** Last three columns summarize volatility of inflation, GDP and their weighted average under different rules for various shocks.

discussed at first and dynamics under the AMPR III is summarized at the end of each section.

The response of the model to a positive technology shock is depicted in figure 1. The positive technology shock causes an improvement in the production process which makes production more efficient. This innovation is accompanied by higher output and lower prices of the products. As a result, inflation decreases. The real exchange rate depreciates which causes imports to be more expensive while exports become more attractive for foreign consumer due to lower domestic prices and the real exchange rate depreciation. Therefore, imports fall and exports rise which results in increase in the net exports. Given this dynamic, the central bank responds by decrease in policy rate so that inflation is brought back to the target. Regarding the financial side of the economy, the loan rate falls on impact because of the relaxed conditions in the economy. The lending is cheaper and demand for credit increases which in turn forces the commercial banks to expand their balance

sheets and leverage. Since entrepreneurs posses more credit, the investment spending rises with a delay.[6]

Figure 2 illustrates an unexpected contraction in bank capital. The shock is calibrated such that the impact of loss in bank capital is persistent and it has a significant effect on the real side of the economy. This exercise serves to illustrate the transmission mechanisms and the importance of the financial sector in the economy. An unexpected negative shock causes bank capital to deteriorate. Since a sufficient amount of bank capital is needed in order to produce loans, the loan supply decreases dramatically which results in highly leveraged banking sector. Given that the loan supply is low, entrepreneurs do not possess enough resources for investment activities and investment falls. At the same time, firms want to hire more workers, they push up wages which results in higher consumption. However, the persistence of the shock causes the real activity to further decline and GDP reaches its trough in the fourth quarter. The central bank reacts to increased inflation (caused by higher wages and financing cost) by a moderate hike of the policy rate. Since the real exchange rate depreciates, entrepreneurs want to make the most profitable deals and exports grow. However, growth of export is negligible (values of order 10^{-4}). On the other hand, there are not enough resources and imports fall dramatically. Overall, contraction in bank capital has significant implications for economic activity and it pushes the economy into deep and prolonged recession.

A domestic supply side shock is represented by a positive consumption preference shock (illustrated by figure 3). The positive shock in consumption preferences causes households to consume more because they value present consumption more than future one. Therefore, their willingness to spend more hours by working increases because higher disposable income represents higher consumption. Labour supply increases, marginal product of physical capital also increases, which stimulates higher investment. Because of higher economic activity, both GDP and inflation increase. The central bank reacts by increasing policy rate in order to decrease inflation. The real exchange rate appreciates on impact causing exports to fall and imports to increase.

Under the AMPR III, the central bank reacts almost in the same manner as in the baseline scenario in case of the shocks to technology and UIP. It is because of the construction of the AMPR III where the weights on financial variables have opposite signs and the respective variables move in inverse directions. Therefore, the responses are almost identical. On the other hand, financial shock – bank capital loss, forces the central bank to react differently. In this particular case, the monetary authority wants to counter attack the adverse implications of the contraction by cutting policy rate even more. However, the shock is excessively persistent and reacting to contemporaneous financial developments causes the situation in the banking sector to deteriorate. Lowering policy rate does not bring any improvement in the overall economic activity. Since low rates do not attract deposits, the commercial banks cannot issue loans (because of the balance sheet identity) which dampens investment activity and brings inflation down. A similar explanation can provided in case of the

[6]The initial negligible drop in investment is caused by adjustment cost imposed on capital and by the collateral constraint.

consumption preference shock. Even though the response of the central bank is almost identical as in the baseline scenario, households give preference to consumption rather than deposits. Since deposits are lower, the commercial banks cannot issue so many loans which dampens investment activity that is responsible for lower GDP and inflation. This transmission suggests that the model works according to "loanable funds theory". However, this exact responses may not be expected in reality. Since this feature of the model is questionable, it is regarded as a challenge for further research.

Lastly, figures 4, 5 and 6 depict the responses of the domestic variables to the shocks originating in the foreign economy. Because the small open economy is significantly dependent on the conditions of economy that represents its trading partner, various foreign disturbances have a considerable impact on the home economy. Therefore these shocks are of a particular interest.

Figure 4 demonstrates the responses to a positive innovation in the foreign output. Excess foreign demand stimulates exports of the domestic economy substantially. As a result, production and investment increase on impact in order to satisfy higher foreign demand. Because marginal costs of production are growing, inflation rises. The central bank accommodates this movement in inflation by hiking policy rate. Due to the intervention of the central bank, the real exchange rate appreciates which causes imports to increase. Given the response of the central bank, the loan rate increases as well, which leads to a slump in demand for loans. Therefore, bank leverage decreases.

Figure 5 shows the reactions of the variables to a positive foreign interest rate shock. Higher foreign interest rate causes the real exchange rate to depreciate on impact, which stimulates the demand for domestic exports. Since the price of imports is disadvantaged by the movement of the real exchange rate, imports fall. A higher domestic production and depreciated exchange rate generate inflationary pressures that are countered by the response of central bank to increase policy rate.

A positive shock to foreign inflation is depicted by figure 6. The shock is followed by the appreciation of the real exchange rate which is mirrored in higher imports and drop in exports. These two effects are severe and the economy experiences recession. This creates the downward pressure on inflation. The central bank is forced to decrease policy rate in order to support production and to increase inflation. The loan rate follows the dynamics of policy rate. In response to this, the commercial banks expand their balance sheets in the following periods in order to satisfy a higher demand for credit. This is followed by heightened investment in the subsequent quarters.

The same reasoning for dynamics of responses under the alternative scenario holds in this case. The dynamics of the model is considerably affected by the amount of deposits and loans issued. Based on the discussion in the previous subsection, when using the augmented rule, the macroeconomic benefits in terms of lower volatilities seems to be significant in case of the disturbances stemming from abroad. The most pronounced effects can be observed in the event of the shocks in inflation and interest rate, where the financial variables bring useful additional information about future inflationary developments and the monetary authority adjusts its policy rate in accordance with this.

4.3. Comparison with similar studies

Compared to the findings of Gambacorta and Signoretti (2014), change of the dynamics under the alternative rule compared to the baseline scenario is not so pronounced. It might be caused by the different construction of the whole model. The model presented in this paper is more complicated and it also encompasses additional features that are responsible for different responses. Moreover, the model represents an open economy, while Gambacorta and Signoretti (2014) construct a closed economy model. Moreover, their model seems to be highly stylized. Their model shows that most beneficial for macroeconomic stability is to implement the augmented monetary policy rule; however, the coefficient on loans is positive.

On the other hand, results of a closed economy model constructed by Aydin and Volkan (2011) suggest that the responses of variables to various shocks are qualitatively and quantitatively almost identical under different monetary policy rules. Their research suggests that almost any kind of financial variable possess useful information; however, their results regarding implied volatilities vary considerably across different shocks and different monetary policy rules. This shows that reacting to financial variables is likely to bring some benefits for macroeconomic stability. Nevertheless, the gains are shock- and model-dependent.

5. Sensitivity analysis and robustness check

First, this chapter offers comparison of implied volatilities under the AMPR III with different weights assigned to the financial variables. Second, the robustness of the results to changes of a selected number of parameters is verified.

5.1. Volatility under the AMPR III with different weights

The following exercise helps to find out to what extent the weights ascribed to the financial variables modify volatility of inflation and output as opposed to baseline calibration of the AMPR III. The weight put on inflation in the policy rule is kept to be fixed at its baseline value 1.7, and therefore, it is not further reported. Table 3 summarizes the results of the repeated simulations for the different combinations of weights put on the financial variables under the all shocks considered (domestic as well as foreign).

Focusing on the cases when more pronounced weight is given to developments in the financial variables, all the shocks, except for the bank capital shock, imply less weighted volatility than the shocks under the baseline calibration do. Deterioration of the performance of the AMPR III in case of the bank capital shock (when there is higher weight ascribed to the credit volume and asset prices) resides in the fact that the most beneficial rule is identified to be the baseline (conventional) rule in this case, as it was shown in the previous chapter. From this implies that reacting with even higher weights causes stronger distortions.

Conclusions made in the previous paragraph are supported by the upper rows in each "shock category". In comparison to baseline calibration of the AMPR III with weights $\varrho_L = -0.3$ and

$\varrho_Q = 0.5$, more modest reactions to financial developments bring less macroeconomic stability than more aggressive reactions and they are more distorting in this sense. On the other, in some particular cases, too aggressive reaction on the financial variables brings less stabilization than more moderate reactions (this can be seen in case of the shock into technology). Overall, this investigation shows that the initial weights considered in the AMPR III are not optimal (as regards macroeconomic stabilization) and a more suitable combination could be found. Nevertheless, even the augmented rule with weights that are less emphasized delivers improvements that are significant. Therefore, conclusions reached in this research should be considered from the qualitative perspective rather than quantitative.

Shock to	ϱ_L	ϱ_Q	**Inflation**	**GDP**	**Weighted sum**	**Gain**
Technology	−0.1	0.1	0.0099	0.0085	0.0107	−11%
	−0.5	0.5	0.0081	0.0102	0.0090	6%
	−0.5	1.0	0.0084	0.0098	0.0093	4%
	−0.5	1.5	0.0086	0.0096	0.0095	2%
Bank capital	−0.1	0.1	0.0009	0.0024	0.0011	21%
	−0.5	0.5	0.0020	0.0024	0.0022	−56%
	−0.5	1.0	0.0017	0.0023	0.0019	−35%
	−0.5	1.5	0.0016	0.0023	0.0018	−28%
Consumption preference	−0.1	0.1	0.0039	0.0095	0.0048	−28%
	−0.5	0.5	0.0027	0.0092	0.0035	5%
	−0.5	1.0	0.0021	0.0090	0.0029	22%
	−0.5	1.5	0.0018	0.0089	0.0026	30%
Foreign output	−0.1	0.1	0.0006	0.0010	0.0007	−19%
	−0.5	0.5	0.0004	0.0009	0.0005	17%
	−0.5	1.0	0.0004	0.0009	0.0005	17%
	−0.5	1.5	0.0003	0.0008	0.0004	36%
Foreign inflation	−0.1	0.1	0.0009	0.0017	0.0011	−26%
	−0.5	0.5	0.0006	0.0014	0.0007	13%
	−0.5	1.0	0.0006	0.0014	0.0007	13%
	−0.5	1.5	0.0006	0.0015	0.0007	12%
Foreign interest rate	−0.1	0.1	0.0018	0.0024	0.0020	−35%
	−0.5	0.5	0.0010	0.0019	0.0012	21%
	−0.5	1.0	0.0010	0.0019	0.0012	21%
	−0.5	1.5	0.0010	0.0019	0.0012	21%

Table 3: **Sensitivity analysis.** Columns called inflation, GDP and weighted sum depict volatility under different setting of the policy weights (ϱ_L, ϱ_Q). Gain is a percentage deviation of volatility from baseline calibration of the AMPR III ($\varrho_L = -0.3$, $\varrho_Q = 0.5$); a positive value represents gain, a negative value represents loss.

