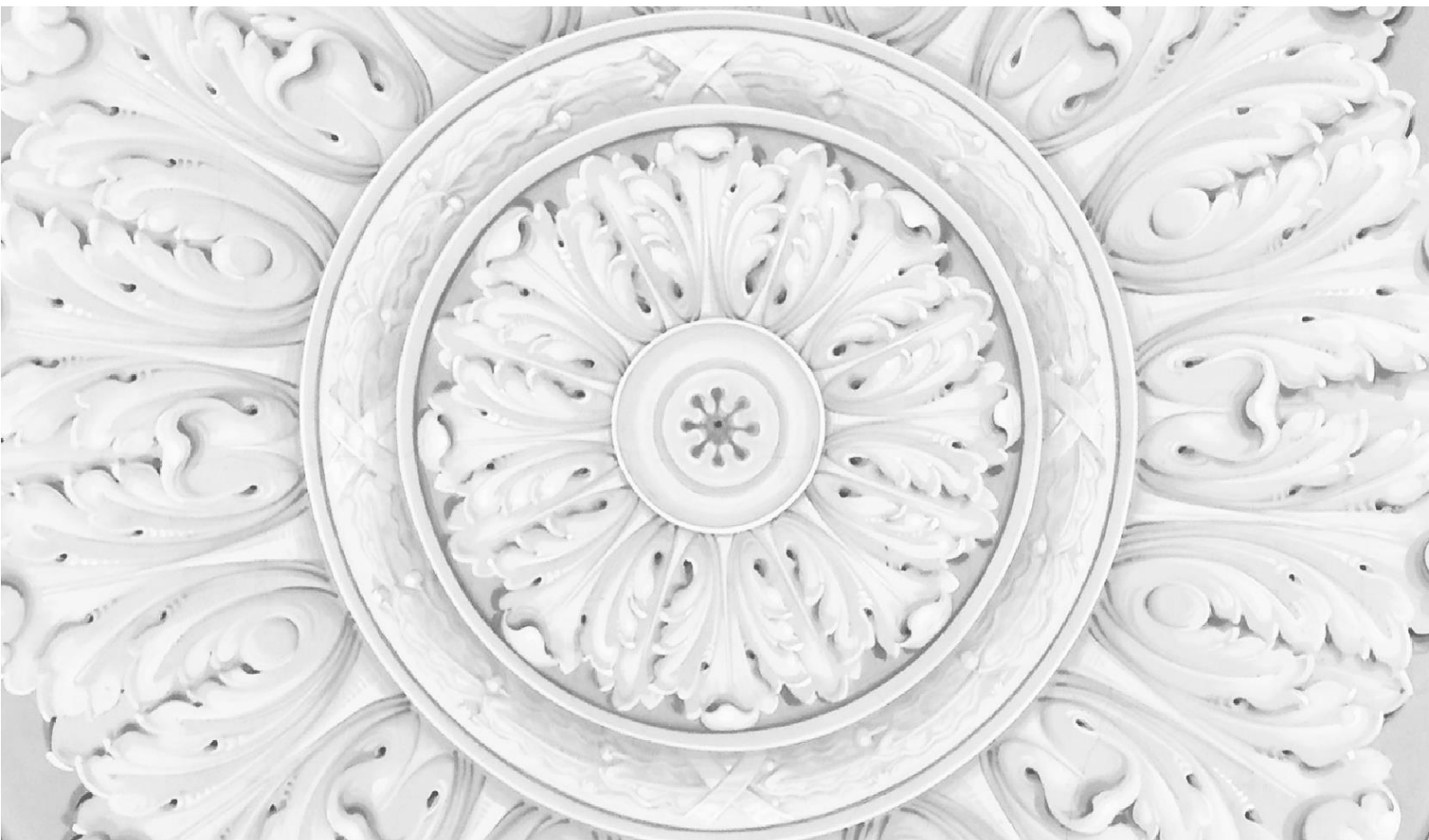# Bank of Russia
The Central Bank of the Russian Federation

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DSGE Model of the Russian
Economy with the Banking Sector

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Abstract

This paper presents the DSGE model of the Russian economy with the banking sector which the Bank of Russia uses for simulation experiments. We show how the introduction of the banking sector changes impulse responses of a standard DSGE model of a small open economy. We also demonstrate that the model has fairly good predictive power. The model enables us to study the effect of banking sector-specific shocks on the economy. Estimation on Russian data has led us to conclude that in this model such shocks did not have a significant effect on the real economy's variables in the period under observation spanning years from 2006 to 2016.

Contents

1. Introduction

Despite the criticism leveled at DSGE models[1], they are a worthwhile starting point for getting an insight into many relationships in an economy. On the one hand, DSGE models can be regarded as a forecasting tool; on the other hand, as models for simulation experiments.

The shrinkage of parameter space stemming from model constraints can be useful for predictive power. On the one hand, it helps alleviate overfitting problems; on the other hand, it imposes constraints which can be too strong and thus distort a true structure of data generation process. In addition to constraints on parameters, prior distributions are oftentimes imposed, which can cause further distortions. This influence can be especially pronounced in small samples. There are a number of studies comparing DSGE models' predictive power with forecasts obtained by other methods (see, for instance, *Edge and Gurkaynak (2010)*, *Domit et al. (2016)*, and *Iversen et al. (2016)*). The results may vary across countries, but DSGE models often lose out to models imposing fewer constraints (to BVAR models, for instance). With respect to previous works devoted to comparison of the predictive power of DSGE models with those of other models for the Russian economy we would like to briefly focus on three of those: *1) Ivashchenko (2013), 2) Kreptsev and Seleznev (2016), and 3) Malakhovskaya (2016)*[2]. The first of them compares the predictive power of DSGE, VAR, and AR models. This study explores a fairly large set of observables but does not include the dynamics of oil variables which can provide useful information for forecasting. Also, the author provides results for just one forecast horizon, which can be insufficient for full understanding of the models' predictive properties. The second study investigates a smaller set of observables but adds oil price movements as observable variables. Unlike *Ivashchenko (2013)*, the authors regard the BVAR model as an alternative, and they also look at just conditional forecasts, which are of greater interest in terms of central bank's forecasts than unconditional ones. The third paper studies a set of observables different from a standard one (which is not in itself either a good or bad feature of the model but only indicates that a different set of data is used for forecasting). The author compares BVAR and VAR with the DSGE model but uses predetrended data, which is unusual for these models and can only weaken their predictive power significantly. Despite the disadvantages listed above, all three papers arrive at the conclusion that DSGE models for the Russian economy are comparable with the alternative ones and are even superior to them. The latter suggests they can be

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[1] See, for instance, *Fagiolo and Roventini (2016)*.

[2] In addition to the three above-mentioned studies, there is a number of studies that aim to construct DSGE models of the Russian economy rather than to serve forecasting purposes, among which *Polbin and Drobyshevsky (2014)* are worth mentioning. We believe that this study provides the most detailed description of the Russian economy.

appropriate for forecasting, at least until much better forecasting models are found. This study does not however seek to construct a good forecasting model. Instead, we are constructing a model for conducting simulation experiments.

Simulation experiments are normally used to answer the following questions: what will happen in a *model economy* if certain developments occur, or what will an optimum behavior be in a *model economy* in a particular situation? We emphasize the importance of the word "model". A model only represents a simplified reality and does not allow factoring in all possible relationships or economic agents' actual behavior in particular situations. Conclusions about something are, rather, a certain initial approximation for a simplified model world and should be rethought in terms of the impact of model assumptions on the result (if this is possible at all). One would think that estimation of model parameters using actual data should help resolve the problem of a model not matching the reality, but this is not the case. Estimation of a model using actual data only allows one to claim that a model economy has some patterns similar to an actual economy, rather than to its structure.[3] Another constraint alongside those described above is structural shifts which can hardly be fully taken account of in estimating a model.

Despite all the drawbacks of model experiments, we, nevertheless, believe that they represent a worthwhile starting point for understanding many processes occurring in an economy. They, for instance, help understand whether particular correlations between variables are possible and identify their potential sources.

This study presents a DSGE model with the banking sector which the Bank of Russia uses for conducting simulation experiments. We first describe a baseline model similar to the NAWM model (*Cristoffel et al. (2008)*) in structure, and then add entrepreneurs to it, as in *Bernanke et al. (1999)* and *Christiano et al. (2014),* as well as the banking sector from *Gerali et al. (2010).* To give one an idea of the model's properties, we show impulse responses under the initial and estimated parameters, as well as decomposition into shocks and predictive power. Impulse responses under the initial calibration are shown in order to help better understand changes arising as the banking sector is added and do not stem from an additional parameter estimation. The rest of the results show the model's behavior with the Russian data. It is worth noting that what we are examining here is not

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[3] If the actual and model economies were stationary, one could claim that a model's economy has moments which are a combination of a prior notions and actual data. But even in this case several problems arise, two of which we will describe here by way of illustration: the length of the sample period and the retention of coincidence of these moments' structure in conducting an experiment. The former is important to the Russian economy because to maintain the plausibility of an assumption about the model's stationarity small samples are used. The result is that the weight of actual data relative to prior distribution shows to be fairly small. The latter problem is more fundamental in nature. Thus, if the moments of the actual economy and the model coincide and then something changes, for example, the monetary policy rule, then no one can be sure that the new moments of the actual economy and the model will coincide.

strictly fixed models. Rather, they are a demonstration of a set of tools used. As such, behavior rules can be easily changed for some agents, some shocks and observable variables can be added or excluded.

The rest of the paper will be structured as follows: Section 2 describes the structure of the models; Section 3 provides an approach to parameter estimation; Section 4 presents the main findings of the study; Section 5 concludes.

2. Model description

This section describes two models: the baseline model and the model with the banking sector. For space considerations, we will only briefly describe the key blocks of the baseline model (see *Smets and Wouters (2003, 2007)*, *Christiano et al. (2005)* и *Cristoffel et al. (2008)*) and dwell on the added specifications in slightly more detail. Although the banking sector presented in this study is similar to that from *Gerali et al. (2010)*, we dwell on this model in more detail for two reasons. First, this sector is not typical for models with a financial accelerator (see *Bernanke et al. (1999)*) and is normally used in models with collateral constraints (see *Gerali et al. (2010)*). Second, we write the problem in a mathematical formulation different from that of *Gerali et al. (2010)*.

Baseline model

The baseline model is a standard model of a small open economy, which is largely similar to that of *Cristoffel et al. (2008)* but has a simpler fiscal sector. A scheme of this economy is presented in Figure 1a (with a scheme of the model with the banking sector shown in Figure 1b). The model economy is comprised of households, producers, domestic retailers, importing retailers, exporting retailers, aggregators of consumer and investment goods, investment firms, oil exporters, a central bank, the fiscal sector, and an external economy. Below we describe all of the above agents and their interaction.

Households

There is a continuum of households in the model economy. j−th household maximizes expected discounted utility (with discount factor β) which is positively related to consumption level,

$C_t(j)$,[4] relative to a certain base level, hC_{t-1}, formed in the economy recursively, and is also negatively related to the number of hours worked, $l_t(j)$:

$$U_t(j) = E_t \sum_{i=0}^{\infty} \beta^i \left(\zeta_t^c \ln(C_{t+i}(j) - hC_{t+i-1}) - \zeta_t^L \frac{(l_{t+i}(j))^{1+\phi}}{1+\phi} \right)$$

where ζ_t^c is an exogenous process representing household consumption preferences, ζ_t^l is an exogenous process responsible for household preferences regarding the number of hours worked, h is the coefficient of habit formation in consumption, ϕ is the curvature on disutility of labor.[5]

In optimizing the utility function, households take into account their budget constraints. At the beginning of the period, they own domestic assets of the previous period, $B_{t-1}(j)$, and (net) foreign assets of the previous period, $B_{t-1}^*(j)$, which are denominated in terms of a national currency at the exchange rate $\mathcal{E}_t$, and also receive payments generated by these assets at interest rates, R_{t-1} and R_{t-1}^{NFA}, respectively. Also, during the period of decision household receive wages for hours worked, $W_t(j)l_t(j)$, and lump-sum payments, $\Pi_t(j)$, which include, among other things, taxes (with a negative sign) and firms' profits (with a positive sign). These funds can be spent to buy consumer goods, $P_tC_t(j)$, and domestic and foreign assets, $B_t(j)$ и $\mathcal{E}_t B_t^*(j)$. Households also bear costs of changes in wages, $\frac{k_w}{2} \left(\frac{W_t(j)}{W_{t-1}(j)e^{g_{w,ss_t}}} - (\pi_{t-1})^{\iota_w}(\pi_*)^{1-\iota_w} \right)^2 W_t l_t$. Wage changes by the value different from the predetermined one, $(\pi_{t-1})^{\iota_w}(\pi_*)^{1-\iota_w}$, are assumed to require additional quadratic costs. The resulting budget constraint is written as:

$$\begin{aligned}
P_t C_t(j) + B_t(j) &+ \mathcal{E}_t B_t^*(j) \\
&= W_t(j)l_t(j) + R_{t-1}B_{t-1}(j) + R_{t-1}^{NFA}\mathcal{E}_t B_{t-1}^*(j) + \Pi_t(j) \\
&- \frac{k_w}{2} \left(\frac{W_t(j)}{W_{t-1}(j)e^{g_{w,ss_t}}} - (\pi_{t-1})^{\iota_w}(\pi_*)^{1-\iota_w} \right)^2 W_t l_t
\end{aligned}$$

where P_t is the price of a unit of consumption, π_t is consumer price growth (inflation), g_{w,ss_t} is a trend wage growth,[6] k_w is the coefficient of the costs of wage growth deviation from the predetermined level, ι_w is the weight of a lagged value in the predetermined wage growth, π_* is the inflation target.

Households also take into account labor demand:[7]

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[4] For space considerations, we will omit the period and household while describing the variables further on. A variable without an index given in parentheses is an aggregated indicator.

[5] Descriptions of all the parameters is provided in Table 1.

[6] Stochastic and deterministic growth are factored in.

[7] This form of labor demand can be more formally derived from the assumption about monopolistic competition.

$$l_t(j) = \left(\frac{W_t(j)}{W_t}\right)^{-\varepsilon_w} l_t$$

where $W_t(j)$ is wages , ε_w is wage elasticity of labor demand.

The first-order conditions are given by:[8]

$$\beta E_t \left(\frac{C_t - hC_{t-1}}{C_{t+1} - hC_t} \frac{R_t}{\pi_{t+1}} \frac{\zeta_{t+1}^c}{\zeta_t^c}\right) = 1 \tag{1}$$

$$R_t = R_t^{NFA} \frac{E_t\left(\frac{C_t - hC_{t-1}}{C_{t+1} - hC_t \pi_{t+1}} \frac{g_{t+1}^{\mathcal{E}} \zeta_{t+1}^c}{\zeta_t^c}\right)}{E_t\left(\frac{C_t - hC_{t-1}}{C_{t+1} - hC_t \pi_{t+1}} \frac{1}{\zeta_t^c} \frac{\zeta_{t+1}^c}{\zeta_t^c}\right)} \tag{2}$$

$$\varepsilon_w \zeta_t^L \frac{(l_t)^\phi}{W_t} P_t + \frac{\zeta_t^c}{C_t - hC_{t-1}}(1 - \varepsilon_w) - \frac{\zeta_t^c}{C_t - hC_{t-1}} k_w \left(\frac{W_t}{W_{t-1} e^{g_{w,ss}t}} - (\pi_{t-1})^{\iota_w} (\pi_*)^{1-\iota_w}\right) \frac{W_t}{W_{t-1} e^{g_{w,ss}t}} +$$

$$\beta E_t \frac{\zeta_{t+1}^c}{C_{t+1} - hC_t} \frac{1}{\pi_{t+1}} k_w \left(\frac{W_{t+1}}{W_t e^{g_{w,ss}t+1}} - (\pi_t)^{\iota_w} (\pi_*)^{1-\iota_w}\right) \frac{W_{t+1}^2}{W_t^2 e^{g_{w,ss}t}} \frac{l_{t+1}}{l_t} = 0 \tag{3}$$

Equation (1) is a standard Euler equation, equation (2) is uncovered interest rate parity, and equation (3) is labor supply.

Producers

j –th producer manufactures goods, $Y_t(j)$, using capital, $K_t(j)$, and labor, $l_t(j)$:

$$Y_t(j) = A_t A_t^c \big(l_t(j)\big)^\alpha \big(K_t(j)\big)^{1-\alpha} \tag{4}$$

where A_t is a technology trend, and A_t^c is the cyclical part of technology.

Each producer pays for $l_t(j)$ of hours worked by households and rents $K_t(j)$ units of capital from investment firms. Profit is here defined as the difference between revenue from the sale of goods, $P_t^Y Y_t(j)$, labor costs, $W_t l_t(j)$, and the cost of capital, $Z_t K_t(j)$:

$$P_t^Y Y_t(j) - W_t l_t(j) - Z_t K_t(j)$$

where P_t^Y is the price of goods sold, and Z_t is the rental cost of capital.

Profit maximization gives the equations of labor and capital demand from producers:

$$\alpha P_t^Y Y_t - W_t l_t = 0 \tag{5}$$

$$(1 - \alpha) P_t^Y Y_t - Z_t K_t = 0 \tag{6}$$

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[8] Hereafter we assume that agents behave symmetrically in an equilibrium.

Domestic retailers

Domestic retailers purchase goods from producers and then sell them to aggregators of consumer goods (households) and aggregators of investment goods (firms) in a market with monopolistic competition. The revenue of the $k - th$ domestic retailer over period t is equal to the value of sold goods, $P_t^H(k)Y_t^H(k)$, while costs are comprised of the cost of purchased goods, $P_t^Y Y_t^H(k)$, and costs incurred in price changes, $\frac{k_H}{2}\left(\frac{P_t^H(k)}{P_{t-1}^H(k)} - (\pi_{t-1}^H)^{\iota_H}(\pi_*)^{1-\iota_H}\right)^2 Y_t P_t^H$, formed similarly to the costs of household wage changes.

Domestic retailers maximize discounted profit (in real terms):

$$E_t \sum_{i=0}^{\infty} \lambda_{t+i} \left(\frac{P_{t+i}^H(k)Y_{t+i}^H(k)}{P_{t+i}} - \frac{P_{t+i}^Y Y_{t+i}^H(k)}{P_{t+i}} - \frac{k_H}{2}\left(\frac{P_{t+i}^H(k)}{P_{t+i-1}^H(k)} - (\pi_{t-1}^H)^{\iota_H}(\pi_*)^{1-\iota_H}\right)^2 Y_{t+i}^H \frac{P_{t+i}^H}{P_{t+i}} \right)$$

taking into account demand for their own products:

$$Y_t^H(k) = \left(\frac{P_t^H(k)}{P_t^H}\right)^{-\varepsilon_{h,t}} Y_t^H$$

where $Y_t^H(k)$ is the quantity of goods sold, $P_t^H(k)$ is the price of goods sold, $\varepsilon_{h,t}$ is the price elasticity of goods sold by domestic retailers , λ_t is the discount factor determined by households' optimization problem, π_t^H is domestic retailers' price growth, k_H is the coefficient of the cost of domestic retailers' price growth deviation from the predetermined level, ι_H is the weight of lagged value in the domestic retailers' predetermined price growth.