5.2. Robustness verification

The following analysis shows to what extent is the model sensitive to the changes in calibration of several variables. In particular, calibration of the several key parameters is changed, simulations with the baseline (conventional) rule and the AMPR III are repeated for all the shocks and the difference in implied volatilities between these two rules is recorded and compared. The parameters that are analysed can be categorized in three groups:

(i) the banking sector parameters: the target value of capital-to-asset ratio ν_B and the rate of capital adjustment costs κ_B;
(ii) the parameters reflecting the stickiness: the rate of investment adjustment cost κ_K and the inverse of the Frisch elasticity of labour supply ϕ;
(iii) the interest rate smoothing parameter ρ_R.

The results of the robustness analysis are summarized in figures 7 and 8.

Regarding the banking sector parameters (first rows in both figures), the results are almost the same when changing the values of κ_B and ν_B. These two parameters (in a multiplicative form) are responsible for the loan supply (in particular, they affect its slope). However, based on the values considered, the multiplication of these parameters is small in its magnitude such that the dynamics of the model is not affected considerably. As regards the second group of parameters, the augmented rule seems to be even more beneficial in case of a higher stickiness. Justification for the result regarding the adjustment cost parameter κ_K is as follows: when κ_K is close to zero, price of assets is very sticky and it almost does not move. From this implies that the augmented rule brings less macroeconomic benefits.

Lastly, the results of the model are not subject to the changes in the smoothing of the policy rate. The only exception is the case of the bank capital shock. When the persistence parameter is lower than 0.75, reacting to the financial variables seems not to be distorting and there is neither loss nor gain with respect to the baseline rule. The opposite holds for the foreign shocks – for high values of ρ_R, the AMPR III delivers more favourable results than the baseline rule. To summarize, despite slight quantitative differences in several cases, the AMPR III brings benefits over the baseline rule for different values of the key parameters. Therefore, conclusions drawn from the initial simulations seem to be robust.

The last exercise shows gains of the AMPR III with respect to the baseline rule with changing weight ascribed to GDP, ω, in the weighted sum described by equation (18). As figure 9 shows, for different weights ω, the AMPR III achieves higher macroeconomic stability in terms of implied volatility in comparison to the baseline rule. However, gain is decreasing with increasing value of ω. The only exception is the bank capital shock, when implementation of the AMPR III seems to have plausible implications for stabilization of GDP (decreasing loss with increasing ω). The analysis suggests that the AMPR III brings significantly lower volatilities in case of inflation, while volatility stabilization regarding GDP is questionable and the rule does not perform so well in this regard (volatility in GDP rather increases with implementation of the AMPR III). Nevertheless,

when considering stable inflation to be the ultimate goal of monetary policy, gains in terms of lower volatility in GDP are secondary.

6. Conclusion

Financial stability and its connection to monetary policy has become one of the most prominent topics discussed in the field of macroeconomics and monetary economics. In the light of the recent financial crisis, the natural question that has arisen is whether two conventional macroeconomic indicators – inflation and output – are sufficient ingredients of the monetary policy rules. Because of the strong relationship between the financial sector and the real side of the economy, the role of the financial variables within the monetary policy rules started to be investigated. Despite the research is growing extensively in this field, the topic is rather new and there is a lot to be examined. Moreover, most studies focus on the closed economies. The purpose of this research is to test the augmented monetary policy rules in the DSGE model for the small open economy that is represented by the Czech Republic.

This research contributes to the existing theoretical evidence by the analysis of the augmented monetary policy rules in the small open economy context. The results show that reacting to the financial variables might be beneficial for the inflation and output stabilization, and therefore for the monetary authority. The analyses show that reacting by the augmented rule (where a positive weight is ascribed to asset prices and a negative weight to credit volume) might bring decrease in inflation and output variability of up to 30%, depending on the shock. The gains are obvious in case of foreign shocks that affect the developments in the small open economy considerably. On the other hand, reacting to the financial variables is counterproductive in case of the severe shock to bank capital. Additionally, the model depicts the importance of the financial sector for the real side of the economy. This connection is most evident in case of bank capital loss, when under-capitalised commercial banks are not able to produce loans and the economy experiences deep recession.

Even though the results seem to be promising, they should be interpreted with certain caution. First, the model does not include any features related to the financial stress (such as an endogenous exit of non-financial firms or the crashes of the commercial banks) that are typical for a financial crisis. Therefore, the augmented rules are tested in normal times and the importance of the augmented rules might be even higher in case of non-ordinary times. Second, the model is linearised. This technique removes any non-linearity which might be characteristic for the crisis periods. Third, the results should be taken as qualitative rather than quantitative. The model is highly stylized, the coefficients are computed based on simplified routines and optimization methods. Therefore, they are likely not to resemble the reality precisely. Fourth, the model demonstrates that it could work according to "loanable funds theory". In this setting, commercial banks do not create money endogenously, which does not need to resemble reality.

To summarize, the model indicates that the financial variables can be useful in monetary policy decision making since the connection between the financial side and the real side of the economy is

significant. Therefore, the financial variables are likely to indicate future inflationary developments and the policy rate should be adjusted accordingly. On the other hand, the model shows that monetary policy itself is not able to respond optimally when an abrupt shock hits the financial sector. This might suggest that rather unconventional monetary policy tool should be implemented. The results of the model are subject to the robustness check that indicates that the results are robust to the changes in the key parameters.

Appendix A. A description of the model

A.1. Households

The economy is populated by rational households of measure γ^H. Each household consumes, works, saves money in a bank that pays the deposit rate, and purchases a non-contingent foreign bond which yields a risk-adjusted return. Households receive positive utility from consuming, while receive disutility from working. Preferences of a representative household are given by the following utility function:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta_H^t A_t^C \log(C_t^H(j) - \iota C_{t-1}^H(j)) - \frac{(H_t(j))^{1+\phi}}{1+\phi} \tag{19}$$

where C_t^H is consumption, ιC_{t-1}^H is the external habit stock with $\iota \in [0,1]$ being a parameter characterizing the degree of habit persistence, H_t is labour supply, ϕ is the inverse of the Frisch wage elasticity of labour supply, $\beta_H \in [0,1]$ is the exogenous discount parameter, and A_t^C is a consumption preference shock. Its deviation from the steady state is assumed to follow an AR(1) process with ε_t^C being normally distributed with zero mean and variance σ_C^2:

$$\hat{a}_t^C = \rho_C \hat{a}_{t-1}^C + \varepsilon_t^C \tag{20}$$

The household's budget constraint is specified as (in real terms):

$$C_t^H(j) + D_t(j) + \mathcal{E}_t B_t(j) \leq W_t H_t(j) + \frac{R_{t-1} D_{t-1}(j)}{\Pi_t} + \frac{R_{t-1}^* F_{t-1} \mathcal{E}_t B_{t-1}(j)}{\Pi_t} + T_t(j) \tag{21}$$

where $\Pi_t = P_t/P_{t-1}$ is the gross inflation rate with P_t being the price level, $\mathcal{E}_t$ is the nominal exchange rate, W_t is the real wage earned by household, R_t is the nominal interest rate on saving deposits D_t, $R_t^* F_t$ is a risk adjusted nominal return paid on foreign bonds B_t (denominated in foreign currency), T_t represents a lump-sum transfer that includes profits from the ownership of domestic retailers, importing retailers and capital goods producers. According to Adolfson, Laseén, and Lindé (2008), the debt-elastic risk premium is defined as:

$$F_t = \exp\left\{\psi^*\left(\frac{\mathcal{E}_t B_t}{P_t Y_{G,t}}\right)\right\} A_t^{UIP} = \exp\left\{\psi^*\left(\frac{L_t^*}{Y_{G,t}}\right)\right\} \tag{22}$$

with $\mathcal{E}_t B_t / Y_{G,t} P_t$ being the real outstanding net foreign assets position of the domestic economy with $Y_{G,t}$ referring to GDP and $\psi^* > 0$ being the parameter characterizing elasticity of the risk premium.

Each household chooses consumption C_t^H, labour supply H_t, bank deposits D_t, and foreign bonds B_t in order to maximize its lifetime discounted utility (19) with respect to the budget constraint (21). Combining first-order conditions of the maximization problem yields (after imposing

symmetry):

$$(H_t)^{\phi} = (C_t^H - \iota C_{t-1}^H)^{-1} W_t A_t^C \tag{23}$$

$$R_t = \frac{1}{\beta_H} \mathbb{E}_t \left\{ \frac{C_{t+1}^H - \iota C_t^H}{C_t^H - \iota C_{t-1}^H} \frac{A_t^C}{A_{t+1}^C} \Pi_{t+1} \right\} \tag{24}$$

$$\frac{R_t}{R_t^*} = \mathbb{E}_t \left\{ \frac{\mathcal{Q}_{t+1} \Pi_{t+1}}{\mathcal{Q}_t \Pi_{t+1}^*} \right\} F_t \tag{25}$$

Equation (23) is the intra-temporal condition defining the trade-off between consumption and leisure, equation (24) is the Euler equation describing the optimal path of consumption, and equation (25) refers to the standard UIP condition.

A.2. Entrepreneurs

Entrepreneurs are modelled as in Gerali et al. (2010). The economy is populated by entrepreneurs of measure γ^E who consume, buy capital, hire labour from households and borrow from banks. They combine production resources and external financing in order to produce wholesale output. They are risk-neutral. In the production of wholesale goods, entrepreneurs face a financing constraint which is the source of financial accelerator.

Each entrepreneur only cares about his/her consumption. By choosing optimal levels of consumption C_t^E, capital K_t^K, the degree of capital utilization U_t, labour H_t and loans from banks L_t, the entrepreneur maximizes the utility function:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta_E^t \log(C_t^E(j) - \iota C_{t-1}^E(j)) \tag{26}$$

subject to the budget constraint:

$$C_t^E(j) + W_t H_t(j) + \frac{R_{t-1}^L L_{t-1}(j)}{\Pi_t} + Q_t^K K_t^K(j) + \psi(U_t(j)) K_{t-1}^K(j) \leq \frac{Y_t^W(j) P_t^W}{P_t} + L_t(j) + Q_t^K (1 - \delta_K) K_{t-1}^K(j) \tag{27}$$

where $\iota \in [0, 1]$ is a parameter characterizing the degree of habit persistence, δ_K represents the depreciation of capital, Q_t^K is the real price of capital, $\psi(U_t) K_{t-1}^K$ represents a real cost of setting a level U_t of capital utilization, and P_t^W is the price of wholesale good. The production function is defined as:

$$Y_t^W(j) = A_t^Y [K_{t-1}^K(j) U_t(j)]^{\alpha} (H_t(j))^{1-\alpha} \tag{28}$$

where K_{t-1}^K is capital purchased at time t, H_t is labour supplied by households and A_t^Y is a productivity shock. Its deviation from the steady state is assumed to follow an AR(1) process with

ε_t^Y being normally distributed with zero mean and variance σ_Y^2:

$$\hat{a}_t^Y = \rho_Y \hat{a}_{t-1}^Y + \varepsilon_t^Y \tag{29}$$

As in Iacoviello (2005), entrepreneurs are limited in the amount of borrowing, because banks insist on entrepreneurs to possess sufficient amount of collateral. The original approach by Iacoviello (2005) is modified according to Gerali et al. (2010), who propose that entrepreneurs are constrained by holdings of capital. This innovation is likely to be more realistic, since entrepreneurs use houses (i.e., real estate) as collateral in Iacoviello (2005). Capital seems to better represent overall balance-sheet condition, and therefore the creditworthiness of a firm. The borrowing constraint is defined as:

$$R_t^L L_t(j) \leq m \mathbb{E}_t \{ Q_{t+1}^K \Pi_{t+1} (1 - \delta_K) K_t^K(j) \} \tag{30}$$

where m is the LTV ratio chosen by the commercial banks.

First-order conditions of the above specified optimization problem are (after imposing symmetry):

$$\begin{aligned}
\lambda_{1,t}^E &= \frac{1}{C_t^E - \iota C_{t-1}^E} && (31)\\
\lambda_{1,t}^E Q_t^K &= \beta_E \lambda_{1,t+1}^E \left[\alpha A_{t+1}^Y U_{t+1}^{\alpha} (K_t^K)^{\alpha-1} H_{t+1}^{1-\alpha} p_{t+1}^W + Q_{t+1}^K (1 - \delta_K) - \psi(U_{t+1}) \right] \\
&\quad + \lambda_{2,t}^E m Q_{t+1}^K \Pi_{t+1} (1 - \delta_K) && (32)\\
\psi'(U_t) &= \alpha A_t^Y [U_t K_{t-1}^K]^{\alpha-1} H_t^{1-\alpha} p_t^W && (33)\\
W_t &= (1 - \alpha) A_t^Y [U_t(j) K_{t-1}^K]^{\alpha} H_t^{-\alpha} p_t^W && (34)\\
\lambda_{1,t}^E &= \lambda_{2,t}^E R_t^L + \beta_E \lambda_{1,t+1}^E \frac{R_t^L}{\Pi_{t+1}} && (35)
\end{aligned}$$

where $p_t^W = P_t^W / P_t$ is the real wholesale price.

A.3. Capital producers

Following Gerali et al. (2010), capital producers combine existing undepreciated capital stock purchased from entrepreneurs (at nominal price P_t) with unsold final goods purchased from retailers as investment goods, I_t, in order to produce new capital K_{t+1}^K. Capital is subject to depreciation represented by the depreciation rate δ_K. Therefore, depreciated capital is replaced with the new capital. The aggregate capital stock evolves according to:

$$K_t^K = \Phi \left(\frac{I_t}{I_{t-1}} \right) + (1 - \delta_K) K_{t-1}^K \tag{36}$$

where $\Phi(\cdot)$ is a concave and increasing production function. Production of capital is subject to quadratic adjustment costs. Therefore, production function of capital is defined as:

$$\Phi\left(\frac{I_t}{I_{t-1}}\right) = I_t - \frac{\kappa_K}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2 I_t \tag{37}$$

where $\kappa_K > 0$ is an adjustment cost parameter.

Capital producers choose the optimal level of investment in order to maximize profits (in real terms):

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \Lambda_{0,t} \left\{ Q_t^K (K_t^K - (1-\delta_K) K_{t-1}^K) - I_t \right\} \tag{38}$$

where $\Lambda_{0,t}$ is a stochastic discount factor. Using law of motion of capital, maximization collapses to:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \Lambda_{0,t} \left\{ Q_t^K \left[1 - \frac{\kappa_K}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2 \right] I_t - I_t \right\} \tag{39}$$

Optimization yields a first order condition:

$$Q_t^K \left[1 - \kappa_K \left(\frac{I_t}{I_{t-1}} - 1\right)\frac{I_t}{I_{t-1}} - \frac{\kappa_K}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2 \right] - 1 + \beta_H \frac{U'(C_{t+1})}{U'(C_t)} \left[Q_{t+1}^K \kappa_K \left(\frac{I_{t+1}}{I_t} - 1\right)\frac{I_{t+1}^2}{I_t^2} \right] = 0 \tag{40}$$

which determines the supply of capital. Moreover, it is the Tobin's Q equation describing the relationship between the price of capital and the marginal adjustment costs. Capital adjustment costs serve as a decelerator of the response of investment to shocks, which enables the price of capital to vary.

A.4. Final goods producers and retailers

Final goods producers aggregate differentiated products purchased from domestic retailers $Y_{H,t}(j_H)$ and importing retailers $Y_{F,t}(j_F)$ into a composite good, which is then sold in a market. Producers utilise technology of the form[7]:

$$Y_t = \left[\eta^{\frac{\mu}{1+\mu}} Y_{H,t}^{\frac{1}{1+\mu}} + (1-\eta)^{\frac{\mu}{1+\mu}} Y_{F,t}^{\frac{1}{1+\mu}} \right]^{1+\mu} \tag{41}$$

where μ is the elasticity of substitution between domestic goods and imported goods, and $\eta \in [0;1]$ measures the degree of openness. The optimization yields the following demand functions for

[7]Both components of the technology are defined by the standard constant elasticity of substitution (CES) functions as $Y_{H,t} = \left(\int_0^1 Y_{H,t}(j_H)^{\frac{1}{1+\mu_H}} dj_H\right)^{1+\mu_H}$ and $Y_{F,t} = \left(\int_0^1 Y_{F,t}(j_F)^{\frac{1}{1+\mu_F}} dj_F\right)^{1+\mu_F}$.

differentiated goods:

$$Y_{H,t}(j_H) = \left(\frac{P_{H,t}(j_H)}{P_{H,t}}\right)^{-\frac{1+\mu_H}{\mu_H}} Y_{H,t} \tag{42}$$

$$Y_{F,t}(j_F) = \left(\frac{P_{F,t}(j_F)}{P_{F,t}}\right)^{-\frac{1+\mu_F}{\mu_F}} Y_{F,t} \tag{43}$$

where μ_H and μ_F measure the substitutability of goods, and demands for aggregate goods are:

$$Y_{H,t} = \eta \left(\frac{P_{H,t}}{P_t}\right)^{-\frac{1+\mu}{\mu}} Y_t \tag{44}$$

$$Y_{F,t} = (1-\eta) \left(\frac{P_{F,t}}{P_t}\right)^{-\frac{1+\mu}{\mu}} Y_t \tag{45}$$

The aggregate price indices are given by:

$$P_{H,t} = \left(\int_0^1 P_{H,t}(j_H)^{-\frac{1}{\mu_H}} dj_H\right)^{-\mu_H} \tag{46}$$

$$P_{F,t} = \left(\int_0^1 P_{F,t}(j_F)^{-\frac{1}{\mu_F}} dj_F\right)^{-\mu_F} \tag{47}$$

and the aggregate consumer price index (CPI) is given by the Dixit-Stiglitz function:

$$P_t = \left[\eta P_{H,t}^{-\frac{1}{\mu}} + (1-\eta) P_{F,t}^{-\frac{1}{\mu}}\right]^{-\mu} \tag{48}$$

For simplicity it is assumed that aggregate demand for exports takes the same form as (45), only with different parameters:

$$Y_{H,t}^* = (1-\eta^*) \left(\frac{P_{H,t}^*}{P_t^*}\right)^{-\frac{1+\mu^*}{\mu^*}} Y_t^* \tag{49}$$

In the economy, there exists three types of monopolistically competitive retailers: home goods retailers, importing retailers and exporting retailers. The aim of retailers is to differentiate respective goods and earn profits. There are no costs related to differentiation of the products. All three types of retailers face a variant of Calvo-pricing scheme proposed by Calvo (1983) in order to introduce nominal rigidities into the model. The sector of retailers is modelled according to Brzoza-Brzezina and Makarski (2011). Since there is no divergence with respect to the original paper, the specifications of the optimization problems are omitted and only the final results are presented.