A solution of the optimization problem is the supply curve for goods sold by domestic retailers:

$$\left(1 - \varepsilon_{h,t}\right) + \varepsilon_{h,t}\frac{P_t^Y}{P_t^H} - k_H(\pi_t^H - (\pi_{t-1}^H)^{\iota_H}(\pi_*)^{1-\iota_H})\pi_t^H + \beta k_H E_t \frac{C_t - hC_{t-1}}{C_{t+1} - hC_t}\frac{\zeta_{t+1}^c}{\zeta_t^c}(\pi_{t+1}^H -$$

$$-(\pi_t^H)^{\iota_H}(\pi_*)^{1-\iota_H})\frac{Y_{t+1}^H}{Y_t^H}\frac{(\pi_{t+1}^H)^2}{\pi_{t+1}} = 0 \qquad\qquad (7)$$

Importing retailers

Similarly to domestic retailers, importing retailers maximize discounted profit but, unlike domestic retailers, they sell goods at price $P_t^F(k)$ and purchase goods abroad, $\mathcal{E}_t P_t^{F*} Im_t(k)$, rather than from producers.

The first-order condition for importing retailers is written similarly to that for domestic retailers:

$$\left(1 - \varepsilon_{f,t}\right) + \varepsilon_{f,t} \frac{\varepsilon_t P_t^{F*}}{P_t^F} - k_F(\pi_t^F - (\pi_{t-1}^F)^{\iota_F}(\pi_*)^{1-\iota_F})\pi_t^F + \beta k_F E_t \frac{C_t - hC_{t-1}}{C_{t+1} - hC_t} \frac{\zeta_{t+1}^C}{\zeta_t^C}(\pi_{t+1}^F -$$

$$-(\pi_t^F)^{\iota_F}(\pi_*)^{1-\iota_F}) \frac{Im_{t+1}}{Im_t} \frac{(\pi_{t+1}^F)^2}{\pi_{t+1}} = 0 \tag{8}$$

where Im_t is the quantity of goods sold by importing retailers, P_t^{F*} is the price of imports, π_t^F is importing retailers' price growth, $\varepsilon_{f,t}$ is the price elasticity of goods sold by importing retailers, k_F is the coefficient of the costs of importing retailers' price growth deviation from the predetermined level, ι_F is the weight of lagged value in importing retailers' predetermined price growth.

Exporting retailers

Like domestic retailers, exporting retailers purchase goods from producers but sell them to foreign economy. Similarly to domestic importers, equation (9) defines the supply of domestic exportables (excluding oil):

$$\left(1 - \varepsilon_{*h,t}\right) + \varepsilon_{*h,t} \frac{P_t^Y}{\varepsilon_t} \frac{1}{P_t^{*H}} - k_{*H}(\pi_t^{*H} - (\pi_{t-1}^{*H})^{\iota_{*H}}(\pi^*)^{1-\iota_{*H}})\pi_t^{*H} + \beta k_{*H} E_t \frac{C_t - hC_{t-1}}{C_{t+1} - hC_t} \frac{\zeta_{t+1}^C}{\zeta_t^C}(\pi_{t+1}^{*H} -$$

$$-(\pi_t^{*H})^{\iota_{*H}}(\pi^*)^{1-\iota_{*H}}) \frac{(\pi_{t+1}^{*H})^2}{\pi_{t+1}} \frac{Y_{t+1}^{*H}}{Y_t^{*H}} \frac{\varepsilon_{t+1}}{\varepsilon_t} = 0 \tag{9}$$

where Y_t^{*H} is the quantity of goods sold by exporting retailers, P_t^{*H} is the price of goods sold by exporting retailers, π_t^{*H} is exporting retailers' price growth, $\varepsilon_{h,t}$ is the price elasticity of goods sold by exporting retailers, k_{*H} is the coefficient of the cost for the exporting retailers' price growth deviation from the predetermined level, ι_{*H} is the weight of lagged value in exporting retailers' predetermined price growth, π^* is the foreign inflation target.

Aggregators of consumer goods

Aggregators of consumer goods purchase goods from domestic retailers, $C_{H,t}(j)$, and importing retailers, $C_{F,t}(j)$, and combine them into final consumption goods, $C_t^p(j)$, using technology:

$$C_t^p(j) = \left(\gamma_C^{\frac{1}{\eta_C}}(C_{H,t}(j))^{1-\frac{1}{\eta_C}} + (1 - \gamma_C)^{\frac{1}{\eta_C}}(C_{F,t}(j))^{1-\frac{1}{\eta_C}}\right)^{\frac{\eta_C}{\eta_C - 1}} \tag{10}$$

where η_C is the elasticity of substitution between imported and domestic goods in final consumption goods, γ_C is the parameter representing the share of domestic goods in final consumption goods.

Profit is written as follows:

$$P_t C_t^p(j) - P_t^H C_{H,t}(j) - P_t^F C_{F,t}(j)$$

Profit maximization defines demand for domestic and foreign goods from the aggregators of consumer goods:

$$C_{H,t} = \gamma_C \left(\frac{P_t^H}{P_t}\right)^{-\eta_C} C_t^p \tag{11}$$

$$C_{F,t} = (1 - \gamma_C) \left(\frac{P_t^F}{P_t}\right)^{-\eta_C} C_t^p \tag{12}$$

We note that introducing this type of aggregators for this model to an accuracy of the costs of wage adjustment is equivalent to introducing the household utility function:

$$U_t(j) = E_t \sum_{i=0}^{\infty} \beta^i \left(\zeta_t^c \ln \left(\left(\gamma_C^{\frac{1}{\eta_C}} (C_{H,t+i}(j))^{1-\frac{1}{\eta_C}} + (1 - \gamma_C)^{\frac{1}{\eta_C}} (C_{F,t+i}(j))^{1-\frac{1}{\eta_C}} \right)^{\frac{\eta_C}{\eta_C-1}} \right. \right.$$
$$\left. \left. - h \left(\gamma_C^{\frac{1}{\eta_C}} (C_{H,t+i-1})^{1-\frac{1}{\eta_C}} + (1 - \gamma_C)^{\frac{1}{\eta_C}} (C_{F,t+i-1})^{1-\frac{1}{\eta_C}} \right)^{\frac{\eta_C}{\eta_C-1}} \right) - \zeta_t^L \frac{(l_{t+i}(j))^{1+\phi}}{1+\phi} \right)$$

Upon model linearization, the costs of wage adjustment will disappear due to their quadratic form, hence the linear versions of the model will be in perfect match. The introduction of goods aggregators is in this case only owed to calculation simplicity.

Aggregators of investment goods

Like aggregators of consumer goods, aggregators of investment goods use domestic goods, $I_{H,t}(j)$, and imports, $I_{F,t}(j)$, to produce investment goods, $(I_t + a(u_t)K_t')(j)$. They use the following technology:

$$(I_t + a(u_t)K_t')(j) = U_t \left(\gamma_I^{\frac{1}{\eta_I}} (I_{H,t}(j))^{1-\frac{1}{\eta_I}} + (1 - \gamma_I)^{\frac{1}{\eta_I}} (I_{F,t}(j))^{1-\frac{1}{\eta_I}} \right)^{\frac{\eta_I}{\eta_I-1}} \tag{13}$$

where I_t is investment, excluding capital costs $(a(u_t)K_t')$, U_t is an investment shock, u_t is capital utilization, K_t' is capital quantity, where η_I is the elasticity of substitution between imported and domestic goods in final investment goods, γ_I is a parameter for the share of domestic goods in final investment goods. Function $a(u_t)$ defines capital costs, which will be described below.

Demand for domestic and foreign goods of aggregators of investment goods:

$$I_{H,t} = \gamma_I \left(\frac{P_t^H}{P_t^I U_t}\right)^{-\eta_I} \frac{I_t + a(u_t)K_t'}{U_t} \tag{14}$$

$$I_{F,t} = (1 - \gamma_I) \left(\frac{P_t^F}{P_t^I U_t}\right)^{-\eta_I} \frac{I_t + a(u_t)K_t'}{U_t} \tag{15}$$

Investment firms

Investment firms purchase goods from aggregators of investment goods, $(P_t^I a(u_t(j))K_t'(j) + P_t^I I_t(j))$, produce capital and rent it out to producers, $(Z_t u_t(j)K_t'(j))$, thus maximizing profit:

$$E_t \sum_{i=0}^{\infty} \lambda_{t+i} \left(\frac{Z_{t+i} u_{t+i}(j)K_{t+i}'(j) - P_{t+i}^I a(u_{t+i}(j))K_{t+i}'(j) - P_{t+i}^I I_{t+i}(j)}{P_{t+i}} \right)$$

and taking into account capital dynamics:

$$K_t'(j) = (1 - \delta)K_{t-1}'(j) + \left(1 - \frac{k_I}{2} \left(\frac{I_{t-1}(j)}{I_{t-2}(j)e^{gI,ss_{t-1}}} - 1 \right)^2 \right) I_{t-1}(j) \tag{16}$$

where k_I is the coefficient of the costs of investment growth deviation from the predetermined growth, δ is the depreciation rate of capital.

A unit of investment, $I_{t-1}(j)$, is assumed to produce $\left(1 - \frac{k_I}{2} \left(\frac{I_{t-1}(j)}{I_{t-2}(j)e^{gI,ss_{t-1}}} - 1 \right)^2 \right) I_{t-1}(j)$

units of capital. It should be noted that quadratic costs, $\frac{k_I}{2} \left(\frac{I_{t-1}(j)}{I_{t-2}(j)e^{gI,ss_{t-1}}} - 1 \right),^2$ can be defined as

any other function which depends on a ratio of investment in two periods, $\frac{I_{t-1}(j)}{I_{t-2}(j)e^{gI,ss_{t-1}}}$, does not

affect the steady state of the model and has a zero first-order derivative. In fact, only second-order derivative, uniquely defined by coefficient k_I (see *Christiano et al. (2005)*), is important to the linearized model dynamics.

Function $a(u)$ is taken to be equal to $\frac{z_{ss}}{p_{ss}^I} \frac{e^{\sigma^a(u-1)} - 1}{\sigma^a}$. The choice of this function type is not

critical either and can be replaced by one parameter, σ^a, equal to a ratio between the first-order and second-order derivatives, and by conditions $a(1) = 0$ and $u_{ss} = 1$[9] (see *Christiano et al. (2005)*).

Investment firms' profit maximization is given by the following three equations:

$$-\frac{Q_t}{P_t} + \beta E_t \frac{C_t - hC_{t-1}}{C_{t+1} - hC_t} \frac{\zeta_{t+1}^c}{\zeta_t^c} \left((1 - \delta)\frac{Q_{t+1}}{P_{t+1}} + \frac{u_{t+1}Z_{t+1} - P_{t+1}^I a(u_{t+1})}{P_{t+1}} \right) = 0 \tag{17}$$

$$-\frac{P_t^I}{P_t} + \frac{Q_t}{P_t} \left(\left(1 - \frac{k_I}{2} \left(\frac{I_t}{I_{t-1}e^{gI,ss_t}} - 1 \right)^2 \right) - k_I \left(\frac{I_t}{I_{t-1}e^{gI,ss_t}} - 1 \right) \frac{I_t}{I_{t-1}e^{gI,ss_t}} \right) +$$

$$+\beta k_I E_t \frac{C_t - hC_{t-1}}{C_{t+1} - hC_t} \frac{\zeta_{t+1}^c}{\zeta_t^c} \frac{Q_{t+1}}{P_{t+1}} \left(\frac{I_{t+1}}{I_t e^{gI,ss_{t+1}}} - 1 \right) \frac{(I_{t+1})^2}{(I_t)^2 e^{gI,ss_{t+1}}} = 0 \tag{18}$$

$$Z_t - P_t^I a'(u_t) = 0 \tag{19}$$

where Q_t is the price of capital.

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[9] Index ss denotes a steady state of the model. Accordingly, u_{ss} is capital utilization in a steady state.

Oil exporters

The model assumes for simplicity that oil accounts for the entire commodity exports. In each period, oil quantity S_t^{oil} is exported at price P_t^{oil}, which is an exogenous process.[10,11]. We also assume that real oil price, p_t^{oil}, is exogenous.

Central bank

The model's central bank conducts interest rate policy and exchange rate policy using rules for the interest rate and reserves, which can, in the general case, be implicit. Interest rate, R_t, is set under the following rule, which reacts to the interest rate of the previous period, R_{t-1}, and current-period inflation, π_t:

$$\frac{R_t}{R_*} = \left(\frac{R_{t-1}}{R_*}\right)^{\phi_R} \left(\frac{\pi_t}{\pi_*}\right)^{(1-\phi_R)\phi_\pi} e^{e_t^R} \tag{20}$$

where e_t^R is a monetary policy shock which reflects the central bank's deviation from the rule, R_* is the steady state interest rate, ϕ_R is the interest rate inertia coefficient, ϕ_π is the inflation coefficient.

A change in reserves, $dRes_t$, is described by the equation which implies the absence of the rule:

$$\frac{dRes_t}{(A_t)^{\frac{1}{\alpha}}P_t^*} = e_t^{res} \tag{21}$$

where e_t^{res} is a reserves shock, P_t^* is the price of foreign goods. A change in reserves is normalized by $(A_t)^{\frac{1}{\alpha}}P_t^*$ to ensure the stationarity of the model.

The fiscal sector

As mentioned above, the model's fiscal sector is simple enough. Unlike *Cristoffel et al. (2008),* taxes are collected as households' lump-sum payments, T_t. All of this tax revenue is spent on government consumption, G_t, under the rule which is defined by an autoregressive process. We effectively assume a balanced budget and the absence of transfers, the latter not being critical if taxes are interpreted as households' net payments.

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[10] This can be interpreted as production without costs with a predetermined volume, S_t^{oil}.
[11] Unless otherwise stated, hereafter we assume that the trend-adjusted logarithm of exogenous process (for the normalization procedure, see Appendix A) follows an AR(1) process.

External economy

The model's external economy is defined by demand for domestic non-commodity exports:

$$Y_t^{*H} = \gamma_{export}(p_t^{*H})^{-\eta_{export}}Y_t^* \tag{22}$$

Coefficient η_{export} denotes the price elasticity of exports, while, γ_{export} is a normalizing factor, and Y_t^* is a foreign economy's output. In general, the external economy is described by a standard New Keynesian model:

$$\beta^* E_t \left(\frac{Y_t^* - h^* Y_{t-1}^*}{Y_{t+1}^* - h^* Y_t^*} \frac{R_t^*}{\pi_{t+1}^*} \frac{\zeta_{t+1}^{*c}}{\zeta_t^{*c}} \right) = 1 \tag{23}$$

$$-\zeta^{*L} \frac{(l_t^*)^{\phi^*}}{w_t^*} + \frac{\zeta_t^{*c}}{Y_t^* - h^* Y_{t-1}^*} = 0 \tag{24}$$

$$Y_t^* = A_t^* A_t^{\frac{1}{\alpha}} l_t^* \tag{25}$$

$$p_t^{*Y} A_t^* A_t^{\frac{1}{\alpha}} - w_t^* = 0 \tag{26}$$

$$(1 - \varepsilon_h^*) + \varepsilon_h^* p_t^{*Y} - k^* (\pi_t^* - (\pi_{t-1}^*)^{\iota_*} (\pi^*)^{1-\iota_*}) \pi_t^* + \beta^* k^* E_t \frac{Y_t^* - h^* Y_{t-1}^*}{Y_{t+1}^* - h^* Y_t^*} \frac{\zeta_{t+1}^{*c}}{\zeta_t^{*c}} (\pi_{t+1}^* -$$

$$(\pi_t^*)^{\iota_*}(\pi^*)^{1-\iota_*}) \frac{Y_{t+1}^*}{Y_t^*} \pi_{t+1}^* = 0 \tag{27}$$

$$\frac{R_t^*}{R^*} = \left(\frac{R_{t-1}^*}{R^*} \right)^{\phi_R^*} \left(\frac{\pi_t^*}{\pi^*} \right)^{(1-\phi_R^*)\phi_\pi^*} e^{e_t^{*R}} \tag{28}$$

Equations (23) and (24) are Euler and labor supply equations similar to equations (1) and (3) for the domestic economy,[12] but, unlike equation (3), workers in equation (24) offer labor in a competitive market. It is assumed for simplicity that in a foreign economy goods are only produced using labor. Consequently, equation (25) is equivalent to equation (4),[13] and equation (26) is equivalent to equation (5). Equation (27) reflects the supply of foreign goods in a foreign economy, similarly to equation (7). Equation (28) is the rule for interest rate policy.

It is also assumed that the external economy is much larger than the domestic economy and hence does not respond to the latter's shocks.

Other equations

The rest of the equations are either balances or definitions.

The dynamics of the private sector's net foreign assets is described by a trade balance equation:

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[12] The asterisked variables are similar to the unasterisked ones for the domestic economy.
[13] In the left part of equation (25), there should be quadratic costs of price adjustment but we do not factor them in because they go away upon linearization.

$$B_t^* = R_{t-1}^{NFA} B_{t-1}^* + IP_t + P_t^{oil} S_t^{oil} + P_t^{*H} Y_t^{*H} - P_t^{F*} IM_t - dRes_t \qquad (29)$$

Net foreign assets of period t, B_t^*, are made up of net foreign assets of the previous period and interest payments generated by them, $R_{t-1}^{NFA} B_{t-1}^*$, export revenue, $P_t^{oil} S_t^{oil} + P_t^{*H} Y_t^{*H}$, less imports, $P_t^{F*} IM_t$, and a change in reserves, $dRes_t$, as well as other payments, IP_t, which may, for example, come from transfers. The key reason for introducing the latter is their ability to regulate the steady state debt level.

Following *Schmitt-Grohe and Uribe (2003),* in order to ensure the unique steady state of the model we introduce a risk premium, which depends on the detrended level of net foreign liabilities, $rer_t d_t^*$ (or $-rer_t b_t^*$), and on the real oil price. The interest rate on net foreign assets is then written as:

$$R_t^{NFA} = R_t^* e^{\varphi_{nfa}(rer_t d_t^* - rer_{ss} d_{ss}^*) - \varphi_{oil}(p_t^{oil} - p_{ss}^{oil})} z_t^{RP} \qquad (30)$$

where z_t^{RP} is the exogenous part of the risk premium, while φ_{nfa} and φ_{oil} are the coefficients for the impact of external debt and the oil price on the risk premium.

The quantity of goods purchased abroad, IM_t, comes from imported goods sold by importing retailers, Im_t, and importers' costs of price adjustment:

$$IM_t = Im_t + \frac{k_F}{2}\left(\frac{P_t^F}{P_{t-1}^F} - (\pi_{t-1}^F)^{\iota_H}(\pi_*)^{1-\iota_F}\right)^2 Im_t \frac{P_t^F}{\varepsilon_t P_t^{F*}} \qquad (31)$$

Goods sold by importing retailers, Im_t, are bought by the aggregators of consumer goods, $C_{F,t}$, and investment goods, $I_{F,t}$:

$$Im_t = C_{F,t} + I_{F,t} \qquad (32)$$

The aggregators of consumer and investment goods also purchase all of domestic retailers' goods:

$$Y_t^H = I_{H,t} + C_{H,t} \qquad (33)$$

Aggregators of consumer goods sell their goods, C_t^p, to households which use these goods for consumption, C_t, and wage adjustment:

$$C_t^p = C_t + \frac{k_w}{2}\left(\frac{W_t}{W_{t-1} e^{g_{w,ss_t}}} - (\pi_{t-1})^{\iota_w}(\pi_*)^{1-\iota_w}\right)^2 \frac{W_t}{P_t} l_t \qquad (34)$$

As described above, the aggregators of investment goods produce $I_t + a(u_t)K_t'$ units of goods and sell them to investment firms, which transform them into capital which is then rented out to producers. The equality of capital, $u_t K_t'$, which investment firms rent out and capital, K_t, which producers rent is written as:

$$u_t K_t' = K_t \qquad (35)$$

Goods produced by firms are used as government consumption and by domestic and exporting retailers:

$$Y_t = G_t + Y_t^H + Y_t^{*H} + \frac{k_H}{2}\left(\frac{P_{t+i}^H}{P_{t+i-1}^H} - (\pi_{t-1}^H)^{\iota_H}(\pi_*)^{1-\iota_H} - (\pi_{t-1}^H)^{\iota_H}(\pi_*)^{1-\iota_H}\right)^2 Y_t^H \frac{P_t^H}{P_t^Y} +$$

$$+ \frac{k_{*H}}{2}\left(\frac{P_t^{*H}}{P_{t-1}^{*H}} - (\pi_{t-1}^{*H})^{\iota_{*H}}(\pi^*)^{1-\iota_{*H}}\right)^2 Y_t^{*H} \frac{\varepsilon_t P_t^{*H}}{P_t^Y} \tag{36}$$

We also complete the definition of the exchange rate growth, $g_t^{\mathcal{E}}$, growth of prices set by domestic retailers, π_t^H, importing retailers, π_t^F, and exporting retailers, π_t^{*H}:

$$g_t^{\mathcal{E}} = \frac{rer_t}{rer_{t-1}}\frac{\pi_t}{\pi_t^*} \tag{37}$$

$$\pi_t^H = \frac{p_t^H}{p_{t-1}^H}\pi_t \tag{38}$$

$$\pi_t^F = \frac{p_t^F}{p_{t-1}^F}\pi_t \tag{39}$$

$$\pi_t^{*H} = \frac{p_t^{*H}}{p_{t-1}^{*H}}\pi_t^* \tag{40}$$

Exogenous processes and shocks

The model contains 18 shocks which define the related autoregressive processes:[14]

e_t^{oil}: a real oil price shock(p_t^{oil}),

e_t^R: a monetary policy shock,

e_t^{res}: a reserves shock,

$e_t^{g_A}$: a permanent technology shock (g_t^A),

$e_t^{A_c}$: a temporary technology shock (A_t^c),

$e_t^{\zeta_c}$: a preferences shock (ζ_t^c),

$e_t^{\zeta_l}$: a labor supply shock (ζ_t^l),

e_t^U: an investment technology shock (U_t),

$e_t^{\varepsilon_h}$: a markup shock for domestic retailers ($\varepsilon_{h,t}$),

$e_t^{\varepsilon_f}$: a markup shock for importing retailers ($\varepsilon_{f,t}$),

$e_t^{\varepsilon_{*h}}$: a markup shock for exporting retailers ($\varepsilon_{*h,t}$),

$e_t^{p_{F*}}$: a shock of relative prices of imported goods (p_t^{F*}),

$e_t^{S_{oil}}$: a shock of oil exports (S_t^{oil}),

$e_t^{Z_{RP}}$: a risk premium shock (z_t^{RP}),

e_t^G: a government consumption shock (G_t),

e_t^{*R}: a foreign monetary policy shock,

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[14] Shocks of central bank policies are assumed to be nonautoregressive.

$e_t^{A_*}$: a foreign temporary technology shock (A_t^*),

$e_t^{\zeta_{c*}}$: a foreign preferences shock (ζ_t^{*c}).

Model with the banking sector

This subsection adds the banking sector to the baseline model. For this to be done, agents that will take loans should first be added. We focus on loans to firms, thereby excluding the propagation of shocks in the banking sector via lending to households. We introduce entrepreneurs to the model, as *Bernanke et al. (1999)* and *Christiano et al. (2014)*. Entrepreneurs buy capital from investment firms. Unlike the baseline model, however, this is "raw" capital which cannot be directly used to produce goods. From "raw" capital, entrepreneurs produce effective capital (suitable for producing goods) and rent it out. Upon completion of the production cycle, used capital is again sold to investment firms. To buy "raw" capital, entrepreneurs can use equity or debt, which helps add loans to the model. As *Christiano et al. (2010)*, we assume that there is a bank unit which is engaged in providing loans to entrepreneurs and operates at zero profit. This unit in fact adds a risk premium to risk-free interest rates set by another bank unit which operates like banks from *Gerali et al (2010)*, taking household deposits and issuing loans.

Below we will dwell in more detail on the objectives of entrepreneurs and banks as well as those of investment firms whose behavior is affected by the introduction of financial frictions.

Entrepreneurs and a risky bank unit

We assume that the economy has a continuum of entrepreneurs distributed with density $f_t(N)$ at time t:

$$N_t = \int_0^\infty f_t(N)dN$$

where N_t is entrepreneurs' aggregated equity in period t.

Each entrepreneur buys "raw" capital using the entrepreneur's equity N_t and loan B_t

$$Q_t\overline{K}_t(N) = B_t(N) + N_t \tag{41}$$

where $\overline{K}_t$ is the amount of "raw" capital bought at time t.

Further on, entrepreneurs suffer an idiosyncratic shock, ω[15], affecting the amount of capital, $\omega\overline{K}_t(N)$, which they can produce from a unit of "raw" capital, $\overline{K}_t(N)$. At time $t+1$, entrepreneurs

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[15] We assume that the shock has mean equal to one.

determine capital utilization, u_t, rent out capital, and then sell capital left after depreciation back to investment firms. Return on a unit of "raw" capital will be equal to ωR_{t+1}^k, where

$$R_t^k = \frac{(u_t Z_t - a(u_t) P_t^I) + (1-\delta) Q_t}{Q_{t-1}} \tag{42}$$

We will refer to the value of an idiosyncratic shock at which income from capital earned by a firm is equal to loan payments as a bankruptcy cutoff at time t. The bankruptcy cutoff is given by the equation:

$$\bar{\omega}_t R_t^k Q_{t-1} \bar{K}_{t-1}(N) = R_t^{en} B_{t-1}(N) \tag{43}$$

where $\bar{\omega}_t$ is a bankruptcy cutoff at time t, R_t^{en} is an interest rate on debt at time $t-1$.

Banks' risky units provide lending to entrepreneurs. A bank and an entrepreneur sign a contract, with an entrepreneur choosing interest payments and loan amounts from a certain "menu". It is assumed that where a specific shock is above the bankruptcy cutoff, $\bar{\omega}_t$, an entrepreneur pays off debt and interest, $R_t^{en} B_{t-1}(N)$, otherwise a bank seizes all of the remaining funds, $\omega R_t^k Q_{t-1} \bar{K}_{t-1}(N)$, but bears costs in proportion to the funds which an entrepreneur has retained,[16] $\mu \omega R_t^k Q_{t-1} \bar{K}_{t-1}(N)$. That said, the "risky" unit itself borrows funds from a bank at interest rate R_t^b. We also assume that the bank's "risky" unit operates at zero profit:

$$\left(1 - \int_0^{\bar{\omega}_t} p_{t-1}(\omega) d\omega\right) R_t^{en} B_{t-1}(N) + (1-\mu) R_t^k Q_{t-1} \bar{K}_{t-1}(N) \int_0^{\bar{\omega}_t} \omega p_{t-1}(\omega) d\omega = R_{t-1}^b B_{t-1}(N)$$

or

$$\Gamma_{t-1}(\bar{\omega}_t) - \mu G_{t-1}(\bar{\omega}_t) = \frac{R_{t-1}^b}{R_t^k} \frac{B_{t-1}(N)}{Q_{t-1} \bar{K}_{t-1}(N)}, \tag{44}$$

where

$$\Gamma_{t-1}(\bar{\omega}_t) = \left(1 - \int_0^{\bar{\omega}_t} p_{t-1}(\omega) d\omega\right) \bar{\omega}_t + G_{t-1}(\bar{\omega}_t)$$

$$G_{t-1}(\bar{\omega}_t) = \int_0^{\bar{\omega}_t} \omega p_{t-1}(\omega) d\omega$$

Entrepreneurs staying afloat earn income from capital, $\omega R_t^k Q_{t-1} \bar{K}_{t-1}(N)$, and receive transfers from households, TR_t^e, paying off loans and interest, $R_t^{en} B_{t-1}(N)$. After aggregation and using the fact that only γ_t part of entrepreneurs "survive", we obtain equity dynamics:

$$N_t = \gamma_t \left(\int_{\bar{\omega}_t}^{\infty} \omega p_{t-1}(\omega) d\omega\right) R_t^k Q_{t-1} \bar{K}_{t-1} - \gamma_t \left(\int_{\bar{\omega}_t}^{\infty} p_{t-1}(\omega) d\omega\right) R_t^{en} B_{t-1} + TR_t^e$$

or

$$N_t = \gamma_t \left(1 - \Gamma_{t-1}(\bar{\omega}_t)\right) R_t^k Q_{t-1} \bar{K}_{t-1} + TR_t^e \tag{45}$$

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[16] For details see *Bernanke et al. (1999)*.

Entrepreneurs maximize expected equity of the next period:

$$E_t\left(\int_{\overline{\omega}_t}^{\infty}\omega p_{t-1}(\omega)d\omega\right)R_{t+1}^k Q_t\overline{K}_t(N) - E_t\left(\int_{\overline{\omega}_t}^{\infty}p_{t-1}(\omega)d\omega\right)R_{t+1}^{en}B_t(N)$$

or

$$E_t\big(1 - \Gamma_t(\overline{\omega}_{t+1})\big)R_{t+1}^k Q_t\overline{K}_t(N)$$

The first-order condition is written as follows:

$$E_t\left(\big(1 - \Gamma_t(\overline{\omega}_{t+1})\big)\frac{R_{t+1}^k}{R_t^b} + \frac{\Gamma_{t'}(\overline{\omega}_{t+1})}{\Gamma_{t'}(\overline{\omega}_{t+1}) - \mu G_{t'}(\overline{\omega}_{t+1})}\left(\frac{R_{t+1}^k}{R_t^b}\big(\Gamma_t(\overline{\omega}_{t+1}) - \mu G_t(\overline{\omega}_{t+1})\big) - 1\right)\right) = 0 \qquad (46)$$

The first-order condition for capital utilization is the same as that for investment firms of the baseline model:

$$\frac{Z_t}{P_t^I} - a'(u_t) = 0 \qquad (47)$$

Investment firms

As in the baseline model, investment firms purchase goods from aggregators of investment goods, $P_t^I I_t(j)$, and produce "raw" capital, $\overline{K}_t(j)$. Unlike the baseline model, "raw" capital is not rented out to producers. Instead, it is sold at the end of period t, $Q_t\overline{K}_t(j)$, and bought at the beginning of period $t + 1$, $Q_t\overline{K}_t'(j)$. Investment firms maximize profit:

$$E_t\sum_{i=0}^{\infty}\lambda_{t+i}\left(\frac{Q_{t+i}\overline{K}_{t+i}(j) - P_{t+i}^I I_{t+i}(j) - Q_{t+i}\overline{K}_{t+i}'(j)}{P_{t+i}}\right)$$

Provided that capital dynamics is:

$$\overline{K}_t(j) = \overline{K}_t'(j) + \left(1 - \frac{k_I}{2}\left(\frac{I_t(j)}{I_{t-1}(j)e^{gI,ss_t}} - 1\right)^2\right)I_t(j) \qquad (48)$$

the first-order condition is written as:

$$-\frac{P_t^I}{P_t} + \frac{Q_t}{P_t}\left(1 - \frac{k_I}{2}\left(\frac{I_t}{I_{t-1}e^{gI,ss_{t-1}}} - 1\right)^2\right) - \frac{Q_t}{P_t}k_I\left(\frac{I_t}{I_{t-1}e^{gI,ss_t}} - 1\right)\frac{I_t}{I_{t-1}e^{gI,ss_t}} +$$

$$+\beta E_t\left(\frac{C_t - hC_{t-1}}{C_{t+1} - hC_t}\frac{\zeta_{t+1}^c}{\zeta_t^c}\frac{Q_{t+1}}{P_{t+1}}\left(\frac{I_{t+1}}{I_t e^{gI,ss_{t+1}}} - 1\right)\frac{(I_{t+1})^2}{(I_t)^2 e^{gI,ss_{t+1}}}\right) = 0 \qquad (49)$$

Banks

As mentioned above, banks consist of two units: one that deals with individual risks and the one engaged in all other operations. The former is described above, so we will only describe the latter.

Assets of the j-th bank in the model are comprised of loans, $B_t(j)$, net interbank transactions, and transactions with a central bank, $IB_t(j)$, while liabilities are made up of deposits, $D_t(j)$, and the bank's equity, $J_t(j)$. The bank's balance sheet can thus be written as:

$$B_t(j) + IB_t(j) = D_t(j) + J_t(j)$$

The bank's profit comes from interest paid on loans, $\left(R^b_{t-1}(j) - 1\right)B_{t-1}(j)$, interest payments on interbank transactions and transactions with a central bank, $(R_{t-1} - 1)IB_{t-1}(j)$, less costs. The costs are made up of interest payments on deposits, $(R^D_{t-1}(j) - 1)D_{t-1}(j)$, costs of managing the bank, $\delta_b J_{t-1}(j)$ and quadratic costs of capital adjustment, $\frac{k^K}{2}\left(\frac{J_t(j)}{B_t(j)} - \omega^J\right)^2 J_t$, loan rates for the bank's risky unit, $\frac{k^b}{2}\left(\frac{R^b_t(j)}{\left(R^b_{t-1}(j)\right)^{\iota_b}(R^b_{ss})^{1-\iota_b}} - 1\right)^2 B_t$, deposit rates $\frac{k^D}{2}\left(\frac{R^D_t(j)}{\left(R^D_{t-1}(j)\right)^{\iota_d}(R^D_{ss})^{1-\iota_d}} - 1\right)^2 D_t$, and one-off transfers to household TR^b_t. Total income is:

$$\Pi^b_t(j) = \left(R^b_{t-1}(j) - 1\right)B_{t-1}(j) + (R_{t-1} - 1)IB_{t-1}(j) - (R^D_{t-1}(j) - 1)D_{t-1}(j) - \frac{k^K}{2}\left(\frac{J_t(j)}{B_t(j)} - \omega^J\right)^2 J_t -$$

$$\frac{k^b}{2}\left(\frac{R^b_t(j)}{\left(R^b_{t-1}(j)\right)^{\iota_b}(R^b_{ss})^{1-\iota_b}} - 1\right)^2 B_t - \frac{k^D}{2}\left(\frac{R^D_t(j)}{\left(R^D_{t-1}(j)\right)^{\iota_d}(R^D_{ss})^{1-\iota_d}} - 1\right)^2 D_t - \delta_b J_{t-1}(j) - TR^b_t \qquad (50)$$

where k^K is the coefficient of the costs of equity-to-loans ratio deviation from the desired level, ω^J, k^b is the coefficient of the costs of deviation of the loan rate for the risky unit, $R^b_t(j)$, from the predetermined level, ι_b is the weight of lagged value in the predetermined level of the loan rate for the risky unit, k^D is the coefficient of the costs of deviation of deposit rate, $R^D_t(j)$, from the predetermined level, ι_d is the weight of lagged value in the predetermined level of the deposit rate.

Banks maximize the discounted value of real transfers to households, which is proportional to profit, $\Pi^b_t(j)$:

$$E_t \sum_{i=0}^{\infty} \frac{\lambda_{t+i}(1 - o_{t+i})}{P_{t+i}} \Pi^b_{t+i}(j)$$

Subject to a balance sheet restriction, capital dynamics, demand for loans,[17] and supply of deposits:

$$J_t(j) = \frac{J_{t-1}(j)}{\varepsilon^{cap}_t} + o_t \Pi^b_t(j) \qquad (51)$$

$$B_t(j) = \left(\frac{R^b_t(j)}{R^b_t}\right)^{-\varepsilon^b_t} B_t$$

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[17] This form of demand can have the following interpretation: loans are not provided directly to the risky unit, but are issued to an intermediary firm which aggregates them. On the other hand, first-order conditions can be regarded as a rule used by the bank in setting interest rates. An alternative rule can, for example, look as follows:

$$R^{DC}_t(j) = \mu^{DC} R_t$$

$$D_t(j) = \left(\frac{R_t^D(j)}{R_t^D}\right)^{\varepsilon_t^D} D_t$$

where $(1 - o_t)$ is the share of transfers to households, ε_t^b is interest rate loan elasticity assumed by banks, ε_t^D is interest rate deposit elasticity assumed by banks, ε_t^{cap} is a capital shock.

The bank's interest income can be rewritten as:

$$\left(R_{t-1}^b(j) - 1\right)B_{t-1}(j) + (R_{t-1} - 1)IB_{t-1}(j) - (R_{t-1}^D(j) - 1)D_{t-1}(j)$$

$$= \left(R_{t-1}^b(j) - 1\right)B_{t-1}(j) + (R_{t-1} - 1)\left(D_{t-1}(j) + J_{t-1}(j) - B_{t-1}(j)\right)$$

$$- (R_{t-1}^D(j) - 1)D_{t-1}(j)$$

$$= \left(R_{t-1}^b(j) - R_{t-1}\right)B_{t-1}(j) + \left(R_{t-1} - R_{t-1}^D(j)\right)D_{t-1}(j) + (R_{t-1} - 1)J_{t-1}(j)$$

$$= \left(R_{t-1}^b(j) - R_{t-1}\right)B_{t-1}(j) + \left(R_{t-1} - R_{t-1}^D(j)\right)\left(B_{t-1}(j) - J_{t-1}(j)\right)$$

$$+ (R_{t-1} - 1)J_{t-1}(j) + \left(R_{t-1} - R_{t-1}^D(j)\right)IB_{t-1}(j)$$

To simplify the model's equations, transfers are set equal to $(R_{t-1} - R_{t-1}^D)IB_{t-1}$. This levels out relevant components in the bank's capital dynamics.