Home goods retailers redistribute goods produced by entrepreneurs to final goods producers. They purchase wholesale goods from entrepreneurs at the wholesale price P_t^W and resell them at

their retail price. The maximization problem yields a first order condition:

$$\mathbb{E}_0 \sum_{\tau=0}^{\infty} \theta_H^{\tau} \Lambda_{t,t+\tau} \left(-\frac{1}{\mu_H} \right) \left\{ \left[x_{H,t,\tau} \widetilde{p}_{H,t}(j_H) - (1+\mu_H) p_{t+\tau}^W \right] Y_{H,t,t+\tau}(j_H) \right\} \tag{50}$$

where $x_{H,t,\tau} = X_{H,t,\tau} / \prod_{s=1}^{\tau} \Pi_{t+s}$ is the real indexation factor, $p_{t+\tau}^W = P_{t+\tau}^W / P_{t+\tau}$ is the real price of wholesale goods, and $\widetilde{p}_{H,t}(j_H) = \widetilde{P}_{H,t}(j_H)/P_t$ is the real price set by optimizing retailers.

Exporting retailers redistribute goods produced by entrepreneurs to foreign households. They purchase wholesale goods from entrepreneurs at the wholesale price P_t^W and resell them at their retail price. The maximization problem yields a first order condition:

$$\mathbb{E}_0 \sum_{\tau=0}^{\infty} (\theta_H^*)^{\tau} \Lambda_{t,t+\tau} \left(-\frac{1}{\mu_H^*} \right) \left\{ \left[x_{t,\tau}^* \widetilde{p}_{H,t}^*(j_H^*) - (1+\mu_H^*) \frac{p_{t+\tau}^W}{\mathcal{Q}_{t+\tau}} \right] Y_{H,t,t+\tau}^*(j_H^*) \right\} \tag{51}$$

where $x_{t,\tau}^* = X_{t,\tau}^* / \prod_{s=1}^{\tau} \Pi_{t+s}^*$ is the real indexation factor and $\widetilde{p}_{H,t}^*(j_H^*) = \widetilde{P}_{H,t}^*(j_H^*)/P_t$ is the real price set by optimizing retailers.

Importing retailers are modelled in the same manner as home goods retailers. It is assumed that the law of one price holds at the wholesale level. Therefore, these retailers purchase the products from foreign entrepreneurs at price $\mathcal{E}_t P_t^*$ (which can be rewritten as $\mathcal{Q}_t P_t$) expressed in domestic currency and they redistribute imported products at the retail price $P_{F,t}$.[8] Since retailers have some degree of power in setting their prices, law of one price does not hold necessarily (i.e. $P_{F,t} \neq \mathcal{E}_t P_t^*$). Hence, this feature introduces the incomplete exchange rate pass-through into the model. The maximization problem yields a first order condition:

$$\mathbb{E}_0 \sum_{\tau=0}^{\infty} \theta_F^{\tau} \frac{\Lambda_{t,t+\tau}^*}{\mathcal{Q}_{t+\tau}} \left(-\frac{1}{\mu_F} \right) \left\{ \left[x_{F,t,\tau} \widetilde{p}_{F,t}(j_F) - (1+\mu_F) \mathcal{Q}_{t+\tau} \right] Y_{F,t,t+\tau}(j_F) \right\} \tag{52}$$

where $x_{F,t,\tau} = X_{F,t,\tau} / \prod_{s=1}^{\tau} \Pi_{t+s}$ is the real indexation factor and $\widetilde{p}_{F,t}(j_F) = \widetilde{P}_{F,t}(j_F)/P_t$ is the real price set by optimizing retailers.

A.5. Commercial banking sector

The banking sector is modelled according to Gambacorta and Signoretti (2014).

Commercial banks (henceforth banks) posses certain market power in intermediation, which enables them to change rates on deposits and loans in response to various shocks. Banks have to obey a balance-sheet condition stating that *loans* = *deposits* + *capital*. Banks also face an "optimal" exogenous target for capital-to-asset ratio (i.e., the inverse of leverage), which can be seen as a simplified tool to study implications of capital requirements set by regulatory authorities. Additionally, the model allows for a feedback loop between financial sector and the real side of the economy. In case of subdued macroeconomic conditions, banks might respond to the situation by

[8] As a modelling simplification, it is assumed that retailers in foreign economy coincide with foreign entrepreneurs, and therefore there is no distinction between foreign wholesale price and foreign retail price.

cutting the volume of issued loans, and therefore aggravating the original conditions.

The banking sector is composed of a continuum of banks indexed by $j \in (0, 1)$. Individual bank consists of two units – wholesale and retail. The role of the wholesale unit is to collect deposits from households and to issue wholesale loans. The retail unit purchases wholesale loans, differentiates them and resells them to entrepreneurs.

A.5.1. Wholesale branch

The wholesale unit of each bank operates under perfect competition. The wholesale unit collects deposits D_t from households at the rate set by the central bank R_t and issues wholesale loans L_t at the wholesale rate R_t^{WL}. The balance sheet of the wholesale branch consists of bank capital K_t^B and deposits D_t on the liability side, while on the asset side can be found wholesale loans L_t (all in real terms). Bank faces an optimal value of capital-to-asset ratio ν_B. Whenever the actual capital-to-asset ratio K_t^B/L_t diverts from the target value ν_B, the bank pays a quadratic adjustment cost parametrized by κ_B. This feature implies that bank leverage ratio determines loans interest rates, which generates feedback loop between the real side of the economy and financial sector. Bank capital evolves according to:

$$K_t^B = (1 - \delta_B)\frac{K_{t-1}^B}{A_t^B} + \Xi_{t-1}^B \tag{53}$$

where δ_B represents the cost for managing the bank's capital position, and Ξ_t^B are overall profits of the bank as outlined by equation (58).[9] A_t^B is a bank capital shock. Its deviation from the steady state is assumed to follow an AR(1) process with ε_t^B being normally distributed with zero mean and variance σ_B^2:

$$\hat{a}_t^B = \rho_B \hat{a}_{t-1}^B + \varepsilon_t^B \tag{54}$$

The wholesale unit of the bank chooses the optimal level of deposits and loans in order to maximize profit:

$$R_t^{WL} L_t(j) - R_t D_t(j) - \frac{\kappa_B}{2}\left(\frac{K_t^B(j)}{L_t(j)} - \nu_B\right)^2 K_t^B(j) \tag{55}$$

subject to the balance constraint $L_t = D_t + K_t^B$, while taking the interest rate R_t and the wholesale rate on loans R_t^{WL} as given. Combining the first-order conditions yields the relationship between the capital-to-asset ratio K_t^B/L_t and the spread between wholesale rates on deposits and loans:

$$R_t^{WL} - R_t = -\kappa_B\left(\frac{K_t^B(j)}{L_t(j)} - \nu_B\right)\left(\frac{K_t^B(j)}{L_t(j)}\right)^2 \tag{56}$$

The left-hand side of the above equation represents the marginal benefit from lending (i.e., an

[9] For simplicity it is assumed that the commercial banks have no dividend policy.

increase in profits from one loan issued), while the right-hand side represents the marginal cost from lending. Banks choose the optimal level of loans such that costs and benefits stemming from changing the leverage ratio are equalized at the margin.

A.5.2. Retail branch

Retail branches of banks operate in a monopolistically competitive market. The retail branch purchases wholesale loans from the wholesale branch, differentiates them at no cost and resells them to entrepreneurs. It is assumed, that retail branch applies constant mark-up μ_B on the wholesale loan rate R_t^{WL}. Therefore, the retail loan rate is defined as:

$$R_t^L = R_t - \kappa_B \left(\frac{K_t^B(j)}{L_t(j)} - \nu_B \right) \left(\frac{K_t^B(j)}{L_t(j)} \right)^2 + \mu_B \tag{57}$$

Bank profits combine all the partial net earnings. Aggregate bank profits (in real terms) are given by:

$$\Xi_t^B = R_t^L L_t - R_t D_t - \frac{\kappa_B}{2} \left(\frac{K_t^B}{L_t} - \nu_B \right)^2 K_t^B \tag{58}$$

A.6. Central bank

Policy of the central bank is described by a few different monetary policy rules. First, since this research focuses on the Czech Republic, a simplified version of the monetary policy rule of the Czech National Bank is outlined. Second, because financial sector significantly affects the real side of the economy, reaction functions augmented by several financial variables are introduced.

A.6.1. Conventional monetary policy rule

In the baseline model, the central bank adjusts the policy rate, R_t, in response to deviations of inflation, Π_t, from its steady-state value. This representation of policy resembles state in which the central bank does not explicitly adjust its policy rate with respect to financial disturbances. Following Andrle et al. (2009), the Czech National Bank implements a regime of inflation targeting with interest rate smoothing. This specific rule takes form:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R} \right)^{\rho_R} \left(\left(\frac{\Pi_t}{\Pi} \right)^{\varrho_\Pi} \right)^{1-\rho_R} \tag{59}$$

where R and Π are the steady-state values of R_t and Π_t respectively, ρ_R depicts inflation persistence, ϱ_Π is a weight characterizing the importance of inflation deviation.

A.6.2. Augmented monetary policy rules (AMPRs)

Compared to the baseline scenario, the central bank reflects developments in financial sector in its policy rule. Generally, AMPR takes the form:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_R} \left(\left(\frac{\Pi_t}{\Pi}\right)^{\varrho_\Pi} \left(\frac{\Psi_t}{\Psi}\right)^{\varrho_\Psi}\right)^{1-\rho_R} \tag{60}$$

where Ψ_t represents financial variable with Ψ being its steady state value and ϱ_Ψ being respective assigned weight.