First-order conditions for loan and deposit interest rates will be written as:

$$-\left(\frac{(1-o_t)}{P_t} + \frac{o_t m_t}{P_t}\right)\left(k^K \varepsilon_t^{DC}\left(\frac{J_t}{B_t^{DC}} - \omega_t^J\right)\left(\frac{J_t}{B_t^{DC}}\right)^2\frac{1}{R_t^{DC}} + k^{DC}\left(\frac{R_t^{DC}}{(R_{t-1}^{DC})^{\iota_{dc}}(R_{ss}^{DC})^{1-\iota_{dc}}} - 1\right)\frac{1}{(R_{t-1}^{DC})^{\iota_{dc}}(R_{ss}^{DC})^{1-\iota_{dc}}}\right) +$$

$$+ E_t\frac{\lambda_{t+1}}{\lambda_t}\left(\frac{(1-o_{t+1})}{P_{t+1}} + \frac{o_{t+1}m_{t+1}}{P_{t+1}}\right)\left((1 - \varepsilon_t^{DC}) + \varepsilon_t^{DC}\frac{R_t}{R_t^{DC}} + k^{DC}\left(\frac{R_{t+1}^{DC}}{(R_t^{DC})^{\iota_{dc}}(R_{ss}^{DC})^{1-\iota_{dc}}} - \right.\right.$$

$$\left.\left.1\right)\frac{\iota_{dc}R_{t+1}^{DC}}{(R_t^{DC})^{\iota_{dc}}(R_{ss}^{DC})^{1-\iota_{dc}}}\frac{1}{R_t^{DC}}\frac{B_{t+1}^{DC}}{B_t^{DC}}\right) = 0 \tag{52}$$

$$-\left(\frac{(1-o_t)}{P_t} + \frac{o_t m_t}{P_t}\right)\left(k^D\left(\frac{R_t^D}{(R_{t-1}^D)^{\iota_d}(R_{ss}^D)^{1-\iota_d}} - 1\right)\frac{1}{(R_{t-1}^D)^{\iota_d}(R_{ss}^D)^{1-\iota_d}}\right) + E_t\frac{\lambda_{t+1}}{\lambda_t}\left(\frac{(1-o_{t+1})}{P_{t+1}} + \frac{o_{t+1}m_{t+1}}{P_{t+1}}\right)\left(-(1 + \varepsilon_t^D) + \right.$$

$$\left.\varepsilon_t^D\frac{R_t}{R_t^D} + k^D\left(\frac{R_{t+1}^D}{(R_t^D)^{\iota_d}(R_{ss}^D)^{1-\iota_d}} - 1\right)\frac{\iota_d R_{t+1}^D}{(R_t^D)^{\iota_d}(R_{ss}^D)^{1-\iota_d}}\frac{1}{R_t^D}\frac{D_{t+1}}{D_t}\right) = 0 \tag{53}$$

where m_t is the Lagrange multiplier on the bank's capital dynamics. Given that variable m goes away in the linearized version of the model, we do not need to differentiate discounted profit with respect to capital for solving the model.

Modified production function

The modification of the baseline model to that with the banking sector produces a quarterly depreciation rate of about 10% (see Appendix A). To achieve adequate values of the depreciation rate, we modify the production function by adding fixed costs, $\Phi(A_t)^{\frac{1}{\alpha}}$, to it:

$$Y_t = A_t A_t^c l_t^{\alpha} K_t^{1-\alpha} - \Phi(A_t)^{\frac{1}{\alpha}} \tag{4*}$$

First-order conditions are in this case rewritten as:

$$\alpha P_t^Y (Y_t + \Phi(A_t)^{\frac{1}{\alpha}}) - W_t l_t = 0 \tag{5*}$$

$$(1 - \alpha) P_t^Y (Y_t + \Phi(A_t)^{\frac{1}{\alpha}}) - Z_t K_t = 0. \tag{6*}$$

Other equations

The equality of capital bought by investment firms, $\bar{K}_t'$, and that sold by entrepreneurs, $(1 - \delta)\bar{K}_{t-1}$:

$$\bar{K}_t' = (1 - \delta)\bar{K}_{t-1} \tag{54}$$

The equality of demand, K_t, and supply, $u_t \bar{K}_{t-1}$, of "raw" capital:

$$K_t = u_t \bar{K}_{t-1} \tag{55}$$

Exogenous processes and shocks

We add four more shocks to the shocks of the baseline model:

$e_t^{\sigma_\omega}$: a risk shock, $(\sigma_{\omega,t})$,

e_t^{γ}: a financial wealth shock, (γ_t),

$e_t^{\varepsilon_D}$: a markup shock for deposit rates, (ε_t^D),

$e_t^{\varepsilon_{cap}}$: a capital dynamics shock, (ε_t^{cap}).

We do not use a markup shock for loan rates because it is similar to the risk shock.

3. Parameter estimation

We use the log-linear[18] approximation to solve the proposed DSGE models and then work with this approximation. Log-linearization is carried out using the Symbolic Toolbox package in MATLAB. To solve the model, the algorithm proposed in *Sims (2002)* is used. We employ Bayesian statistics for approximating the posterior distributions of parameters (prior distributions are presented in Table 2). In particular, the adaptive Metropolis-Hastings algorithm,[19] similar to the algorithm from *Roberts and Rosenthal (2009)*, is used. Its only difference from the standard Random-Walk

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[18] For variables which can change sign, we relied on usual linearization.
[19] The first 300,000 out of 400,000 iterations were excluded.

Metropolis-Hastings algorithm is that proposal density is adaptive. Proposal density at the $n-$th iteration is written as:

$$q(\theta'|\theta) = 0.95N\left(\theta, \frac{2.38^2}{d}\Sigma_n\right) + 0.05N\left(\theta, \frac{0.1^2}{d}H\right)$$

if $n > 5d$ and

$$q(\theta'|\theta) = N\left(\theta, \frac{0.1^2}{d}H\right)$$

otherwise. Σ_n is an estimate of the covariance matrix at n-th iteration , H is the negative inverse Hessian, d is the dimension of parameter space.

To estimate the baseline model, 18 series are used:

$dlnGDP_t$: change in the logarithm of the real GDP,

$dlnConsumption_t$: change in the logarithm of the real consumption,

$dlnInvestment_t$: change in the logarithm of the real investment,

$dlnExport_t$: change in the logarithm of the real exports,

$dlnGov\_consumption_t$: change in the logarithm of the real government consumption,

$dlnWage_t$: change in the logarithm of the real wage,

$lnMIACR_t$: the logarithm of the quarter-average overnight interbank market rate,

$dlnP\_GDP_t$: change in the logarithm of the GDP deflator,

$dlnCPI_t$: change in the logarithm of the CPI,

$dlnP\_im_t$: change in the logarithm of the imports deflator,

$dlnP\_ex_t$: change in the logarithm of the exports deflator,

$dlnP\_inv_t$: change in the logarithm of the investment deflator,

$dRes2Export_t$: the ratio of reserves change to exports,

$dlnExch_t$: change in the logarithm of the average exchange rate in the last month of the quarter,

$lnFED_t$: the logarithm of quarter-average FFR,

$dlnGDP\_US_t$: change in the logarithm of the real U.S. GDP,

$dlnGDP\_DEF\_US_t$: change in the logarithm of the U.S. GDP deflator,

$dlnOil_t$: change in the logarithm of the real Urals oil price.

To estimate the model with the banking sector, the following four variables are used:

$dlnLoan_t$: change in the logarithm of nonfinancial organizations' ruble-denominated bank debt of all maturities,

$dlnCapital_t$: change in the logarithm of credit institutions' capital and income,

$lnLoanRate_t$: the logarithm of the interest rate on loans to nonfinancial organizations with maturities of 1 to 3 years,

$lnDepRate_t$: the logarithm of the interest rate on household deposits with maturities of 1 to 3 years.

A model variable closest to the one actually observed is selected for each series. For the baseline model, the relationship between normalized and observed variables is written as follows:[20]

$$dlnGDP_t = ln(g_t^A)$$
$$+ ln\left(C_t^p + p_{t-1}^Y G_t + p_{t-1}^I(I_t + a(u_t)K_t') + rer_{t-1}p_{t-1}^{*H}Y_t^{*H} + rer_{t-1}p_{t-1}^{oil}S_t^{oil}\right.$$
$$\left. - rer_{t-1}p_{t-1}^{*F}IM_t\right)$$
$$- ln\left(C_{t-1}^p + p_{t-1}^Y G_{t-1} + p_{t-1}^I(I_{t-1} + a(u_{t-1})K_{t-1}') + rer_{t-1}p_{t-1}^{*H}Y_{t-1}^{*H}\right.$$
$$\left. + rer_{t-1}p_{t-1}^{oil}S_{t-1}^{oil} - rer_{t-1}p_{t-1}^{*F}IM_{t-1}\right) + e_t^{dlnGDP}$$

$$dlnConsumption_t = ln(g_t^A) + ln(C_t^p) - ln(C_{t-1}^p) + e_t^{dlnConsumption}$$

$$dlnInvestment_t = ln(g_t^A) + ln(I_t + a(u_t)K_t') - ln(I_{t-1} + a(u_{t-1})K_{t-1}') + e_t^{dlnInvestment}$$

$$dlnExport_t = ln(g_t^A) + ln\left(rer_{t-1}p_{t-1}^{*H}Y_t^{*H} + rer_{t-1}p_{t-1}^{oil}S_t^{oil}\right)$$
$$- ln\left(rer_{t-1}p_{t-1}^{*H}Y_{t-1}^{*H} + rer_{t-1}p_{t-1}^{oil}S_{t-1}^{oil}\right) + e_t^{dlnExport}$$

$$dlnGov\_consumption_t = ln(g_t^A) + ln(G_t) - ln(G_{t-1}) + e_t^{dlnGov\_consumption}$$

$$dlnWage_t = ln(g_t^A) + ln(w_t) - ln(w_{t-1}) + e_t^{dlnWage}$$

$$lnMIACR_t = 4ln(R_t) + e_t^{lnMIACR}$$

$$dlnP\_GDP_t = ln(\pi_t)$$
$$+ ln\left(C_t^p + p_t^Y G_t + p_t^I(I_t + a(u_t)K_t') + rer_t p_t^{*H}Y_t^{*H} + rer_t p_t^{oil}S_t^{oil} - rer_t p_t^{*F}IM_t\right)$$
$$- ln\left(C_t^p + p_{t-1}^Y G_t + p_{t-1}^I(I_t + a(u_t)K_t') + rer_{t-1}p_{t-1}^{*H}Y_t^{*H} + rer_{t-1}p_{t-1}^{oil}S_t^{oil}\right.$$
$$\left. - rer_{t-1}p_{t-1}^{*F}IM_t\right) + e_t^{dlnP\_GDP}$$

$$dlnCPI_t = ln(\pi_t) + e_t^{dlnCPI}$$

$$dlnP\_im_t = ln(\pi_t) + ln(rer_t p_t^{*F}) - ln(rer_{t-1}p_{t-1}^{*F}) + e_t^{dlnP\_im}$$

$$dlnP\_ex_t = ln(\pi_t) + ln\left(rer_t p_t^{*H}Y_t^{*H} + rer_t p_t^{oil}S_t^{oil}\right) - ln\left(rer_{t-1}p_{t-1}^{*H}Y_t^{*H} + rer_{t-1}p_{t-1}^{oil}S_t^{oil}\right)$$
$$+ e_t^{dlnP\_ex}$$

$$dlnP\_inv_t = ln(\pi_t) + ln(p_t^I) - ln(p_{t-1}^I) + e_t^{dlnP\_inv}$$

$$dRes2Export_t = \frac{dres_t}{p_t^{*H}Y_t^{*H} + p_t^{oil}S_t^{oil}} + e_t^{dRes2Export}$$

$$dlnExch_t = ln(g_t^\varepsilon) + e_t^{dlnExch}$$

$$lnFED_t = ln(R_t^*) + e_t^{lnFED}$$

$$dlnGDP\_US_t = ln(g_t^A) + ln(Y_t^*) - ln(Y_{t-1}^*) + e_t^{dlnGDP\_US}$$

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[20] We note that the money market and monetary policy rates coincide in the models. With reference to the model we mean the monetary policy rate, while the observable variables imply the money market rates.

$$dlnGDP\_DEF\_US_t = ln(\pi_t^*) + e_t^{dlnGDP\_DEF\_US}$$

$$dlnOil_t = ln(p_t^{oil}) - ln(p_{t-1}^{oil})$$

where e_t^X is a measurement error for variable X.

These series are used for the baseline model. We introduce minor modifications for the model with the banking sector, which naturally follow from the model. We do not, however, include financial intermediation services in GDP for simplicity. The rest of the variables are written as follows:

$$dlnLoan_t = ln(g_t^A) + ln(\pi_t) + ln(b_t) - ln(b_{t-1}) + e_t^{dlnLoan}$$

$$dlnCapital_t = ln(g_t^A) + ln(\pi_t) + ln(j_t) - ln(j_{t-1}) + e_t^{dlnCapital}$$

$$lnLoanRate_t = ln\big(E_t(R_{t+1}^{en} R_{t+2}^{en} R_{t+3}^{en} R_{t+4}^{en})\big) + e_t^{lnLoanRate}$$

$$lnDepRate_t = ln\big(E_t(R_t^D R_{t+1}^D R_{t+2}^D R_{t+3}^D)\big) + e_t^{lnDepRate}$$

For the baseline model, we set measurement error variances equal to 10% of observable series variances for all indicators, except for the real oil price and the ratio of change in reserves to exports. The model assumes a steady state real oil price, while introducing measurement errors for its growth may shift its steady state level, which we seek to avoid in this model. The variance of the measurement error of the change-in-reserves-to-exports ratio is set at 50%. We do this because the balance of payments contains certain components which we do not factor in, assuming the ip_t process to be constant,[21] because its introduction seeks to make sure that the debt level would not be tens of times the GDP.

Also, given that our banking sector is fairly stylized, loans are provided for one period and capital dynamics take into account far from all the payments, we set measurement errors for changes in loans and capital equal to 50%. Although the maturities of the model's interest rates on loans and deposits do not quite match the maturities of the observable rates, measurement errors are set equal to 10% for them. The reason is that, among other things, the replacement of the above rates with shorter ones does not change the results of the model significantly.

A part of the model's parameters and ratios are calibrated. The annual steady state value of the interest rate is set at 7.5%. The inflation target is 4%. For a foreign economy, these values are equal to 4.5% and 2% respectively. A steady state growth rate is set at 1.5% for both economies. Capital share in the production function was set equal to $\frac{1}{3}$. All elasticities related to imperfect competition are calibrated at a level of 10. The curvature on disutility of labor is set at 2 for both economies. Steady state labor is calibrated at 1. Values of exogenous processes are set to 1, unless

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[21] This assumption can be easily changed if necessary.

otherwise stated in Appendix A. We also calibrate key nominal ratios in the economy in such a way as to roughly correlate them with historical averages. The ratios of investment and government consumption to consumption equal 0.4 each. The exports-to-consumption ratio is taken as 0.6, assuming that oil accounts for two thirds of the entire exports. The share of imports in consumption (investment) is set at 0.35 (0.3). The ratio of ip to exports is assumed to equal 0.28. Steady state values of the real oil price and the real exchange rate are taken as 1. These parameters are common for both models.

A number of parameters are additionally calibrated for the model with the banking sector. This model is fairly stylized, therefore we select some parameters for it so as to link them with generally accepted values.[22] The entrepreneurs' "survival" rate is set at 0.97. Monitoring costs are equal to 0.2. The steady state default level is taken as 0.007. The ratio of entrepreneurs' equity to assets is set at 0.5, close to the Russian data.

We set the quarterly depreciation rate at 2.5% for the model with banking sector. The effect of this choice on the model's behavior is discussed below. Steady state levels for the loan and deposit rates are taken as 12.5% and 6% respectively. These levels conform to the model's constraints: the deposit rate is higher than the sum of inflation and the economy's growth rates but lower than the interbank market rate, while the loan rate is higher than that of the interbank market. The steady-state loan rate is close to the historical one, while the deposit (medium-term) rate was historically higher than the interbank rate, which does not allow its level to be fully matched with the data. The coefficient for costs of managing bank is set at 0.005, helping ensure an adequate profit-to-equity ratio. The ratio of bank equity to loans to nonfinancial organizations is set equal to 0.4.

A foreign economy is preliminarily estimated (pointwise) on U.S. data over the period from 1Q 1971 to 4Q 2008. To estimate the domestic economy's parameters, we use data described above over the period from 1Q 2006 to 3Q 2016.[23]

4. Results

This section shows some features of the models described above. We first show the models' behavior in the course of the initial calibration of parameters which are not estimated on the data. We then demonstrate how the addition of data shifts parameter estimates and the model's impulse

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[22] The calibration can be changed easily but none of many other values we tried produced qualitatively different results.

[23] The series were seasonally adjusted if necessary using X-12 ARIMA.

responses. At the end of the section we look at the model's correlation with the Russian data, showing the shock decomposition and the model's predictive power.

Initial calibration

We shall first look at the model's behavior under the parameters presented in the first column of Table 2. Since the baseline model is fairly standard, for space considerations we show the impact of only some of the shocks: an oil price shock, a risk premium shock and a monetary policy shock.[24] The economy's response to these shocks is presented in Figures 2a–2c.

The exchange rate appreciates in response to a positive oil price shock, making imports cheaper and hence bringing down the prices of consumer and investment goods. A fall in prices of consumer goods results in an interest rate decline, which, coupled with other factors, causes the production of investment and consumer goods to expand and GDP to grow. Meanwhile exports dwindle, affected by the rising exchange rate.

A risk premium shock pushes up the interest rate at which domestic economic agents can borrow funds in foreign markets but does not change the interest rate itself in foreign countries. As an oil price shock, this shock affects the exchange rate and the interest rate on foreign loans but with the opposite sign, and therefore produces a qualitatively similar effect (with the opposite sign).

The economy responds to a positive monetary policy shock, i.e., an interest rate rise above the given rule, by reducing consumption and investment, because the interest rate directly affects investment firms and households' decisions in the baseline model. An interest rate rise also strengthens the exchange rate, making imports cheaper. All this brings prices down. As in the case of the oil shock, exports decline as the exchange rate appreciates.

To demonstrate what the inclusion of the banking sector contributes to the model, we show the economy's response to the same three shocks. Impulse responses for the model with the banking sector are also presented in Figures 2a–2c. To give a clearer idea of the dynamics, we introduce, in addition to observable values, short-term loan and deposit rates in diagrams and also draw an interest rate from the baseline model as an analogue.

Entrepreneurs' excess return on capital (and its expected values) plays an important role in the model with entrepreneurs. It is easy to see from equation (46) that with monitoring costs equaling zero, the expected return on a unit of "raw" capital will be equal to the interest rate on loans. In this case, entrepreneurs will not make any additional contribution to the linearized model's dynamics. Combining also equations (46) and (44), one can see that only the debt-to-capital or capital-to-equity

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[24] Results on impulse responses to the other shocks can be provided upon request.

ratios have an effect on excess return. Other things being equal, the high ratio of bought "raw" capital to equity increases a premium on interest rates, bringing about a more significant investment decline. In addition to this effect, there are an effect of the banking sector smoothing interest rates and an effect of change in steady state as a result of a different steady state structure of rates.

Having conducted several complementary experiments which are not presented here for space considerations, we have found that the effect of introducing the financial sector is a key one for a monetary policy shock. As in *Bernanke et al. (1999)*, a monetary policy shock increases the ratio of "raw" capital to equity, resulting in a larger difference between the expected return on capital and the loan rate, causing a steeper investment fall. As regards the risk-premium shock, the first effect is less pronounced than the third one, which, as a result of the shift in the level of interest rates, shifts the steady state of the model and elasticities, affecting the model's dynamics. The decomposition of the change in the oil shock impulse responses into the above effects cannot be done as easily and includes all three sources of change.

Despite the banking sector's quantitative impact on the model, its qualitative effect is not as strong. But one of the key advantages of the model with the banking sector is that it provides the opportunity to look at the effect of a number of complementary shocks on the economy. Figures 3a–3c present impulse responses to six shocks, two of which appear in the baseline model (shown for clarity) and the other four are new ones.

Figure 3a shows the monetary policy and capital dynamics shocks. The standard deviation of the second shock is scaled in such a way as to ensure the same loan rate response in the first period. We note that both shocks push the loan rate higher. This follows from equation (52), whose linearized form represents the loan rate as the weighted sum of previous and expected loan rates, as well as the monetary policy rate and the deviation of the equity-to-loans ratio from the desired level (with a negative sign). On the other hand, it can be seen from equation (53) that the deposit rate depends on the monetary policy rate but does not depend on equity-to-loans ratio. A monetary policy shock increases both the loan and deposit rate, whereas a capital dynamics shock only pushes up the loan rate, causing lending, investment, GDP and inflation to decline. This pushes the monetary policy rate down, putting pressure on the deposit rate. We also note that consumption grows in the model with the banking sector because deposit rates fall in this model and there is no consumer lending in it.

Figure 3b presents the economy's responses to the risk shock and the markup shock for deposit rates. The former of these shocks has an effect on the economy that is similar to the impact of the capital dynamics shock, but, unlike the risk shock, the capital dynamics shock involves a sharp drop in the bank's equity. The markup shock for deposit rates affects, above all, deposit rather than loan rates, pushing them up, which in turn depresses consumption, thereby driving down GDP and

inflation. Similarly to the risk shock, this lowers the monetary policy rate, which is a normalizing variable in Figure 3b.

The financial wealth and investment activity technology shocks increase investment (chosen as the normalizing variable). The former, however, brings about a rise in entrepreneurs' equity, stimulating demand for capital and hence for goods required for the production of investment goods, while the latter improves the technology of aggregators of investment goods, depressing demand for goods required for the production of investment goods. Although investment grows in both cases, prices in the economy go up under the former shock and fall under the latter. We also note that loans go down under the former shock and increase in the short term under the latter. This happens because under the financial wealth shock, loans are replaced by additional equity, while the investment activity shock makes entrepreneurs take more loans to buy capital.

As mentioned above, we set the capital depreciation rate equal to 2.5%. This choice affects the model's structure to a certain extent. For example, the depreciation rate determines the banking sector's size and fixed costs in the domestic goods production function. We note that because the entrepreneurs' sector and the banking sector are stylized, the size of the latter relative to the real economy is not calibrated. We show instead that changing the depreciation rate in the initial calibration does not change impulse responses[25] radically. Figures 4a–4c show the economy's response to the monetary policy, oil price and capital dynamics shocks with the depreciation rate equaling 2.5%, 5%, and 10%. It can be seen from these diagrams that the effect of the depreciation rate pretty much depends on the shock type but, nevertheless, does not change the key results of the model.

Estimated parameters

Before moving on to the impulse responses, decomposition, and forecasts, we will present the estimates of posterior distribution of the parameters. Table 3 shows the model estimation results obtained using the MH algorithm described above. The estimate of posterior distribution mode was taken as the initial point. It is easy to see that the posterior means are close to the prior ones for most of the parameters. This is most likely due to the short sample.[26] This assumption agrees with the results of *Kreptsev and Seleznev (2016)*, where the authors arrive at the same conclusion based on the test from *Muller (2012)*. But this can also be due to the fact that the optimization algorithm finds a local optimum (the quasi-Newton algorithm and the simulated annealing algorithm are used). We

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[25] We note that the depreciation rate is far from the only parameter affecting the banking sector's size in the model.
[26] This calls for further examination.

note this only after tens of thousands of MH-algorithm iterations, where it jumps to points with much higher posterior density values, changing, however, just some of the parameters (for example, k_{*H}). As a result, we cannot be absolutely certain that our algorithm discovers all modes even after 400,000 iterations.

Figures 5a–5c present 68-percent credible intervals of the economy's response to oil price, risk premium and monetary shocks. These diagrams are similar to Figures 2a–2c but are constructed using estimated parameters. Although the results are similar, estimation does adjust the results. For example, under the initial calibration, exports fall more significantly for the oil price shock in the model with the banking sector, while the estimated parameters show a more significant fall in the baseline model. A similar situation, but with the opposite sign, occurs with respect to wages. Under the risk premium shock, much the same is seen for investment and GDP. Additionally, the latter changes sign in the initial periods. The monetary policy shock keeps ratios between the variables unchanged but, as under the other shocks, the shape of responses still undergoes minor changes.

Results for the banking sector shocks are shown in Figures 6a–6d. They only change in quantitative terms, so we do not dwell on them in more detail; their description reproduces that for the initial calibration.

Shock decomposition and forecasting

In figures 7a–7f, we show which shocks the model uses to explain the key macro variables' behavior. With respect to the baseline model, we select three key shocks for each variable. For the model with the banking sector, four more shocks are introduced, referred to as the banking sector shocks. It can be seen from Figure 7a that GDP performance is dominated by a permanent technology shock, an exports shock, and a markup shock for exporting retailers. Based on the data, the model attributes the 2008–2009 GDP decline to a fall in exports rather than to an oil price drop. One has to remember that this is just an interpretation of data by the models which have a rather rigid structure.[27] It is seen from Figures 7b and 7c, however, that the oil price shock affects consumption and investment, which are GDP components. It is noteworthy that almost all of this effect is canceled out by imports. Also, a risk premium shock is one of the most important for both observables and, together with the oil price shock, plays a significant role in the 2014–2015 downturn. The risk premium and oil price shocks account for virtually all exchange rate movements, as can be seen from Figure 7d. Despite this, the two models differ in decomposing the change in exchange rate fluctuations into these shocks. As one can see, the risk premium shock plays a more important role

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[27] Introduction of correlated shocks may change this result.

in the baseline model than in the model with the banking sector. The banking sector shocks make a relatively minor contribution to the four variables described above. It would be fair to say that it is only for investment that this contribution is to some extent comparable to the prevalent shocks. These effects look logical: a major channel of the banking sector's influence is loans for buying capital, which creates demand for investment. As is clear from Figure 7e, except for one short episode, the banking sector shocks have no effect on inflation but have a significant impact on the interest rate because of its persistency (see Figure 7f). The model therefore suggests that the banking sector shocks had virtually no effect on the real economy in the 2006–2016 period. As the exchange rate affects import prices, the model indicates a significant effect of risk premium shocks and oil price ones on inflation. Since we set inflation in steady state at 4%, the model shows that rates were not high enough to bring it down to this level by generating monetary policy shocks.

Further on in this section, we will compare the predictive properties of the above two models with a number of alternatives under known external variables (the oil price, foreign GDP, a foreign GDP deflator and a foreign interest rate). We choose the AR(1)-process and the BVAR model (with the same variables as in the baseline model) as alternatives. The AR(1)-process is a model which does not explicitly account for external variables dynamics and provides a certain benchmark for our forecasts. BVAR models are usually chosen as alternatives to DSGE models, and we keep to this tradition in this study. We use BVAR with prior distributions, as in *Giannone et al. (2015),*[28,29] with three prior distributions combined: *Minnesota prior*, *dummy-initial observation* and *sum-of-coefficients*.

Forecasts for a horizon of up to 12 quarters are only considered, with just the last 23 points taken as a testing sample. The parameters are estimated recursively for each of the models, and then a forecast is constructed. An OLS is used to estimate parameters for the AR(1) model. With respect to the BVAR model, a mode of posterior distribution for hyperparameters is first identified, then a modal covariance matrix is found under these parameters, followed by the modal values of the coefficients. Modal parameters are also used for the DSGE model.

Data is slightly adjusted for the BVAR model. All real variables are set in terms of levels. Forecasts for these variables for other models are also converted to levels but are initially constructed in terms of increments.

In constructing forecasts, we in fact conduct a pseudo-real experiment aiming to answer a question about whether a particular model would be suitable for forecasting seasonally adjusted, as

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[28] The use of other prior distributions may improve the model's predictive properties, but this issue is beyond the scope of this study.
[29] Following the original study, we choose 5 lags.

necessary, data (not in real time), using the information shown to the model (all variables up to the current period and external variables for the forecast horizon). This experiment is of course far from the procedure normally used in forecasting but it gives hope that we will be able to detect models which substantially diverge from the values of the variables.

Tables 4a–4f present relative RMSEs for GDP, consumption, investment, an exchange rate change, as well as CPI changes and MIACR on a horizon of 1 to 12 quarters. All RMSEs are given relative to the AR(1) model. A model which has a better historical forecasts than the AR (1) is found for all variables except for the CPI. The baseline model is the most accurate for GDP on a horizon of one to three quarters, BVAR is best used on a horizon from four to seven quarters. The model with the banking sector, however, outperforms the other models on a horizon of 8 to 12 quarters. It is also superior for consumption on all horizons. Although the BVAR model comfortably outperforms the others for investment, we note that the model with the banking sector has a better predictive power than the baseline one. Both DSGE models forecast an exchange rate change better than the other models but the baseline model is marginally more accurate. Either the baseline DSGE model or BVAR is the best for the MIACR on various horizons. Unfortunately, none of the models outperform AR(1) for a CPI change, possibly as a result of setting the inflation target at a historically inaccurate 4% in the case of the DSGE model, with the baseline model steadily performing no worse than the model with the banking sector.

It can be inferred from the above that the accuracy of DSGE models proposed in this study is on a par with other models for most of the indicators. Moreover, the inclusion of the banking sector can both improve and worsen the models' predictive properties, depending on which indicator is forecasted.

5. Conclusion

This paper describes the DSGE model of the Russian economy which the Bank of Russia uses for simulation experiments, as well as its extended version with the banking sector. We show that the proposed models have adequate and well interpretable impulse responses under both the initial calibration and estimated parameters. Also, both models have fairly good predictive properties. Despite the fact that we primarily see the major benefit of the models proposed coming from simulation exercises, we also believe that they can be used for forecasting purposes as well.

As mentioned in the Introduction, the proposed model is a good starting point for understanding a variety of macroeconomic effects. For example, a number of channels of joint

implementation of monetary and macroprudential policy can be investigated. In particular, the introduction of various rules for setting bank capital requirements can be studied as part of macroprudential policy.

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Appendix A. Detrending and steady state

Baseline model detrending

We detrend the equations by dividing nominal variables by the CPI in the relevant period. These variables are denoted by the relevant lower case symbols. We also detrend retailers and producers' sales, consumption, government consumption, investment, oil exports, imports, real wages, capital, change in reserves, net foreign liabilities, foreign output, and foreign wages by dividing them by $(A_t)^{\frac{1}{\alpha}}$, but without changing symbols. We denote growth of $(A_t)^{\frac{1}{\alpha}}$ as g_t^A.

Households

$$\beta E_t \left(\frac{C_t - h(g_t^A)^{-1} C_{t-1}}{g_{t+1}^A C_{t+1} - hC_t} \frac{R_t}{\pi_{t+1}} \frac{\zeta_{t+1}^C}{\zeta_t^C} \right) = 1 \tag{A.1}$$

$$R_t = R_t^{NFA} \frac{E_t \left(\frac{C_t - h(g_t^A)^{-1} C_{t-1} g_{t+1}^{\mathcal{E}} \zeta_{t+1}^C}{g_{t+1}^A C_{t+1} - hC_t} \frac{1}{\pi_{t+1}} \frac{\zeta_{t+1}^C}{\zeta_t^C} \right)}{E_t \left(\frac{C_t - h(g_t^A)^{-1} C_{t-1}}{g_{t+1}^A C_{t+1} - hC_t} \frac{1}{\pi_{t+1}} \frac{\zeta_{t+1}^C}{\zeta_t^C} \right)} \tag{A.2}$$

$$\varepsilon_w \zeta_t^L \frac{(l_t)^\phi}{w_t} + \frac{\zeta_t^C}{C_t - h(g_t^A)^{-1} C_{t-1}} (1 - \varepsilon_w) - \frac{\zeta_t^C}{C_t - hC_{t-1}} k_w \left(\frac{w_t}{w_{t-1}} \pi_t - (\pi_{t-1})^{\iota_w} (\pi_*)^{1-\iota_w} \right) \frac{w_t}{w_{t-1}} \pi_t +$$

$$\beta E_t \frac{\zeta_{t+1}^C}{g_{t+1}^A C_{t+1} - hC_t} k_w \left(\frac{w_{t+1}}{w_t} \pi_{t+1} - (\pi_t)^{\iota_w} (\pi_*)^{1-\iota_w} \right) \frac{w_{t+1}^2}{w_t^2} \pi_{t+1} g_{t+1}^A \frac{l_{t+1}}{l_t} = 0 \tag{A.3}$$

Producers

$$Y_t = A_t^c l_t^\alpha K_t^{1-\alpha} \tag{A.4}$$

$$\alpha p_t^Y Y_t - w_t l_t = 0 \tag{A.5}$$

$$(1 - \alpha) p_t^Y Y_t - z_t K_t = 0 \tag{A.6}$$

Retailers

$$\left(1 - \varepsilon_{h,t}\right) + \varepsilon_{h,t} \frac{p_t^Y}{p_t^H} - k_H(\pi_t^H - (\pi_{t-1}^H)^{\iota_H}(\pi_*)^{1-\iota_H})\pi_t^H + \beta k_H E_t \frac{C_t - h(g_t^A)^{-1} C_{t-1}}{g_{t+1}^A C_{t+1} - hC_t} \frac{\zeta_{t+1}^C}{\zeta_t^C} (\pi_{t+1}^H -$$

$$(\pi_t^H)^{\iota_H}(\pi_*)^{1-\iota_H}) \frac{Y_{t+1}^H}{Y_t^H} \frac{(\pi_{t+1}^H)^2}{\pi_{t+1}} g_{t+1}^A = 0 \tag{A.7}$$

$$\left(1 - \varepsilon_{f,t}\right) + \varepsilon_{f,t}\frac{rer_t p_t^{F*}}{p_t^F} - k_F(\pi_t^F - (\pi_{t-1}^F)^{\iota_F}(\pi_*)^{1-\iota_F})\pi_t^F + \beta k_F E_t \frac{C_t - h(g_t^A)^{-1}C_{t-1}}{g_{t+1}^A C_{t+1} - hC_t}\frac{\zeta_{t+1}^c}{\zeta_t^c}(\pi_{t+1}^F -$$

$$(\pi_t^F)^{\iota_F}(\pi_*)^{1-\iota_F})\frac{Im_{t+1}}{Im_t}\frac{(\pi_{t+1}^F)^2}{\pi_{t+1}}g_{t+1}^A = 0 \tag{A.8}$$

$$\left(1 - \varepsilon_{*h,t}\right) + \varepsilon_{*h,t}\frac{p_t^Y}{rer_t}\frac{1}{p_t^{*H}} - k_{*H}(\pi_t^{*H} - (\pi_{t-1}^{*H})^{\iota_{*H}}(\pi^*)^{1-\iota_{*H}})\pi_t^{*H} +$$

$$\beta k_{*H} E_t \frac{C_t - h(g_t^A)^{-1}C_{t-1}}{g_{t+1}^A C_{t+1} - hC_t}\frac{\zeta_{t+1}^c}{\zeta_t^c}(\pi_{t+1}^{*H} - (\pi_t^{*H})^{\iota_{*H}}(\pi^*)^{1-\iota_{*H}})\frac{(\pi_{t+1}^{*H})^2}{\pi_{t+1}}\frac{Y_{t+1}^{*H}}{Y_t^{*H}}g_{t+1}^A g_{t+1}^{\mathcal{E}} = 0 \tag{A.9}$$

Aggregators

$$C_t^p = \left(\gamma_C^{\frac{1}{\eta_C}}C_{H,t}^{1-\frac{1}{\eta_C}} + (1-\gamma_C)^{\frac{1}{\eta_C}}C_{F,t}^{1-\frac{1}{\eta_C}}\right)^{\frac{\eta_C}{\eta_C-1}} \tag{A.10}$$

$$C_{H,t} = \gamma_C(p_t^H)^{-\eta_C}C_t^p \tag{A.11}$$

$$C_{F,t} = (1-\gamma_C)(p_t^F)^{-\eta_C}C_t^p \tag{A.12}$$

$$I_t + a(u_t)K_t' = U_t\left(\gamma_I^{\frac{1}{\eta_I}}I_{H,t}^{1-\frac{1}{\eta_I}} + (1-\gamma_I)^{\frac{1}{\eta_I}}I_{F,t}^{1-\frac{1}{\eta_I}}\right)^{\frac{\eta_I}{\eta_I-1}} \tag{A.13}$$

$$I_{H,t} = \gamma_I\left(\frac{p_t^H}{p_t^I U_t}\right)^{-\eta_I}\frac{I_t + a(u_t)K_t'}{U_t} \tag{A.14}$$

$$I_{F,t} = (1-\gamma_I)\left(\frac{p_t^F}{p_t^I U_t}\right)^{-\eta_I}\frac{I_t + a(u_t)K_t'}{U_t} \tag{A.15}$$