Credit (AMPR I). The developments in credit market have a significant impact on the real side of the economy, because increase in credit supply encourages economic players to be more active. This augmented rule accounts for credit volume under two considerations. Since there has been reached no agreement about the role of credit in financial stability yet, the central banks reacts: (i) by encouraging credit to firms (i.e., non-financial sector), or (ii) by discouraging credit. The AMPR I is given by:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_R} \left(\left(\frac{\Pi_t}{\Pi}\right)^{\varrho_\Pi} \left(\frac{L_t}{L}\right)^{\varrho_L}\right)^{1-\rho_R} \tag{61}$$

where L_t refers to loans granted to entrepreneurs, L is its steady state value and $\varrho_L \lessgtr 0$ is assigned weight. Following Aydin and Volkan (2011), ϱ_L is set to ± 0.3.

Asset prices (AMPR II). Following Gambacorta and Signoretti (2014), the central bank accounts for asset prices (which are represented by Q_t^K) in its monetary policy rule. To motivate this rule, assume increase in asset prices. Such movement implies a higher value of collateral that can be pledged against loan. This in turn enhances investment and spending. Therefore, rising asset prices could indicate a future inflationary pressures. The AMPR II is described by:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_R} \left(\left(\frac{\Pi_t}{\Pi}\right)^{\varrho_\Pi} \left(\frac{Q_t^K}{Q^K}\right)^{\varrho_Q}\right)^{1-\rho_R} \tag{62}$$

where Q^K is its steady state value of Q_t^K and $\varrho_Q > 0$ is assigned weight.

Credit and asset prices combined (AMPR III). The last augmented monetary policy rule combines both mentioned financial variables – credit and asset prices. The AMPR III is defined as:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_R} \left(\left(\frac{\Pi_t}{\Pi}\right)^{\varrho_\Pi} \left(\frac{L_t}{L}\right)^{\varrho_L} \left(\frac{Q_t^K}{Q^K}\right)^{\varrho_Q}\right)^{1-\rho_R} \tag{63}$$

where the weights are the same as in the previous augmented rules.

A.7. Foreign sector

The foreign sector is represented by simple AR(1) processes. Even though that the recent literature employs VAR models as a representation of the foreign sector (such as Christiano et al.,

2011), this paper does not follow this approach for the following reason. The VAR model is complicated and the coefficients are estimated so as to maximize the criterion function and to fit the data. The results of the VAR estimation are not straightforward and there is no economic intuition behind the estimated values of respective coefficients. Moreover, the VAR model entails additional dynamics that cannot be described easily and it introduces unclear oscillations in the responses to the foreign shocks. Therefore, the foreign sector is represented by the following system of equations:

$$\begin{pmatrix} \hat{y}_t^* \\ \hat{\pi}_t^* \\ \hat{r}_t^* \end{pmatrix} = \begin{pmatrix} \rho_{y^*} & 0 & 0 \\ 0 & \rho_{\pi^*} & 0 \\ 0 & 0 & \rho_{r^*} \end{pmatrix} \begin{pmatrix} \hat{y}_{t-1}^* \\ \hat{\pi}_{t-1}^* \\ \hat{r}_{t-1}^* \end{pmatrix} + \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \varepsilon_t^{y^*} \\ \varepsilon_t^{\pi^*} \\ \varepsilon_t^{r^*} \end{pmatrix} \tag{64}$$

where $\varepsilon_t^{y^*} \sim iid(0, \sigma_{y^*}^2)$, $\varepsilon_t^{\pi^*} \sim iid(0, \sigma_{\pi^*}^2)$, $\varepsilon_t^{r^*} \sim iid(0, \sigma_{r^*}^2)$, and the autocorrelation coefficients ρ_{y^*}, ρ_{π^*}, $\rho_{r^*} \in (0, 1)$.

A.8. Market clearing conditions and GDP

It is assumed, that banks use all deposits and bank capital to originate loans. Therefore, the following condition has to be met in equilibrium:

$$L_t = D_t + K_t^B \tag{65}$$

In market for final goods has to hold that:

$$C_t + I_t + \psi(U_t) K_{t-1}^K + \delta_B \frac{K_{t-1}^B}{\Pi_t} = Y_t \tag{66}$$

where aggregate consumption C_t is composed of two ingredients – consumption of households and consumption of entrepreneurs:

$$C_t = \gamma^H C_t^H + \gamma^E C_t^E \tag{67}$$

where $\gamma^H + \gamma^E = 1$.

Aggregate production of wholesale goods has to satisfy demand from home economy as well as demand from foreign economy:

$$Y_t^W = \int_0^1 Y_{H,t}(j) dj + \int_0^1 Y_{H,t}^*(j) dj \tag{68}$$

Balance of payments ensures that supply of new loans to foreign economy equals interest rate payments on previous debt plus nominal net exports:

$$\int_0^1 \mathcal{E}_t P_{H,t}^*(j_H^*) Y_{H,t}^*(j_H^*) dj_H^* + \mathcal{E}_t L_t^* = \int_0^1 P_{F,t}(j_F) Y_{F,t}(j_F) dj_F + R_{t-1}^* F_{t-1} \mathcal{E}_t L_{t-1}^* \tag{69}$$

Lastly, gross domestic product ($Y_{G,t}$) is defined as a sum of final goods exploited in domestic economy and net exports:

$$P_t Y_{G,t} = P_t Y_t + \int_0^1 \mathcal{E}_t P^*_{H,t}(j^*_H) Y^*_{H,t}(j^*_H) dj^*_H - \int_0^1 P_{F,t}(j_F) Y_{F,t}(j_F) dj_F \tag{70}$$

Appendix B. The full model equation block

The following log-linearised equations characterise the model.

B.1. Households

Debt-elastic risk premium (22):

$$\hat{f}_t = \psi^* \frac{L^*}{Y_G} \hat{l}_t^* - \psi^* \frac{L^*}{Y_G} \hat{y}_{G,t}$$

Intra-temporal optimality condition between consumption and leisure (23):

$$\hat{h}_t = \frac{\hat{w}_t}{\phi} - \frac{\hat{c}_t^H - \iota \hat{c}_{t-1}^H}{(1-\iota)\phi} + \frac{\hat{a}_t^C}{\phi}$$

Inter-temporal optimality condition (24):

$$\hat{r}_t = \frac{\hat{c}_{t+1}^H - \iota \hat{c}_t^H}{1-\iota} - \frac{\hat{c}_t^H - \iota \hat{c}_{t-1}^H}{1-\iota} + \mathbb{E}_t\{\hat{\pi}_{t+1}\} + \hat{a}_t^C - \hat{a}_{t+1}^C$$

UIP condition (25):

$$\hat{r}_t - \hat{r}_t^* = \mathbb{E}_t\{\hat{q}_{t+1}\} - \hat{q}_t + \mathbb{E}_t\{\hat{\pi}_{t+1}\} - \mathbb{E}_t\{\hat{\pi}_{t+1}^*\} + \hat{f}_t$$

B.2. Entrepreneurs

Flow of funds (27):

$$\begin{aligned} \frac{\gamma^E C^E}{C} \frac{C}{Y_G} \hat{c}_t^E \;=\; & \frac{p^W Y^W}{Y_G}(\hat{p}_t^W + \hat{y}_t^W) + \frac{1-\delta_K}{\delta_K} \frac{I}{Y_G}(\hat{q}_t^K + \hat{k}_{t-1}^K) + \frac{L}{Y_G} \hat{l}_t \\ & - \frac{WH}{Y_G}(\hat{w}_t + \hat{h}_t) - \frac{I}{\delta_K Y_G}(\hat{q}_t^K + \hat{k}_t^K) - \frac{\psi'(1) I}{\delta_K Y_G} \hat{u}_t \\ & - \frac{R^L L}{\Pi Y_G}(\hat{r}_{t-1}^L + \hat{l}_{t-1} - \hat{\pi}_t) \end{aligned}$$

Production function (28):

$$\hat{y}_t^W = \alpha \hat{k}_{t-1}^K + \alpha \hat{u}_t + (1-\alpha)\hat{h}_t + \hat{a}_t^Y$$

Collateral constraint (30):

$$\hat{r}_t^L + \hat{l}_t = \mathbb{E}_t\{\hat{q}_{t+1}^K\} + \mathbb{E}_t\{\hat{\pi}_{t+1}\} + \hat{k}_t^K$$

Marginal utility of entrepreneurial consumption (31):

$$\hat{\lambda}^E_{1,t} = \frac{\iota \hat{c}^E_{t-1} - \hat{c}^E_t}{1-\iota}$$

Optimal level of capital (32):

$$\begin{aligned}\hat{q}^K_t &= (1-\delta_K)\beta_E \mathbb{E}_t\{\hat{q}^K_{t+1} + \hat{\lambda}^E_{1,t+1} - \hat{\lambda}^E_{1,t}\} + \beta_E \psi'(1)\mathbb{E}_t\left\{\hat{\lambda}^E_{1,t+1} - \hat{\lambda}^E_{1,t} + \frac{\psi''(1)}{\psi'(1)}\hat{u}_{t+1}\right\} \\ &+ m(1-\delta_K)\Pi\left[\left(\frac{1}{R^L} - \frac{\beta_E}{\Pi}\right)\mathbb{E}_t\{\hat{q}^K_{t+1}\} - \frac{1}{R^L}\mathbb{E}_t\{\hat{r}^L_t - \hat{\pi}_{t+1}\}\right. \\ &\left. - \frac{\beta_E}{\Pi}\mathbb{E}_t\{\hat{\lambda}^E_{1,t+1} - \hat{\lambda}^E_{1,t}\}\right]\end{aligned}$$

Capital utilization (33):

$$\hat{u}_t = \frac{\psi'(1)}{\psi''(1)}[\hat{p}^W_t + (1-\alpha)(\hat{h}_t - \hat{u}_t - \hat{k}^K_{t-1}) + \hat{a}_t]$$

Labour demand (34):

$$\hat{w}_t = \hat{p}^W_t + \alpha k^K_{t-1} + \alpha \hat{u}_t - \alpha \hat{h}_t + \hat{a}^Y_t$$

B.3. Capital producers

Law of motion of capital (36):

$$\hat{k}^K_t = \delta_K \hat{i}_t + (1-\delta_K)\hat{k}^K_{t-1}$$

Price of capital (40):

$$\hat{q}^K_t = \frac{1+\beta_H}{\kappa_K}\hat{i}_t - \frac{1}{\kappa_K}\hat{i}_{t-1} - \frac{\beta_H}{\kappa_K}\mathbb{E}_t\{\hat{i}_{t+1}\}$$

B.4. Final goods producers

Technology (41):

$$\hat{y}_t = \eta^{\frac{\mu}{1+\mu}}\left(\frac{Y_H}{Y}\right)^{\frac{1}{1+\mu}}\hat{y}_{H,t} + (1-\eta)^{\frac{\mu}{1+\mu}}\left(\frac{Y_F}{Y}\right)^{\frac{1}{1+\mu}}\hat{y}_{F,t}$$

Demand for home goods (44):

$$\hat{y}_{H,t} = -\frac{1+\mu}{\mu}\hat{p}_{H,t} + \hat{y}_t$$

Demand for imports (45):

$$\hat{y}_{F,t} = -\frac{1+\mu}{\mu}\hat{p}_{F,t} + \hat{y}_t$$

Demand for exports (49):

$$\hat{y}^*_{H,t} = -\frac{1+\mu^*}{\mu^*}\hat{p}^*_{H,t} + \hat{y}^*_t$$

B.5. Retailers

Domestic goods price (50):

$$\frac{\theta_H}{1-\theta_H}(\hat{p}_{H,t} - \hat{p}_{H,t-1} + \hat{\pi}_t - \varsigma_H\hat{\pi}_{t-1}) = (1-\beta_H\theta_H)(\hat{p}^W_t - \hat{p}_{H,t}) + \frac{\beta_H\theta_H}{1-\theta_H}(\mathbb{E}_t\{\hat{p}_{H,t+1}\} - \hat{p}_{H,t} + \mathbb{E}_t\{\hat{\pi}_{t+1}\} - \varsigma_H\hat{\pi}_t)$$

Exported goods price (51):

$$\frac{\theta^*_H}{1-\theta^*_H}(\hat{p}^*_{H,t} - \hat{p}^*_{H,t-1} + \hat{\pi}^*_t - \varsigma^*_H\hat{\pi}^*_{t-1}) = (1-\beta^*_H\theta^*_H)(\hat{p}^W_t - \hat{q}_t - \hat{p}^*_{H,t}) + \frac{\beta^*_H\theta^*_H}{1-\theta^*_H}(\mathbb{E}_t\{\hat{p}^*_{H,t+1}\} - \hat{p}^*_{H,t} + \mathbb{E}_t\{\hat{\pi}^*_{t+1}\} - \varsigma^*_H\hat{\pi}^*_t)$$

Imported goods price (52):

$$\frac{\theta_F}{1-\theta_F}(\hat{p}_{F,t} - \hat{p}_{F,t-1} + \hat{\pi}_t - \varsigma_F\hat{\pi}_{t-1}) = (1-\beta_H\theta_F)(\hat{q}_t - \hat{p}_{F,t}) + \frac{\beta_H\theta_F}{1-\theta_F}(\mathbb{E}_t\{\hat{p}_{F,t+1}\} - \hat{p}_{F,t} + \mathbb{E}_t\{\hat{\pi}_{t+1}\} - \varsigma_F\hat{\pi}_t)$$

B.6. Commercial banking sector

Bank capital (53):

$$\hat{k}^B_t = \delta_B\hat{\xi}^B_{t-1} + (1-\delta_B)(\hat{k}^B_{t-1} - \hat{a}^B_t)$$

Spread (57):

$$\hat{r}^L_t R^L - \hat{r}_t R = -\kappa_B\nu^3_B(\hat{k}^B_t - \hat{l}_t)$$

Bank profits (58):

$$\hat{\xi}_t^B = \frac{(R+\mu_B)\left(\frac{R\hat{r}_t - \kappa_B \nu_B^3(\hat{k}_t^B - \hat{l}_t)}{R^L} + \hat{l}_t\right) - R(1-\nu_B)(\hat{r}_t + \hat{d}_t)}{R\nu_B + \mu_B}$$

B.7. Central bank

Conventional monetary policy rule (59):

$$\hat{r}_t = \rho_R \hat{r}_{t-1} + (1-\rho_R)(\varrho_\Pi \hat{\pi}_t)$$

AMPR I (61):

$$\hat{r}_t = \rho_R \hat{r}_{t-1} + (1-\rho_R)(\varrho_\Pi \hat{\pi}_t + \varrho_L \hat{l}_t)$$

AMPR II (62):

$$\hat{r}_t = \rho_R \hat{r}_{t-1} + (1-\rho_R)(\varrho_\Pi \hat{\pi}_t + \varrho_Q \hat{q}_t^K)$$

AMPR III (63):

$$\hat{r}_t = \rho_R \hat{r}_{t-1} + (1-\rho_R)(\varrho_\Pi \hat{\pi}_t + \varrho_L \hat{l}_t + \varrho_Q \hat{q}_t^K)$$

B.8. Foreign sector

The system of AR(1) equations (64):

$$\begin{pmatrix} \hat{y}_t^* \\ \hat{\pi}_t^* \\ \hat{r}_t^* \end{pmatrix} = \begin{pmatrix} \rho_{y^*} & 0 & 0 \\ 0 & \rho_{\pi^*} & 0 \\ 0 & 0 & \rho_{r^*} \end{pmatrix} \begin{pmatrix} \hat{y}_{t-1}^* \\ \hat{\pi}_{t-1}^* \\ \hat{r}_{t-1}^* \end{pmatrix} + \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \varepsilon_t^{y^*} \\ \varepsilon_t^{\pi^*} \\ \varepsilon_t^{r^*} \end{pmatrix}$$

B.9. Market clearing conditions and GDP

Commercial bank constraint (65):

$$\hat{l}_t = (1-\nu_B)\hat{d}_t + \nu_B \hat{k}_t^B$$

Final goods (66):

$$\frac{C}{Y_G}\hat{c}_t + \frac{I}{Y_G}\hat{i}_t + \frac{\psi'(1)I}{\delta_K Y_G}\hat{u}_t + \frac{\Xi^B}{Y_G \Pi}(\hat{k}_{t-1}^B - \hat{\pi}_t) = \frac{Y}{Y_G}\hat{y}_t$$

Aggregate consumption (67):

$$\hat{c}_t = \gamma^H \frac{C^H}{C}\hat{c}_t^H + \gamma^E \frac{C^E}{C}\hat{c}_t^E$$

Wholesale goods (68):

$$\hat{y}_t^W = \frac{Y_H}{Y_H + Y_H^*}\hat{y}_{H,t} + \frac{Y_H^*}{Y_H + Y_H^*}\hat{y}_{H,t}^*$$

Balance of payments (69):

$$\frac{p_F Y_F}{Y_G}(\hat{p}_{F,t} + \hat{y}_{F,t}) + \frac{L^* R}{Y_G \Pi}(\hat{q}_t - \hat{q}_{t-1} + \hat{f}_{t-1} + \hat{r}_{t-1}^* - \hat{\pi}_t^* + \hat{l}_{t-1}^*) = \frac{p_H^* Y_H^* \mathcal{Q}}{Y_G}(\hat{q}_t + \hat{p}_{H,t}^* + \hat{y}_{H,t}^*) + \frac{L^*}{Y_G}\hat{l}_t^*$$

Gross domestic product (70):

$$\hat{y}_{G,t} = \frac{Y}{Y_G}\hat{y}_t + \frac{p_H^* Y_H^* \mathcal{Q}}{Y_G}(\hat{p}_{H,t}^* + \hat{y}_{H,t}^* + \hat{q}_t) - \frac{p_F Y_F}{Y_G}(\hat{p}_{F,t} + \hat{y}_{F,t})$$

B.10. Remaining exogenous processes

Consumption preference shock (20):

$$\hat{a}_t^C = \rho_C \hat{a}_{t-1}^C + \varepsilon_t^C$$

Productivity shock (29):

$$\hat{a}_t^Y = \rho_Y \hat{a}_{t-1}^Y + \varepsilon_t^Y$$

Bank capital shock (54):