Investment firms

$$g_t^A K_t' = (1-\delta)K_{t-1}' + \left(1 - \frac{k_I}{2}\left(\frac{I_{t-1}}{I_{t-2}} - 1\right)^2\right)I_{t-1} \tag{A.16}$$

$$-q_t + \beta E_t \frac{C_t - h(g_t^A)^{-1}C_{t-1}}{g_{t+1}^A C_{t+1} - hC_t}\frac{\zeta_{t+1}^c}{\zeta_t^c}\left((1-\delta)q_{t+1} + u_{t+1}z_{t+1} - p_{t+1}^I a(u_{t+1})\right) = 0 \tag{A.17}$$

$$-p_t^I + q_t\left(\left(1 - \frac{k_I}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2\right) - k_I\left(\frac{I_t}{I_{t-1}} - 1\right)\frac{I_t}{I_{t-1}}\right) +$$

$$+\beta k_I E_t \frac{C_t - h(g_t^A)^{-1}C_{t-1}}{g_{t+1}^A C_{t+1} - hC_t}\frac{\zeta_{t+1}^c}{\zeta_t^c}q_{t+1}\left(\frac{I_{t+1}}{I_t} - 1\right)\frac{(I_{t+1})^2}{(I_t)^2}g_{t+1}^A = 0 \tag{A.18}$$

$$z_t - p_t^I a'(u_t) = 0 \tag{A.19}$$

Central bank

$$\frac{R_t}{R_*} = \left(\frac{R_{t-1}}{R_*}\right)^{\phi_R} \left(\frac{\pi_t}{\pi_*}\right)^{(1-\phi_R)\phi_\pi} e^{e_t^R} \tag{A.20}$$

$$dres_t = e_t^{res} \tag{A.21}$$

External economy

$$Y_t^{*H} = \gamma_{export}(p_t^{*H})^{-\eta_{export}} Y_t^* \tag{A.22}$$

$$\beta^* E_t \left(\frac{Y_t^* - h^*(g_t^A)^{-1} Y_{t-1}^*}{g_{t+1}^A Y_{t+1}^* - h^* Y_t^*} \frac{R_t^*}{\pi_{t+1}^*} \frac{\zeta_{t+1}^{*c}}{\zeta_t^{*c}}\right) = 1 \tag{A.23}$$

$$-\zeta^{*L}\frac{(l_t^*)^{\phi^*}}{w_t^*} + \frac{\zeta_t^{*c}}{Y_t^* - h^*(g_t^A)^{-1} Y_{t-1}^*} = 0 \tag{A.24}$$

$$Y_t^* = A_t^* l_t^* \tag{A.25}$$

$$p_t^{*Y} A_t^* - w_t^* = 0 \tag{A.26}$$

$$(1 - \varepsilon_h^*) + \varepsilon_h^* p_t^{*Y} - k^*(\pi_t^* - (\pi_{t-1}^*)^{\iota_*}(\pi^*)^{1-\iota_*})\pi_t^* + \beta^* k^* E_t \frac{Y_t^* - h^*(g_t^A)^{-1} Y_{t-1}^*}{g_{t+1}^A Y_{t+1}^* - h^* Y_t^*} \frac{\zeta_{t+1}^{*c}}{\zeta_t^{*c}} (\pi_{t+1}^* -$$

$$-(\pi_t^*)^{\iota_*}(\pi^*)^{1-\iota_*})\frac{Y_{t+1}^*}{Y_t^*}\pi_{t+1}^* g_{t+1}^A = 0 \tag{A.27}$$

$$\frac{R_t^*}{R^*} = \left(\frac{R_{t-1}^*}{R^*}\right)^{\phi_R^*} \left(\frac{\pi_t^*}{\pi^*}\right)^{(1-\phi_R^*)\phi_\pi^*} e^{e_t^{*R}} \tag{A.28}$$

Other equations

$$\frac{R_{t-1}^{NFA}}{g_t^A \pi_t^*} d_{t-1}^* = d_t^* + p_t^{oil} S_t^{oil} + p_t^{*H} Y_t^{*H} - p_t^{F*} IM_t - dres_t \tag{A.29}$$

$$R_t^{NFA} = R_t^* e^{\varphi_{nfa}(rer_t d_t^* - rer_{ss} d_{ss}^*)} z_t^{RP} \tag{A.30}$$

$$IM_t = Im_t + \frac{k_F}{2}(\pi_t^F - (\pi_{t-1}^F)^{\iota_H}(\pi_*)^{1-\iota_F})^2 Im_t \frac{p_t^F}{rer_t p_t^{F*}} \tag{A.31}$$

$$Im_t = I_{F,t} + C_{F,t} \tag{A.32}$$

$$Y_t^H = I_{H,t} + C_{H,t} \tag{A.33}$$

$$C_t^p = C_t + \frac{k_w}{2}\left(\frac{w_t}{w_{t-1}}\pi_t - (\pi_{t-1})^{\iota_w}(\pi_*)^{1-\iota_w}\right)^2 w_t l_t \tag{A.34}$$

$$K_t = u_t K_t' \tag{A.35}$$

$$Y_t = Y_t^H + Y_t^{*H} + G_t + \frac{k_H}{2}(\pi_t^H - (\pi_{t-1}^H)^{\iota_H}(\pi_*)^{1-\iota_H})^2 Y_t^H \frac{p_t^H}{p_t^Y} + + \frac{k_{*H}}{2}(\pi_t^{*H} -$$

$$(\pi_{t-1}^{*H})^{\iota_{*H}}(\pi^*)^{1-\iota_{*H}})^2 Y_t^{*H} \frac{rer_t p_t^{*H}}{p_t^Y} \tag{A.36}$$

$$g_t^{\mathcal{E}} = \frac{rer_t}{rer_{t-1}} \frac{\pi_t}{\pi_t^*} \tag{A.37}$$

$$\pi_t^H = \frac{p_t^H}{p_{t-1}^H} \pi_t \tag{A.38}$$

$$\pi_t^F = \frac{p_t^F}{p_{t-1}^F} \pi_t \tag{A.39}$$

$$\pi_t^{*H} = \frac{p_t^{*H}}{p_{t-1}^{*H}} \pi_t^* \tag{A.40}$$

Solution of a system for the steady state of the baseline model

To accelerate the procedure for solving a system for the steady state[30] of the model, we follow the algorithm described below.

We start the solution of the system with solving the external economy block. The steady state interest rate and inflation are set at a given level:

$$R_{ss}^* = R_{ss}^{*obs}$$

$$\pi_{ss}^* = \pi_{ss}^{*obs}$$

The discount factor for foreign households is determined from equation (A.23) provided the economic growth rate is known:

$$\beta^* = \frac{\pi_{ss}^* g_{ss}^A}{R_{ss}^*}$$

The relative price of intermediate goods and real wages in a foreign economy are found from equations (A.27) and (A.26):

$$p_{ss}^{*Y} = \frac{\varepsilon_h^* - 1}{\varepsilon_h^*}$$

$$w_{ss}^* = p_{ss}^{*Y} A_{ss}^*$$

Combining (A.24) and (A.25), and also setting l_{ss}^* equal to one, we obtain an equation for finding ζ^{*L}:

$$\zeta^{*L} = \frac{\zeta_{ss}^{*C}}{1 - h^*(g_{ss}^A)^{-1}} \frac{w_{ss}^*}{A_t^*(l_{ss}^*)^{1+\phi^*}}$$

From (A.25) we find Y_{ss}^*:

$$Y_{ss}^* = A_{ss}^* l_{ss}^*$$

Having found the value for the steady state of an external economy, we move on to finding a steady state for the domestic economy. Setting a steady state for the real exchange rate at one, we obtain from equation (A.8):

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[30] A state in which detrended variables do not change in the absence of shocks.

$$p_{ss}^F = \frac{\varepsilon_{f,ss}}{\varepsilon_{f,ss} - 1} rer_{ss} p_{ss}^{F*}$$

We calibrate the shares of imports in consumption and investment. Using the share of imports in consumption and equation (A.12) we obtain:

$$\gamma_C = 1 - \left(\frac{P^F C_F}{PC^p}\right)_{ss} (p_{ss}^F)^{\eta_C - 1}$$

Next we express the relative price of domestic goods from equations (A.10)−(A.12):

$$p_{ss}^H = \left(\frac{1}{\gamma_C} - \frac{1 - \gamma_C}{\gamma_C} (p_{ss}^F)^{1-\eta_C}\right)^{\frac{1}{1-\eta_C}}$$

Using the share of imports in investment, we find from (A.14) и (A.15):

$$\gamma_I = \frac{\left(1 - \left(\frac{P^F I_F}{P^I I}\right)_{ss}\right)\left(\frac{p_t^H}{p_t^F}\right)^{\eta_I - 1}}{\left(\frac{P^F I_F}{P^I I}\right)_{ss} + \left(1 - \left(\frac{P^F I_F}{P^I I}\right)_{ss}\right)\left(\frac{p_t^H}{p_t^F}\right)^{\eta_I - 1}}$$

The price of investment goods is expressed from the system of equations (A.13)−(A.15) :

$$p_{ss}^I = \frac{(\gamma_I (p_{ss}^H)^{1-\eta_I} + (1 - \gamma_I)(p_{ss}^F)^{1-\eta_I})^{\frac{1}{1-\eta_C}}}{U_{ss}}$$

The price of domestic goods, the price of exports and the price of capital are easily found from equations (A.7), (A.9) and (A.18), respectively:

$$p_{ss}^{Y,p} = \frac{\varepsilon_{h,ss} - 1}{\varepsilon_{h,ss}} p_{ss}^H$$

$$p_{ss}^{*H} = \frac{\varepsilon_{*h,ss}}{\varepsilon_{*h,ss} - 1} \frac{p_{ss}^{Y,p}}{rer_{ss}}$$

$$q_{ss} = p_{ss}^I$$

Having found relative prices in the domestic economy, we move on to the rest of the variables. Similarly to the variables for a foreign economy, we set inflation and the interest rate and then find the discount factor from equation (A.1):

$$R_{ss} = R_{ss}^{obs}$$

$$\pi_{ss} = \pi_{ss}^{obs}$$

$$\beta = \frac{\pi_{ss} g_{ss}^A}{R_{ss}}$$

From equations (A.37)−(A.40), we find:

$$g_{ss}^\varepsilon = \frac{\pi_{ss}}{\pi_{ss}^*}$$

$$\pi_{ss}^H = \pi_{ss}$$

$$\pi_{ss}^F = \pi_{ss}$$

$$\pi_{ss}^{*H} = \pi_{ss}^*$$

We chose function $a(u_t)$ so that in the steady state

$$u_{ss} = 1$$

Next we formulate a system of equations for finding a steady state of consumption, capital, the exogenous process for household preferences regarding hours worked, and the capital depreciation rate.

Combining equations (A.3), (A.5), (A.6), (A.17), and (A.18), we obtain:

$$\frac{\alpha}{1-\alpha}\frac{K_{ss}}{l_{ss}}\left(\frac{g_{ss}^A}{\beta}+\delta-1\right)q_{ss} = \frac{\varepsilon_w}{\varepsilon_w-1}\zeta_{ss}^L\frac{(l_{ss})^\phi}{\zeta_{ss}^C}C_{ss}(1-h(g_{ss}^A)^{-1})$$

Combining (A.3) and (A.5), we obtain the second equation:

$$(1-\alpha)p_{ss}^Y A_{ss}^c\left(\frac{l_{ss}}{K_{ss}}\right)^\alpha = \left(\frac{g_{ss}^A}{\beta}+\delta-1\right)q_{ss}$$

The third equation is a combination of equations (A.4), (A.11), (A.14), (A.16), (A.22), (A.33), (A.36), and calibration of a non-oil exports ratio to consumption and a ratio of government consumption to consumption:

$$A_{ss}^c l_{ss}{}^\alpha K_{ss}^{1-\alpha} = \gamma_I\left(\frac{p_{ss}^H}{p_{ss}^I U_{ss}}\right)^{-\eta_I}\frac{(g_{ss}^A+\delta-1)K_{ss}}{U_{ss}} + \gamma_C(p_{ss}^H)^{-\eta_C}C_{ss} + \left(\frac{\mathcal{E}P^{*H}Y^{*H}}{PC}\right)_{ss}\frac{C_{ss}}{p_{ss}^{*H}rer_{ss}}$$

$$+ \left(\frac{P^Y G}{PC}\right)_{ss}\frac{C_{ss}}{p_{ss}^Y}$$

The last of the equations defines a calibrated ratio of investment to consumption:

$$\left(\frac{P^I I}{PC}\right)_{ss} = \frac{(g_{ss}^A+\delta-1)p_{ss}^I K_{ss}}{C_{ss}}$$

We multiply the second equation by K_{ss} and use the third and the fourth:

$$(1-\alpha)p_{ss}^Y\left(\gamma_I\left(\frac{p_{ss}^H}{p_{ss}^I U_{ss}}\right)^{-\eta_I}\left(\frac{P^I I}{PC}\right)_{ss}\frac{1}{p_{ss}^I U_{ss}} + \gamma_C(p_{ss}^H)^{-\eta_C} + \left(\frac{\mathcal{E}P^{*H}Y^{*H}}{PC}\right)_{ss}\frac{1}{p_{ss}^{*H}rer_{ss}}\right.$$

$$\left. + \left(\frac{P^Y G}{PC}\right)_{ss}\frac{1}{p_{ss}^Y}\right) = \frac{\frac{g_{ss}^A}{\beta}+\delta-1}{g_{ss}^A+\delta-1}\frac{q_{ss}}{p_{ss}^I}\left(\frac{P^I I}{PC}\right)_{ss}$$

From this, we express

$$\delta = \frac{const1(g_{ss}^A-1)+1-\frac{g_{ss}^A}{\beta}}{1-const1}$$

where

$$const1 = \frac{(1-\alpha)p_{ss}^Y \left(\gamma_I \left(\frac{p_{ss}^H}{p_{ss}^I U_{ss}}\right)^{-\eta_I} \left(\frac{P^I I}{PC}\right)_{ss} \frac{1}{p_{ss}^I U_{ss}} + \gamma_C (p_{ss}^H)^{-\eta_C} + \left(\frac{\mathcal{E}P^{*H}Y^{*H}}{PC}\right)_{ss} \frac{1}{p_{ss}^{*H} rer_{ss}} + \left(\frac{P^Y G}{PC}\right)_{ss} \frac{1}{p_{ss}^Y} \right)}{\frac{q_{ss}}{p_{ss}^I} \left(\frac{P^I I}{PC}\right)_{ss}}$$

From equation (A.17) we obtain an equation for the rental cost of capital:

$$z_{ss} = \left(\frac{g_{ss}^A}{\beta} + \delta - 1\right) q_{ss}$$

From the second equation, we express capital:

$$K_{ss} = \left(\frac{z_{ss}}{(1-\alpha)p_{ss}^Y A_{ss}^C}\right)^{-\frac{1}{\alpha}} l_{ss}$$

From equation (A.16), we find a steady state for investment:

$$I_{ss} = (g_{ss}^A + \delta - 1)K_{ss}$$

The fourth equation defines a steady state for consumption:

$$C_{ss} = \frac{(g_{ss}^A + \delta - 1)p_{ss}^I K_{ss}}{\left(\frac{P^I I}{PC}\right)_{ss}}$$

And finally, from the first equation, we express a steady state for the exogenous process of household preferences regarding the number of hours worked:

$$\zeta_{ss}^L = \frac{\varepsilon_w - 1}{\varepsilon_w} \frac{\alpha}{1-\alpha} \frac{\frac{K_{ss}}{l_{ss}} \left(\frac{g_{ss}^A}{\beta} + \delta - 1\right) q_{ss}\zeta_{ss}^C}{C_{ss}(1 - h(g_{ss}^A)^{-1})(l_{ss})^\phi}$$

The other variables are easily expressed from the rest of the equations:

$$Y_{ss} = A_{ss}^C l_{ss}{}^\alpha K_{ss}^{1-\alpha}$$

$$w_{ss} = \frac{\alpha p_{ss}^Y Y_{ss}}{l_{ss}}$$

$$R_{ss}^{NFA} = \frac{R_{ss}}{g_{ss}^{\mathcal{E}}}$$

$$z_{ss}^{RP} = \frac{R_{ss}^{NFA}}{R_{ss}^*}$$

$$I_{H,ss} = \gamma_I \left(\frac{p_{ss}^H}{p_{ss}^I U_{ss}}\right)^{-\eta_I} \frac{I_{ss}}{U_{ss}}$$

$$I_{F,ss} = (1-\gamma_I) \left(\frac{p_{ss}^F}{p_{ss}^I U_{ss}}\right)^{-\eta_I} \frac{I_{ss}}{U_{ss}}$$

$$C_{H,ss} = \gamma_C (p_{ss}^H)^{-\eta_C} C_{ss}^p$$

$$C_{F,ss} = (1-\gamma_C)(p_{ss}^F)^{-\eta_C} C_{ss}^p$$

$$G_{ss} = \left(\frac{P^Y G}{PC}\right)_{ss} \frac{C_{ss}}{p_{ss}^Y}$$

$$Y_{ss}^H = I_{H,ss} + C_{H,ss}$$

$$Im_{ss} = I_{F,ss} + C_{F,ss}$$

$$Y_t^{*H} = Y_{ss} - Y_{ss}^H - G_{ss}$$

$$\gamma_{export} = \frac{Y_{ss}^{*H}}{(p_{ss}^{*H})^{-\eta_{export}} Y_{ss}^*}$$

$$S_{ss}^{oil} = \left(\frac{\mathcal{E} P^{oil} S}{PC}\right)_{ss} \frac{C_{ss}}{rer_{ss} p_{ss}^{oil}}$$

$$d_{ss}^* = \frac{p_{ss}^{oil} S_{ss}^{oil} + p_{ss}^{*H} Y_{ss}^{*H} - p_{ss}^{F*} Im_{ss} + ip_{ss}}{\frac{R_{ss}^{NFA}}{g_{ss}^A \pi_{ss}^*} - 1}$$

Detrending in the model with the banking sector

We detrend variables in the model with the banking sector in the same way as in the baseline model. The symbols follow the same principle.