$$\hat{a}_t^B = \rho_B \hat{a}_{t-1}^B + \varepsilon_t^B$$

Appendix C. Figures and tables

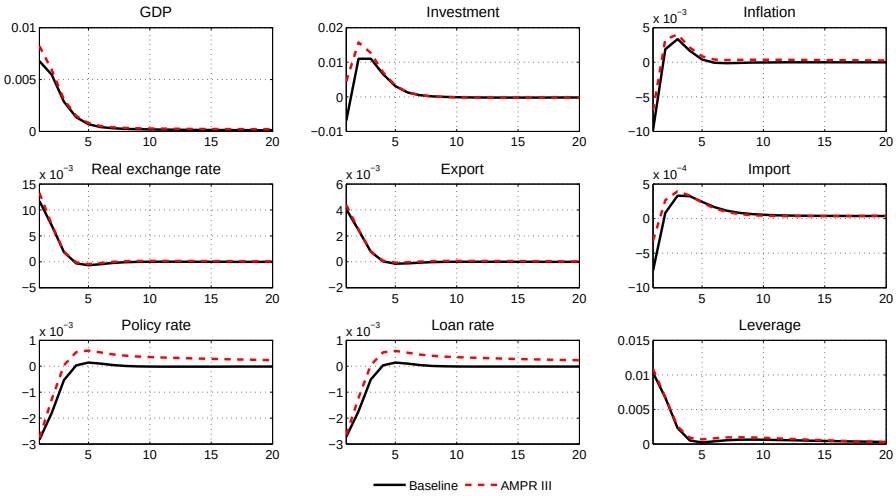

Figure 1. **IRF – technology shock.**

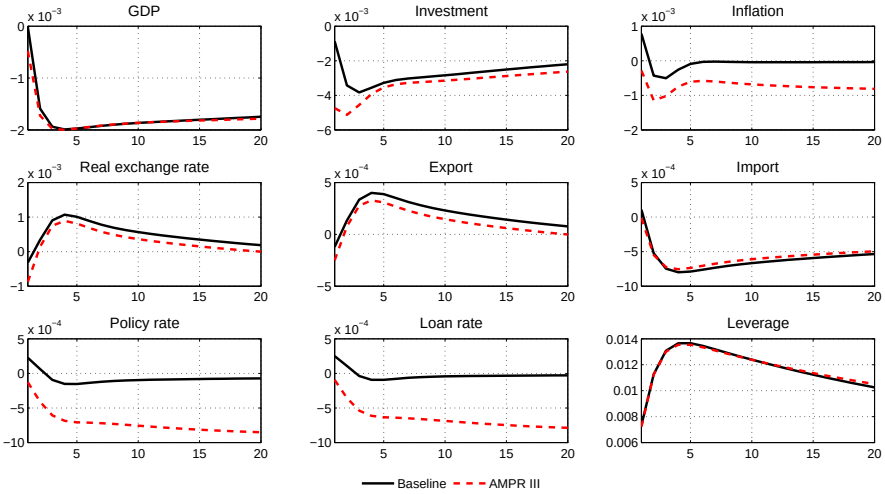

Figure 2. **IRF – bank capital loss.**

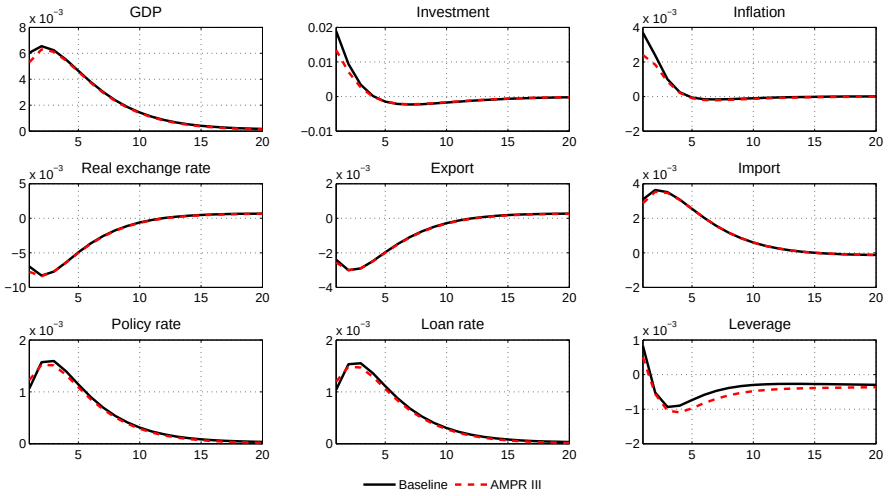

Figure 3. **IRF – consumption preference shock.**

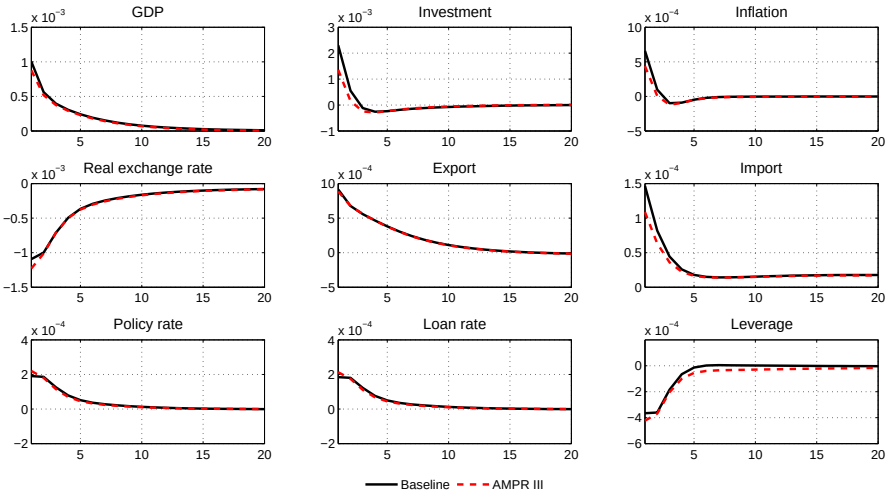

Figure 4. **IRF – foreign output shock.**

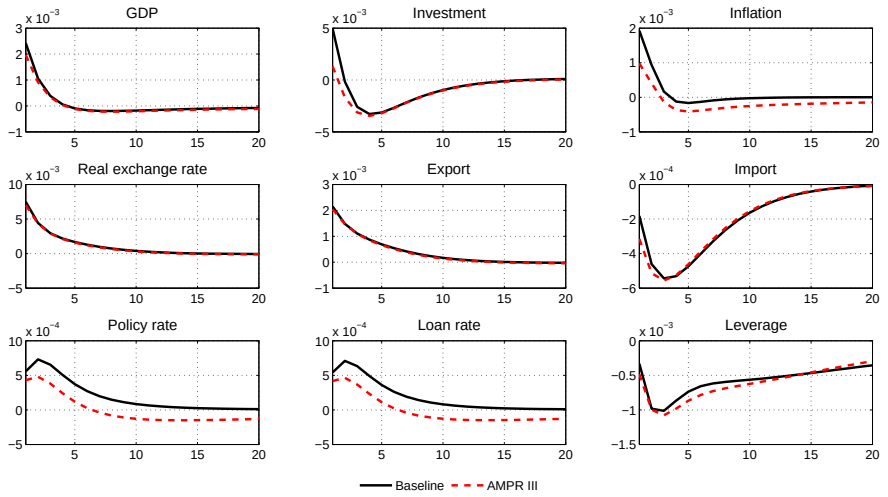

Figure 5. **IRF – foreign interest rate shock.**

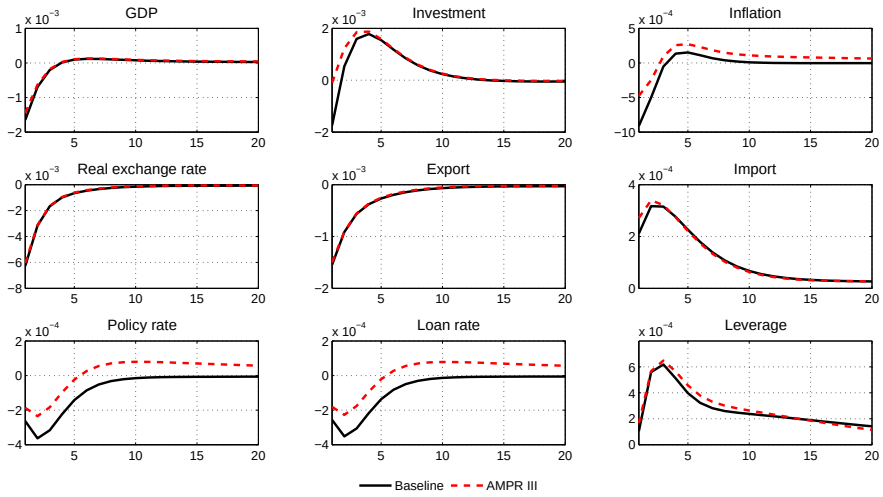

Figure 6. **IRF – foreign inflation shock.**

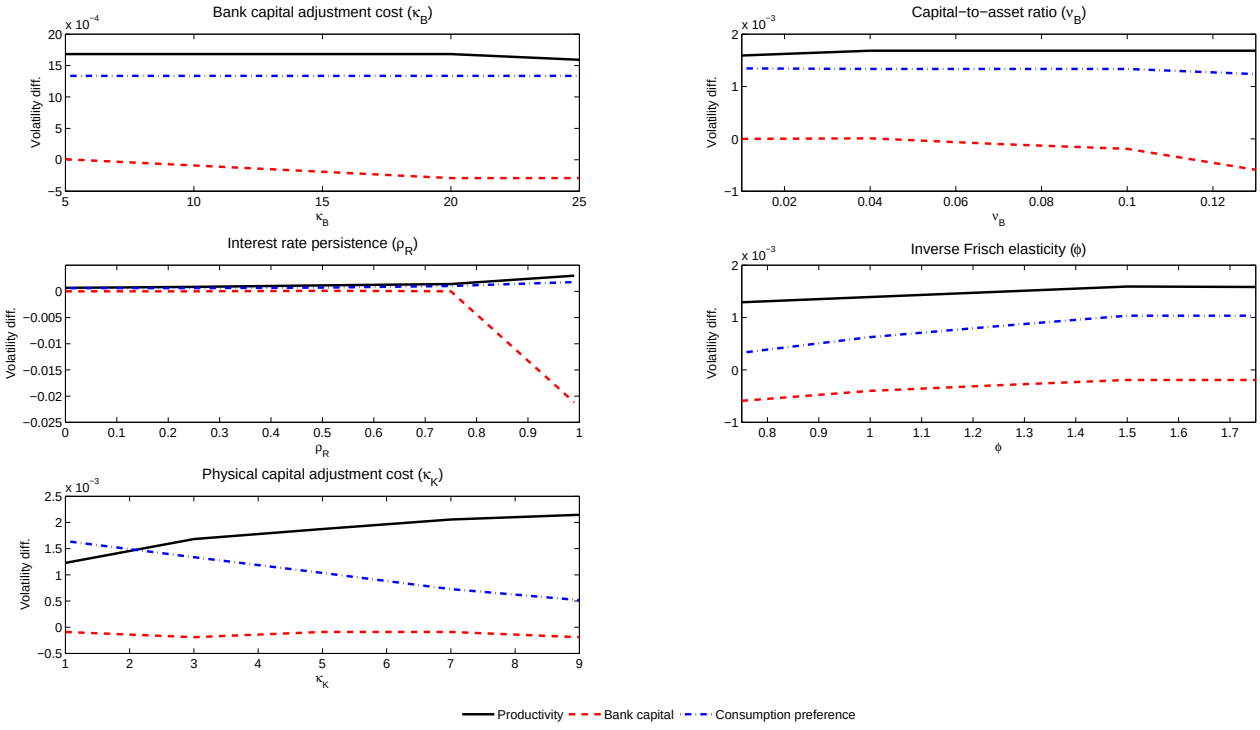

Figure 7. **Robustness check – domestic shocks.** A vertical axis depicts the difference between implied volatilities of the baseline (conventional) rule and the AMPR III.