Entrepreneurs and a bank's risky unit

$$q_t \bar{K}_t = b_t + n_t \tag{A.41}$$

$$R_t^k = \frac{(u_t z_t - a(u_t) p_t^I) + (1-\delta) q_t}{q_{t-1}} \pi_t \tag{A.42}$$

$$\bar{\omega}_t R_t^k q_{t-1} \bar{K}_{t-1} = R_t^{en} b_{t-1} \tag{A.43}$$

$$\Gamma_{t-1}(\bar{\omega}_t) - \mu G_{t-1}(\bar{\omega}_t) = \frac{R_{t-1}^b}{R_t^k} \frac{b_{t-1}}{q_{t-1} \bar{K}_{t-1}} \tag{A.44}$$

$$n_t = \frac{\gamma_t (1 - \Gamma_{t-1}(\bar{\omega}_t)) R_t^k q_{t-1} \bar{K}_{t-1}}{\pi_t} + tr_t^e \tag{A.45}$$

$$E_t \left((1 - \Gamma_t(\bar{\omega}_{t+1})) \frac{R_{t+1}^k}{R_t^b} + \frac{\Gamma_{t'}(\bar{\omega}_{t+1})}{\Gamma_{t'}(\bar{\omega}_{t+1}) - \mu G_{t'}(\bar{\omega}_{t+1})} \left(\frac{R_{t+1}^k}{R_t^b} \left(\Gamma_t(\bar{\omega}_{t+1}) - \mu G_t(\bar{\omega}_{t+1}) \right) - 1 \right) \right) = 0 \tag{A.46}$$

$$\frac{z_t}{p_t^I} - a'(u_t) = 0 \tag{A.47}$$

Investment firms

$$\bar{K}_t = \bar{K}_t' + \left(1 - \frac{k_I}{2} \left(\frac{I_t}{I_{t-1} e^{g_{I,ss_t}}} - 1\right)^2\right) I_t \tag{A.48}$$

$$-p_t^I + q_t\left(\left(1 - \frac{k_I}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2\right) - k_I\left(\frac{I_t}{I_{t-1}} - 1\right)\frac{I_t}{I_{t-1}}\right) +$$

$$+\beta k_I E_t \frac{C_t - h(g_t^A)^{-1}C_{t-1}}{g_{t+1}^A C_{t+1} - hC_t}\frac{\zeta_{t+1}^c}{\zeta_t^c}q_{t+1}\left(\frac{I_{t+1}}{I_t} - 1\right)\frac{(I_{t+1})^2}{(I_t)^2}g_{t+1}^A = 0 \tag{A.49}$$

Banks

$$\Pi_t^b = \frac{(R_{t-1}^b - R_{t-1})}{g_t^A \pi_t}b_{t-1} + \frac{R_{t-1} - \delta_b - 1}{g_t^A \pi_t}j_{t-1} + \frac{R_{t-1} - R_{t-1}^D}{g_t^A \pi_t}(b_{t-1} - j_{t-1}) - \frac{k^K}{2}\left(\frac{j_t}{b_t} - \omega^J\right)^2 j_t - \frac{k^b}{2}\left(\frac{R_t^b}{(R_{t-1}^b)^{\iota_b}(R_{ss}^b)^{1-\iota_b}} - \right.$$

$$\left. 1\right)^2 b_t - \frac{k^D}{2}\left(\frac{R_t^D}{(R_{t-1}^D)^{\iota_d}(R_{ss}^D)^{1-\iota_d}} - 1\right)^2 d_t \tag{A.50}$$

$$j_t = \frac{j_{t-1}}{g_t^A \pi_t} + o_t \Pi_t^b \tag{A.51}$$

$$-((1 - o_t) + o_t m_t)\left(k^K \varepsilon_t^b\left(\frac{j_t}{b_t} - \omega^J\right)\left(\frac{j_t}{b_t}\right)^2\frac{1}{R_t^b} + k^b\left(\frac{R_t^b}{(R_{t-1}^b)^{\iota_b}(R_{ss}^b)^{1-\iota_b}} - 1\right)\frac{1}{(R_{t-1}^b)^{\iota_b}(R_{ss}^b)^{1-\iota_b}}\right) +$$

$$\beta E_t \frac{C_t - h(g_t^A)^{-1}C_{t-1}}{g_{t+1}^A C_{t+1} - hC_t}\frac{\zeta_{t+1}^c}{\zeta_t^c}\left(\frac{(1-o_{t+1})}{\pi_{t+1}} + \frac{o_{t+1}m_{t+1}}{\pi_{t+1}}\right)\left(\left(1 - \varepsilon_t^b\right) + \varepsilon_t^b\frac{R_t}{R_t^b} + k^b\left(\frac{R_{t+1}^b}{(R_t^b)^{\iota_b}(R_{ss}^b)^{1-\iota_b}} - \right.\right.$$

$$\left.\left. 1\right)\frac{\iota_b R_{t+1}^b}{(R_t^b)^{\iota_b}(R_{ss}^b)^{1-\iota_b}}\frac{g_{t+1}^A \pi_{t+1}}{R_t^b}\frac{b_{t+1}}{b_t}\right) = 0 \tag{A.52}$$

$$-((1 - o_t) + o_t m_t)\left(k^D\left(\frac{R_t^D}{(R_{t-1}^D)^{\iota_d}(R_{ss}^D)^{1-\iota_d}} - 1\right)\frac{1}{(R_{t-1}^D)^{\iota_d}(R_{ss}^D)^{1-\iota_d}}\right) + \beta E_t \frac{C_t - h(g_t^A)^{-1}C_{t-1}}{g_{t+1}^A C_{t+1} - hC_t}\frac{\zeta_{t+1}^c}{\zeta_t^c}\left(\frac{(1-o_{t+1})}{\pi_{t+1}} + \right.$$

$$\left. \frac{o_{t+1}m_{t+1}}{\pi_{t+1}}\right)\left(-(1 + \varepsilon_t^D) + \varepsilon_t^D\frac{R_t}{R_t^D} + k^D\left(\frac{R_{t+1}^D}{(R_t^D)^{\iota_d}(R_{ss}^D)^{1-\iota_d}} - 1\right)\frac{\iota_d R_{t+1}^D}{(R_t^D)^{\iota_d}(R_{ss}^D)^{1-\iota_d}}\frac{g_{t+1}^A \pi_{t+1}}{R_t^D}\frac{d_{t+1}}{d_t}\right) = 0 \tag{A.53}$$

Modified production function

$$Y_t = A_t^c l_t^\alpha K_t^{1-\alpha} - \Phi \tag{A.4*}$$

$$\alpha p_t^Y(Y_t + \Phi) - w_t l_t = 0 \tag{A.5*}$$

$$(1 - \alpha)p_t^Y(Y_t + \Phi) - z_t K_t = 0 \tag{A.6*}$$

Other equations

$$g_t^A \bar{K}_t' = (1 - \delta)\bar{K}_{t-1} \tag{A.54}$$

$$g_t^A K_t = u_t \bar{K}_{t-1} \tag{A.55}$$

Steady state in the model with the banking sector

The solution of a system of equations for steady state largely coincides with solving such a system for steady state in the baseline model, so we will only describe the part which is different from the baseline model.

It is easy to find from (A.52) and (A.53):

$$R_{ss}^{DC} = \frac{\varepsilon_{ss}^{DC}}{\varepsilon_{ss}^{DC} - 1} R_{ss}$$

$$R_{ss}^{D} = \frac{\varepsilon_{ss}^{D}}{\varepsilon_{ss}^{D} + 1} R_{ss}$$

Defining the ratio of equity to loans, we obtain:

$$j_{ss} = \left(\frac{j}{b^{DC}}\right)_{ss} b_{ss}^{DC}$$

We also assume that:

$$\omega^{J} = \left(\frac{j}{b^{DC}}\right)_{ss}$$

From (A.50) and (A.51), we find:

$$\pi_{ss}^{b} = \frac{\left(R_{ss}^{b} - R_{ss}\right)}{g_{ss}^{A} \pi_{ss}} b_{ss} + \frac{R_{ss} - \delta_b - 1}{g_{ss}^{A} \pi_{ss}} j_{ss} + \frac{R_{ss} - R_{ss}^{D}}{g_{ss}^{A} \pi_{ss}} (b_{ss} - j_{ss})$$

$$o_{ss} = \left(1 - \frac{1}{g_{ss}^{A} \pi_{ss}}\right) \left(\frac{j}{\pi^{b}}\right)_{ss}$$

The price block is computed similarly to the baseline model. Differences begin from the equations for finding the depreciation rate. But the depreciation rate is set from the start, so additional free parameter Φ is found from a similar equation. Equation for Φ looks as follows:

$$\frac{\left(\frac{R_{ss}^{k}}{\pi_{ss}} + \delta - 1\right) q_{ss}}{(g_{ss}^{A} + \delta - 1) p_{ss}^{I} (1 - \alpha) p_{ss}^{Y}} \left(\frac{P^{I} I}{PC}\right)_{ss} - \frac{\Phi}{C_{ss}} =$$

$$= \gamma_{I} \left(\frac{p_{ss}^{H}}{p_{ss}^{I} U_{ss}}\right)^{-\eta_{I}} \left(\frac{P^{I} I}{PC}\right)_{ss} \frac{1}{p_{ss}^{I} U_{ss}} + \gamma_{C} (p_{ss}^{H})^{-\eta_{C}} + \left(\frac{\mathcal{E} P^{*H} Y^{*H}}{PC}\right)_{ss} \frac{C_{ss}}{p_{ss}^{*H} rer_{ss}} + \left(\frac{P^{Y} G}{PC}\right)_{ss} \frac{1}{p_{ss}^{Y}}$$

From this, we easily express:

$$\frac{\Phi}{C_{ss}} = \frac{\left(\frac{R_{ss}^{k}}{\pi_{ss}} + \delta - 1\right) q_{ss}}{(g_{ss}^{A} + \delta - 1) p_{ss}^{I} (1 - \alpha) p_{ss}^{Y}} \left(\frac{P^{I} I}{PC}\right)_{ss} - \gamma_{I} \left(\frac{p_{ss}^{H}}{p_{ss}^{I} U_{ss}}\right)^{-\eta_{I}} \left(\frac{P^{I} I}{PC}\right)_{ss} \frac{1}{p_{ss}^{I} U_{ss}} - \gamma_{C} (p_{ss}^{H})^{-\eta_{C}} - \left(\frac{\mathcal{E} P^{*H} Y^{*H}}{PC}\right)_{ss} \frac{C_{ss}}{p_{ss}^{*H} rer_{ss}} - \left(\frac{P^{Y} G}{PC}\right)_{ss} \frac{1}{p_{ss}^{Y}}$$

We, however, do not yet know the value of R_{ss}^{k} at this time. The sequence of actions to find it is described below.

From equation (A.42), we obtain:

$$z_{ss} = \left(\frac{R_{ss}^{k}}{\pi_{ss}} + \delta - 1\right) q_{ss}$$

We also define the steady state level of bankruptcies and the ratio of equity to assets, which helps determine the financial sector's variables.

Following *Del Negro and Schorfheide (2012),* we use lognormal distribution for an idiosyncratic shock. Let us introduce the notation:

$$z_{ss}^{\omega} = \frac{ln\,\bar{\omega}_{ss} + 0.5\sigma_{\omega,ss}^2}{\sigma_{\omega,ss}}$$

Then

$$\Gamma(\bar{\omega}_{ss}) = \bar{\omega}_{ss}\big(1 - \Phi(z_{ss}^{\omega})\big) + \Phi\big(z_{ss}^{\omega} - \sigma_{\omega,ss}\big)$$

$$G(\bar{\omega}_{ss}) = \Phi\big(z_{ss}^{\omega} - \sigma_{\omega,ss}\big)$$

$$\Gamma'(\bar{\omega}_{ss}) = 1 - \Phi(z_{ss}^{\omega})$$

$$G'(\bar{\omega}_{ss}) = \frac{1}{\sigma_{\omega,ss}}\phi(z_{ss}^{\omega})$$

where $\Phi(x)$ is a cumulative function of normal distribution with a mean of 0 and a variance of 1, $\phi(x)$ is a density function for the same distribution.

From equation system (A.43), (A.44), and (A.46), we find $\bar{\omega}_{ss}$, $\sigma_{\omega,ss}$, R_{ss}^{en}, and R_{ss}^k. It is worth noting that the solution only depends on $\left(1 - \frac{n}{q\bar{K}}\right)_{ss}$, Φ_{ss}, R_{ss} and μ, which are set externally, therefore, we solve this system only once for all parameterizations.

Further solution is similar to that of the baseline model.

Appendix B. Tables and figures

Table 1. Parameter notation

Parameter	Meaning
β	Discount factor of households
h	Coefficient of habit formation in consumption
ϕ	Curvature on disutility of labor
k_w	Coefficient of the costs of wage growth deviation from the predetermined level
ι_w	Weight of lagged value in the predetermined wage growth
ε_w	Wage elasticity of labor demand
π_*	Inflation target
α	labor share in the production function
k_H	Coefficient of the costs of domestic retailers' price growth deviation from the predetermined level
ι_H	Weight of lagged value in the domestic retailers' predetermined price growth
k_F	Coefficient of the costs of importing retailers' price growth deviation from the predetermined level
ι_F	Weight of lagged value in the importing retailers' predetermined price growth
k_{*H}	Coefficient of the costs of exporting retailers' price growth deviation from the predetermined level
ι_{*H}	Weight of lagged value in the exporting retailers' predetermined price growth
π^*	Foreign inflation target
γ_C	Parameter representing the share of domestic goods in consumption
η_C	Elasticity of substitution between domestic and imported goods in consumption
γ_I	Parameter representing the share of domestic goods in investment
η_I	Elasticity of substitution between domestic and imported goods in investment
δ	Depreciation rate on capital

k_I	Coefficient of the costs of investment growth deviation from the predetermined level
β^*	Discount factor of foreign households
h^*	Coefficient of habit formation in foreign consumption
ϕ^*	Curvature on disutility of labor in a foreign economy
ζ^{*L}	Coefficient of negative labor utility
ε_h^*	Price elasticity of goods sold in a foreign economy
k^*	Coefficient of the costs of retailers' price growth deviation from the predetermined level in a foreign economy
ι_*	Weight of lagged value in the retailers' predetermined price growth in a foreign economy
R^*	Level of the foreign steady state nominal interest rate
ϕ_R^*	Interest rate inertia coefficient in a foreign interest rate policy rule
ϕ_π^*	Inflation coefficient in a foreign interest rate policy rule
R_*	Level of the steady state nominal interest rate
ϕ_R	Interest rate inertia coefficient in the interest rate policy rule
ϕ_π	Inflation coefficient in the interest rate policy rule
φ_{nfa}	Coefficient for the impact of external debt on the risk premium
φ_{oil}	Coefficient for the impact of the oil price on the risk premium
γ_{export}	Normalizing factor in the exports demand equation
η_{export}	Price elasticity of exports
σ_a	Curvature for the costs of using capital
μ	Costs of monitoring
Φ	Fixed costs in modified production function
δ_b	Coefficient for the costs of managing bank
k^D	Coefficient of the costs of deposit rates deviation from the predetermined level

ι_d	Weight of the lagged value in the predetermined level of deposit rates
k^b	Coefficient of the costs of loan rate for the risky unit deviation from the predetermined level
ι_b	Weight of the lagged value in the predetermined level of loan rate for the risky unit
k^K	Coefficient of the costs of the equity-to-loans ratio deviation from the desired level
ρ^{oil}	Autocorrelation of real oil prices
ρ^{g_A}	Autocorrelation of the permanent technology process
ρ^{ζ_c}	Autocorrelation of the exogenous process of household preferences
ρ^{ζ_l}	Autocorrelation of the exogenous process of household preferences regarding the number of hours worked
ρ^{A_c}	Autocorrelation of temporary technology process
ρ^U	Autocorrelation of an investment technology process
ρ^{ε_h}	Autocorrelation of demand elasticity for domestic retailers
ρ^{ε_f}	Autocorrelation of demand elasticity for importing retailers
$\rho^{p_{F*}}$	Autocorrelation of relative prices of imported goods
$\rho^{\varepsilon_{*h}}$	Autocorrelation of demand elasticity for exporting retailers
$\rho^{S_{oil}}$	Autocorrelation of oil exports
$\rho^{Z_{RP}}$	Autocorrelation of the exogenous part of the risk premium
$\rho^{\zeta_{c*}}$	Autocorrelation of the exogenous process of foreign household preferences
ρ^{A_*}	Autocorrelation of temporary technology process in a foreign economy
ρ^G	Autocorrelation of government consumption
ρ^{σ_ω}	Autocorrelation of standard deviation of idiosyncratic shock for entrepreneurs
ρ^γ	Autocorrelation of entrepreneurs' "survival" process
ρ^{ε_D}	Autocorrelation of interest rate elasticity of deposits
ρ^{cap}	Autocorrelation of a capital dynamics shock

σ^{oil}	Standard deviation of a real oil price shock
σ^{*R}	Standard deviation of a foreign monetary policy shock
σ^{R}	Standard deviation of a monetary policy shock
σ^{res}	Standard deviation of a reserves shock
σ^{g_A}	Standard deviation of a permanent technology shock
σ^{ζ_c}	Standard deviation of a preferences shock
σ^{ζ_l}	Standard deviation of a labor supply shock
σ^{A_c}	Standard deviation of a temporary technology shock
σ^{U}	Standard deviation of an investment technology shock
σ^{ε_h}	Standard deviation of a markup shock for domestic retailers
σ^{ε_f}	Standard deviation of a markup shock for importing retailers
$\sigma^{p_{F*}}$	Standard deviation of a shock of relative prices of imported goods
$\sigma^{\varepsilon_{*h}}$	Standard deviation of a markup shock for exporting retailers
$\sigma^{S_{oil}}$	Standard deviation of a shock of oil exports
σ^{ZRP}	Standard deviation of a risk premium shock
$\sigma^{\zeta_{c*}}$	Standard deviation of a foreign preferences shock
σ^{A_*}	Standard deviation of a foreign temporary technology shock
σ^{G}	Standard deviation of a government consumption shock
σ^{σ_ω}	Standard deviation of a risk shock
σ^{γ}	Standard deviation of a financial wealth shock
σ^{ε_D}	Standard deviation of a markup shockfor deposit rates
$\sigma^{\varepsilon_{cap}}$	Standard deviation of a capital dynamics shock

Table 2. Prior distributions

Parameter	Mean	Std	Shape	Lower bound	Upper bound	Scale
h	0.5	0.05	beta	0.01	0.99	1
k_w	50	10	gamma	0.1	2000	1
ι_w	0.5	0.1	beta	0.01	0.99	1
k_H	20	5	gamma	0.1	2000	1
ι_H	0.5	0.1	beta	0.01	0.99	1
k_F	20	5	gamma	0.1	2000	1
ι_F	0.5	0.1	beta	0.01	0.99	1
k_{*H}	20	5	gamma	0.1	2000	1
ι_{*H}	0.5	0.1	beta	0.01	0.99	1
η_C	1.01	0.1	normal	0.01	20	1
η_I	1.01	0.1	normal	0.01	20	1
k_I	2	0.5	gamma	0.1	2000	1
σ_a	1	0.3	normal	0.01	2000	1
h^*	0.5	0.05	beta	0.01	0.99	1
k^*	20	5	gamma	0.1	2000	1
ι_*	0.5	0.1	beta	0.01	0.99	1
ϕ_R^*	0.8	0.05	beta	0.01	0.99	1
ϕ_π^*	1.5	0.1	normal	1.2	2000	1
ϕ_R	0.8	0.05	beta	0.01	0.99	1
ϕ_π	1.5	0.1	normal	1.2	2000	1
η_{export}	1	0.1	gamma	0	20	1
$\rho^{oil,fast}$	0.9	0.1	beta	0.01	0.99	1
ρ^{g_A}	0.5	0.1	beta	0.01	0.95	1
ρ^{ζ_c}	0.7	0.1	beta	0.01	0.99	1
ρ^{ζ_l}	0.5	0.1	beta	0.01	0.99	1
ρ^{A_c}	0.7	0.1	beta	0.01	0.99	1
ρ^U	0.7	0.1	beta	0.01	0.99	1
$\rho^{\varepsilon h}$	0.5	0.1	beta	0.01	0.99	1
$\rho^{\varepsilon f}$	0.5	0.1	beta	0.01	0.99	1
$\rho^{p_{F*}}$	0.5	0.1	beta	0.01	0.99	1
$\rho^{\varepsilon *h}$	0.5	0.1	beta	0.01	0.99	1
$\rho^{S_{oil}}$	0.7	0.1	beta	0.01	0.99	1
$\rho^{z_{RP}}$	0.7	0.1	beta	0.01	0.99	1
$\rho^{\zeta_{c*}}$	0.7	0.1	beta	0.01	0.99	1
ρ^{A_*}	0.7	0.1	beta	0.01	0.99	1
ρ^G	0.7	0.1	beta	0.01	0.99	1
σ^{oil}	1	2	inverse gamma	0.01	20	10
σ^{*R}	0.3	2	inverse gamma	0.01	20	100
σ^R	0.3	2	inverse gamma	0.01	20	100
σ^{res}	0.5	2	inverse gamma	0.01	20	10
σ^{g_A}	0.3	2	inverse gamma	0.01	20	100
σ^{ζ_c}	0.3	2	inverse gamma	0.01	20	10
σ^{ζ_l}	0.3	2	inverse gamma	0.01	20	10