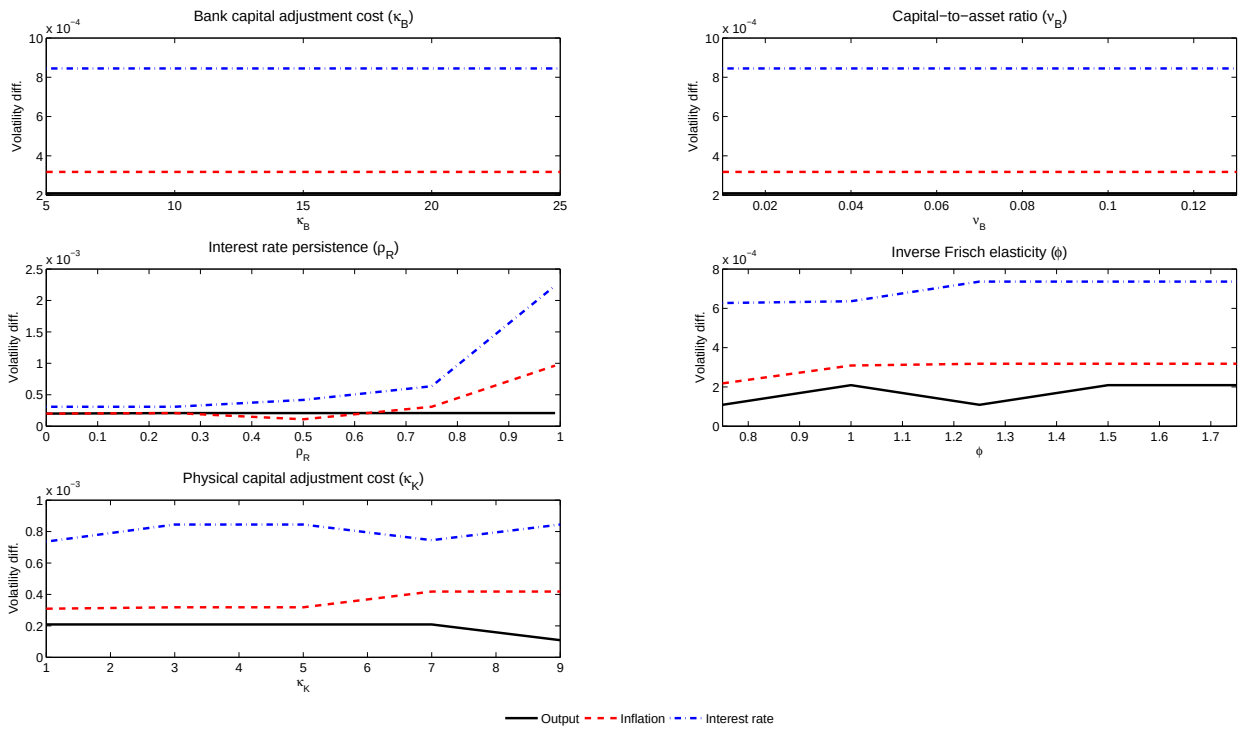

Figure 8. **Robustness check – foreign shocks.** A vertical axis depicts the difference between implied volatilities of the baseline (conventional) rule and the AMPR III.

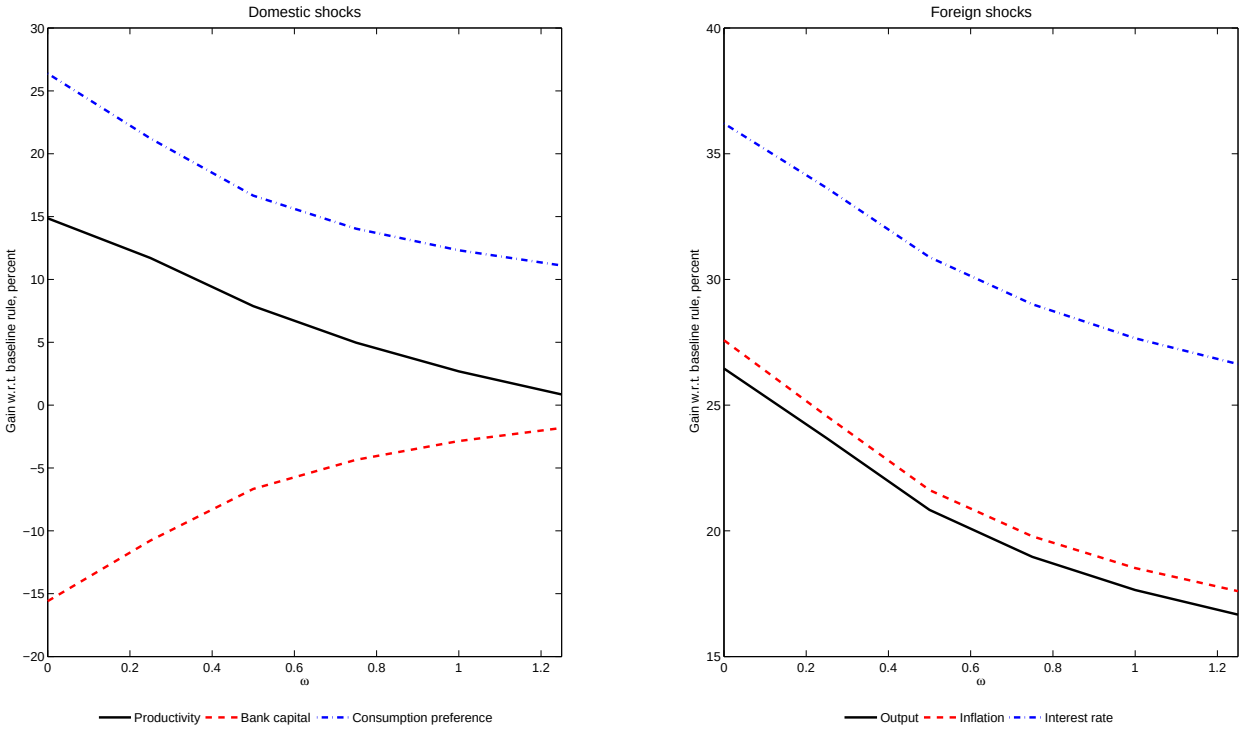

Figure 9. **Robustness check – weight on GDP ω.** A vertical axis depicts percentage difference with respect to the baseline rule; a positive value represents gain, a negative value represents loss.

Parameter		Value
$\psi'(1)$	capital utilization parameter	0.0569
$\psi'(1)/\psi''(1)$	capital utilization parameter	0.2000
κ_K	rate of capital adjustment costs	3.0000
δ_K	rate of capital depreciation	0.0350
ϱ_Q	financial side weight – asset prices	0.5
ϱ_L	financial side weight – credit	± 0.3
ϱ_Π	inflation weight	1.7000
ρ_R	interest rate smoothing	0.8300
ν_B	capital-to-asset ratio target value	0.0900
μ_B	mark-up on loan rate	0.0500
κ_B	rate of capital adjustment costs	11.490
δ_B	share of bank capital used in capital maintenance	0.0590
α	capital share in production	0.3000
β_E	exogenous discount factor	0.9850
γ_E	share of entrepreneurs in the economy	0.2500
ρ_B	AR(1) parameter of bank capital shock	0.4138
ρ_Y	AR(1) parameter of domestic productivity shock	0.3642
ρ_M	AR(1) parameter of LTV shock	0.1040
μ	elasticity of substitution of domestic goods	1.8700
μ^*	elasticity of substitution of foreign goods	1.9230
η	degree of openness	0.7357
ρ_{π^*}	AR coefficient of foreign inflation shock	0.6256
ρ_{r^*}	AR coefficient of foreign interest rate shock	0.7570
ρ_{y^*}	AR coefficient of foreign output shock	0.8024
ψ^*	elasticity of risk premium	0.0005
β_H^*	exogenous discount factor	0.9985
ρ_C	AR coefficient of consumption preference shock	0.6980
β_H	exogenous discount factor	0.9999
ι	habit persistence	0.7000
ϕ	inverse elasticity of labour supply	1.8800
γ_H	share of households in the economy	0.7500
θ_H^*	exported goods Calvo parameter	0.5000
θ_H	home goods Calvo parameter	0.4000
θ_F	imported goods Calvo parameter	0.5000
ς_H^*	inflation indexation – exported goods	0.4949
ς_H	inflation indexation – home goods	0.3233
ς_F	inflation indexation – imported goods	0.3428
Ξ^B/Y_G	banks' profit to GDP ratio	0.5924
C/Y_G	consumption to GDP ratio	0.5177
Π	domestic CPI inflation	2.0000
C^E/C	entrepreneurs' consumption to consumption ratio	0.2685
$p_H^* Y_H^* \mathcal{Q}/Y_G$	exports to GDP ratio	0.2430
$Y_H^*/(Y_H + Y_H^*)$	exports to home production ratio	0.2430
L^*/Y_G	foreign assets to GDP ratio	1.0000
R	home interest rate	2.0002
$Y_H/(Y_H + Y_H^*)$	home goods to home production ratio	0.7570
C^H/C	households consumption to consumption ratio	1.2438
$p_F Y_F/Y_G$	imports to GDP ratio	0.2107
I/Y_G	investment to GDP ratio	0.1538
R^L	interest rate on loans	2.2002
L/Y_G	loans to GDP ratio	0.6139
Y/Y_G	output to GDP ratio	0.9677
M	stochastic LTV ratio	0.6371
$p^W Y^W/Y_G$	wholesale production to GDP ratio	0.8333

Table 4: **Values of parameters.**

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