σ^{A_c}	0.65	2	inverse gamma	0.01	20	100
σ^{U}	0.15	2	inverse gamma	0.01	20	10
$\sigma^{\varepsilon h}$	0.65	2	inverse gamma	0.01	20	10
$\sigma^{\varepsilon f}$	0.65	2	inverse gamma	0.01	20	10
$\sigma^{p_{F*}}$	0.65	2	inverse gamma	0.01	20	10
$\sigma^{\varepsilon_{*h}}$	0.65	2	inverse gamma	0.01	20	10
$\sigma^{S_{oil}}$	0.3	2	inverse gamma	0.01	20	10
$\sigma^{Z_{RP}}$	0.3	2	inverse gamma	0.01	20	100
$\sigma^{\zeta_{c*}}$	0.3	2	inverse gamma	0.01	20	10
σ^{A_*}	0.65	2	inverse gamma	0.01	20	100
σ^{G}	1	2	inverse gamma	0.01	20	10
$\varphi_{nfa}/(d_{ss}rer_{ss})$	1	0.3	normal	0.01	200	100
φ_{oil}	1	0.3	normal	0.01	200	100
ρ^{σ_ω}	0.5	0.1	beta	0.01	0.99	1
σ^{σ_ω}	0.3	2	inverse gamma	0.01	20	1
k^{K}	20	5	gamma	0.1	2000	10
k^{D}	10	5	gamma	0.1	2000	10
k^{b}	10	5	gamma	0.1	2000	10
ι_b	0.5	0.1	beta	0.01	0.99	1
ι_d	0.5	0.1	beta	0.01	0.99	1
$\rho^{\varepsilon D}$	0.5	0.1	beta	0.01	0.99	1
ρ^{γ}	0.5	0.1	beta	0.01	0.99	1
ρ^{cap}	0.5	0.1	beta	0.01	0.99	1
$\sigma^{\varepsilon D}$	0.3	2	inverse gamma	0.01	20	0.1
σ^{γ}	0.3	4	inverse gamma	0.01	0.4	100
σ^{cap}	0.3	2	inverse gamma	0.01	20	100

Table 3. Characteristics of posterior distribution

Parameter	Prior		Baseline		Banks	
	Mean	Std	Mean	Std	Mean	Std
h	0.5	0.05	0.54	0.04	0.53	0.04
k_w	50	10	55.80	9.61	59.91	9.56
ι_w	0.5	0.1	0.45	0.09	0.46	0.09
k_H	20	5	24.10	4.65	21.30	4.02
ι_H	0.5	0.1	0.50	0.10	0.50	0.09
k_F	20	5	21.91	4.86	26.39	4.94
ι_F	0.5	0.1	0.40	0.10	0.41	0.09
k_{*H}	20	5	4.67	1.25	4.62	1.18
ι_{*H}	0.5	0.1	0.41	0.10	0.41	0.10
η_C	1.01	0.1	0.91	0.10	0.94	0.10
η_I	1.01	0.1	0.97	0.10	0.98	0.10
k_I	2	0.5	3.76	0.62	4.58	0.76
σ_a	1	0.3	1.06	0.24	1.18	0.27
ϕ_R	0.8	0.05	0.86	0.02	0.88	0.01
ϕ_π	1.5	0.1	1.48	0.10	1.47	0.08
η_{export}	1	0.1	0.68	0.07	0.71	0.07

ρ^{oil}	0.9	0.1	0.85	0.04	0.90	0.02
ρ^{g_A}	0.5	0.1	0.69	0.04	0.69	0.05
ρ^{ζ_c}	0.7	0.1	0.77	0.08	0.81	0.07
ρ^{ζ_l}	0.5	0.1	0.53	0.09	0.56	0.09
ρ^{A_c}	0.7	0.1	0.55	0.08	0.60	0.10
ρ^{U}	0.7	0.1	0.64	0.09	0.64	0.10
ρ^{ε_h}	0.5	0.1	0.68	0.13	0.54	0.09
ρ^{ε_f}	0.5	0.1	0.50	0.10	0.53	0.11
$\rho^{p_{F*}}$	0.5	0.1	0.55	0.14	0.53	0.10
$\rho^{\varepsilon_{*h}}$	0.5	0.1	0.61	0.09	0.57	0.09
$\rho^{S_{oil}}$	0.7	0.1	0.62	0.11	0.64	0.09
$\rho^{z_{RP}}$	0.7	0.1	0.68	0.07	0.81	0.06
ρ^{G}	0.7	0.1	0.86	0.06	0.85	0.06
σ^{oil}	1	2	1.80	0.20	1.76	0.19
σ^{R}	0.3	2	0.44	0.07	0.40	0.06
σ^{res}	0.5	2	1.60	0.81	1.03	0.31
σ^{g_A}	0.3	2	0.50	0.09	0.43	0.08
σ^{ζ_c}	0.3	2	0.44	0.07	0.40	0.07
σ^{ζ_l}	0.3	2	1.25	0.25	1.23	0.23
σ^{A_c}	0.65	2	2.26	0.43	1.50	0.32
σ^{U}	0.15	2	0.20	0.03	0.20	0.02
σ^{ε_h}	0.65	2	3.25	0.69	3.28	0.62
σ^{ε_f}	0.65	2	1.10	1.23	0.62	0.51
$\sigma^{p_{F*}}$	0.65	2	0.36	0.06	0.38	0.06
$\sigma^{\varepsilon_{*h}}$	0.65	2	19.44	0.53	19.47	0.50
$\sigma^{S_{oil}}$	0.3	2	0.54	0.08	0.55	0.08
$\sigma^{z_{RP}}$	0.3	2	1.85	0.54	0.72	0.30
σ^{G}	1	2	0.12	0.02	0.12	0.01
$\varphi_{nfa}/(d_{ss}rer_{ss})$	1	0.3	0.40	0.25	0.67	0.22
φ_{oil}	1	0.3	1.23	0.30	1.16	0.28
ρ^{σ_ω}	0.5	0.1	-	-	0.62	0.07
σ^{σ_ω}	0.3	2	-	-	0.18	0.04
k^{K}	20	5	-	-	6.07	1.49
k^{D}	10	5	-	-	11.80	4.68
k^{b}	10	5	-	-	24.27	5.85
ι_b	0.5	0.1	-	-	0.36	0.08
ι_d	0.5	0.1	-	-	0.60	0.08
ρ^{ε_D}	0.5	0.1	-	-	0.85	0.04
ρ^{Y}	0.5	0.1	-	-	0.57	0.13
ρ^{cap}	0.5	0.1	-	-	0.52	0.07
σ^{ε_D}	0.3	2	-	-	0.10	0.02
σ^{Y}	0.3	2	-	-	0.26	0.10
σ^{cap}	0.3	2	-	-	3.14	0.38

Table 4a. Relative RMSEs for logarithm of GDP

	Baseline	Banks	BVAR
1	**0.92**	1.13	0.99
2	**0.81**	1.04	0.83
3	**0.67**	0.86	0.70
4	0.68	0.81	**0.66**
5	0.65	0.73	**0.59**
6	0.62	0.64	**0.57**
7	0.59	0.58	**0.57**
8	0.58	**0.54**	0.61
9	0.56	**0.50**	0.58
10	0.57	**0.49**	0.54
11	0.54	**0.46**	0.48
12	0.52	**0.43**	0.48

Table 4b. Relative RMSEs for logarithm of consumption

	Baseline	Banks	BVAR
1	0.75	**0.72**	0.92
2	0.64	**0.60**	0.61
3	0.55	**0.49**	0.55
4	0.49	**0.43**	0.48
5	0.40	**0.33**	0.50
6	0.34	**0.27**	0.51
7	0.28	**0.20**	0.52
8	0.27	**0.17**	0.50
9	0.25	**0.16**	0.54
10	0.22	**0.13**	0.54
11	0.20	**0.11**	0.58
12	0.18	**0.09**	0.60

Table 4c. Relative RMSEs for logarithm of investment

	Baseline	Banks	BVAR
1	1.20	1.12	**0.67**
2	1.62	1.55	**0.53**
3	1.78	1.74	**0.55**
4	2.04	1.95	**0.55**
5	1.73	1.63	**0.67**
6	1.56	1.39	**0.59**
7	1.43	1.23	**0.58**
8	1.24	1.05	**0.56**
9	1.10	0.90	**0.50**
10	0.94	0.76	**0.42**
11	0.88	0.69	**0.45**
12	0.80	0.62	**0.45**

Table 4d. Relative RMSEs for change in logarithm of exchange rate

	Baseline	Banks	BVAR
1	0.71	**0.70**	1.02
2	**0.73**	0.74	1.08
3	**0.76**	0.77	0.87
4	**0.75**	0.76	1.09
5	**0.73**	0.74	1.21
6	**0.75**	0.76	1.25
7	**0.75**	0.76	1.09
8	**0.72**	0.74	1.05
9	**0.72**	0.74	1.10
10	**0.72**	0.73	1.08
11	**0.71**	0.73	1.13
12	**0.70**	0.72	1.21

Table 4e. Relative RMSEs for change in the logarithm of CPI

	Baseline	Banks	BVAR
1	0.96	0.96	**0.93**
2	1.20	1.20	1.43
3	1.25	1.28	1.62
4	1.19	1.27	1.47
5	1.26	1.38	1.65
6	1.24	1.39	1.78
7	1.24	1.39	1.34
8	1.22	1.37	1.33
9	1.21	1.34	1.36
10	1.20	1.31	1.61
11	1.16	1.26	1.71
12	1.16	1.24	1.92

Таблица 4f. Relative RMSEs for the logarithm of MIACR

	Baseline	Banks	BVAR
1	**0.91**	0.99	0.97
2	**0.77**	0.94	0.82
3	0.80	0.94	**0.79**
4	0.81	0.94	**0.77**
5	0.79	0.93	**0.73**
6	0.75	0.90	**0.69**
7	0.79	0.98	**0.76**
8	**0.76**	0.96	0.78
9	**0.74**	0.96	0.80
10	**0.71**	0.94	0.83
11	**0.69**	0.92	0.80
12	**0.67**	0.89	0.75

Figure 1a. Scheme of the baseline model

Investment firms — Goods — Importing retailers

Goods (Investment firms → Importing retailers)

Domestic retailers — Goods — Producers — Goods — Exporting retailers

Капитал (Investment firms → Producers)

Goods (Importing retailers → External retailers)

Goods (Exporting retailers → External retailers)

External retailers

Government consumption

Fiscal sector

Labor

Taxes

Oil

Oil exporters

Households — Goods

Goods (Domestic retailers → Households)

Net foreign assets

Reserves

Deposits

Central bank

Figure 1b. Scheme of the model with the banking sector

«Raw» capital

Investment firms — Goods — Importing retailers

Goods (Investment firms)

Domestic retailers — Goods — Producers — Goods — Exporting retailers

Goods (Importing retailers → External economy)

Goods (Exporting retailers → External economy)

External economy

Capital

Government consumption

Fiscal sector

Labor

Taxes

Oil

Oil exporters

Entrepreneurs

Goods

Households — Goods

Net foreign assets

Loans

Deposits

Reserves

Loans (Risky bank's unit → Bank)

Risky bank's unit — Loans — Bank — Loans — Central bank

Figure 2a. Oil price shock (baseline model – blue line; model with the banking sector – red line)
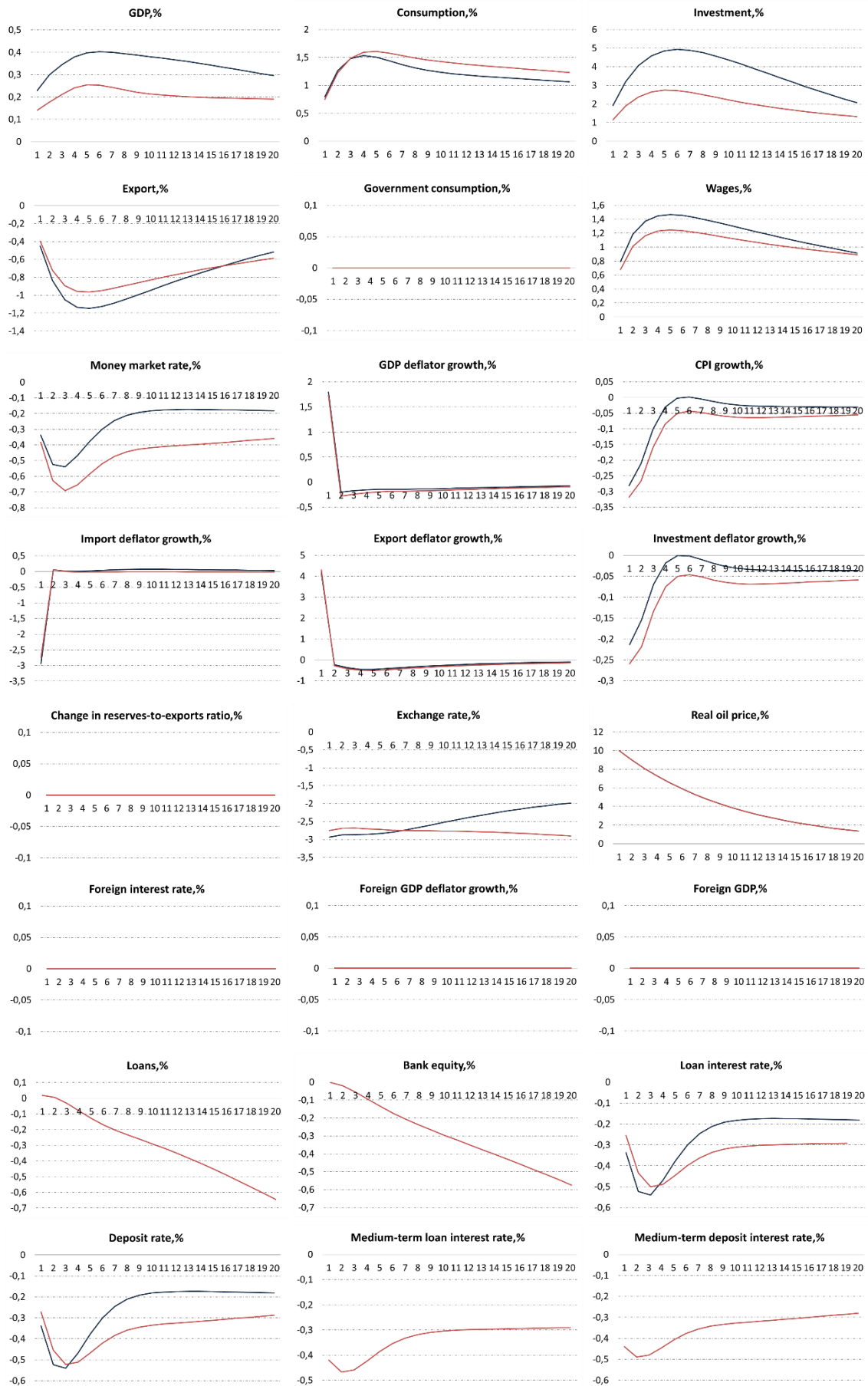
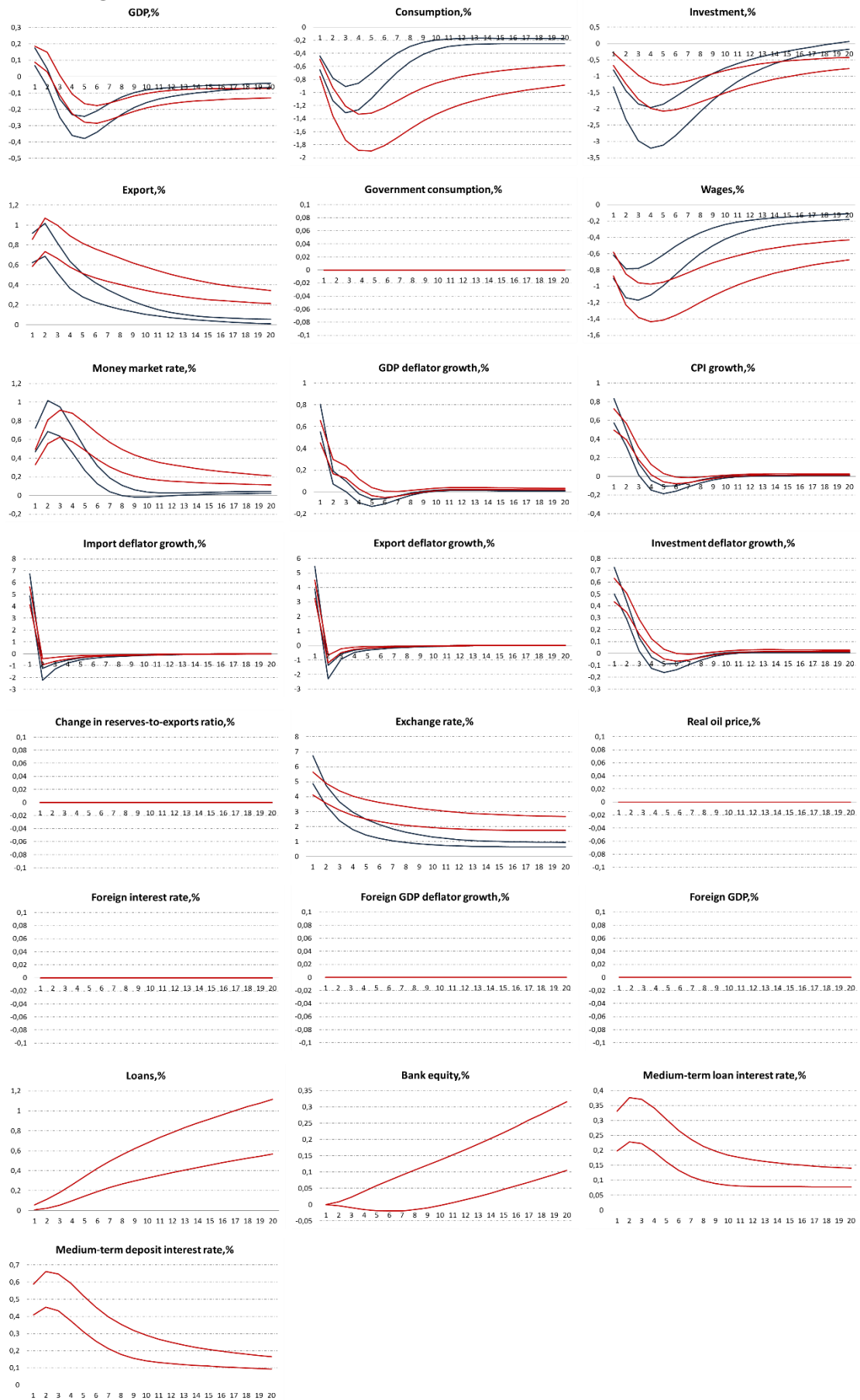*Figure 2b. Risk premium shock (base model – blue line, model with the banking sector – red line)*
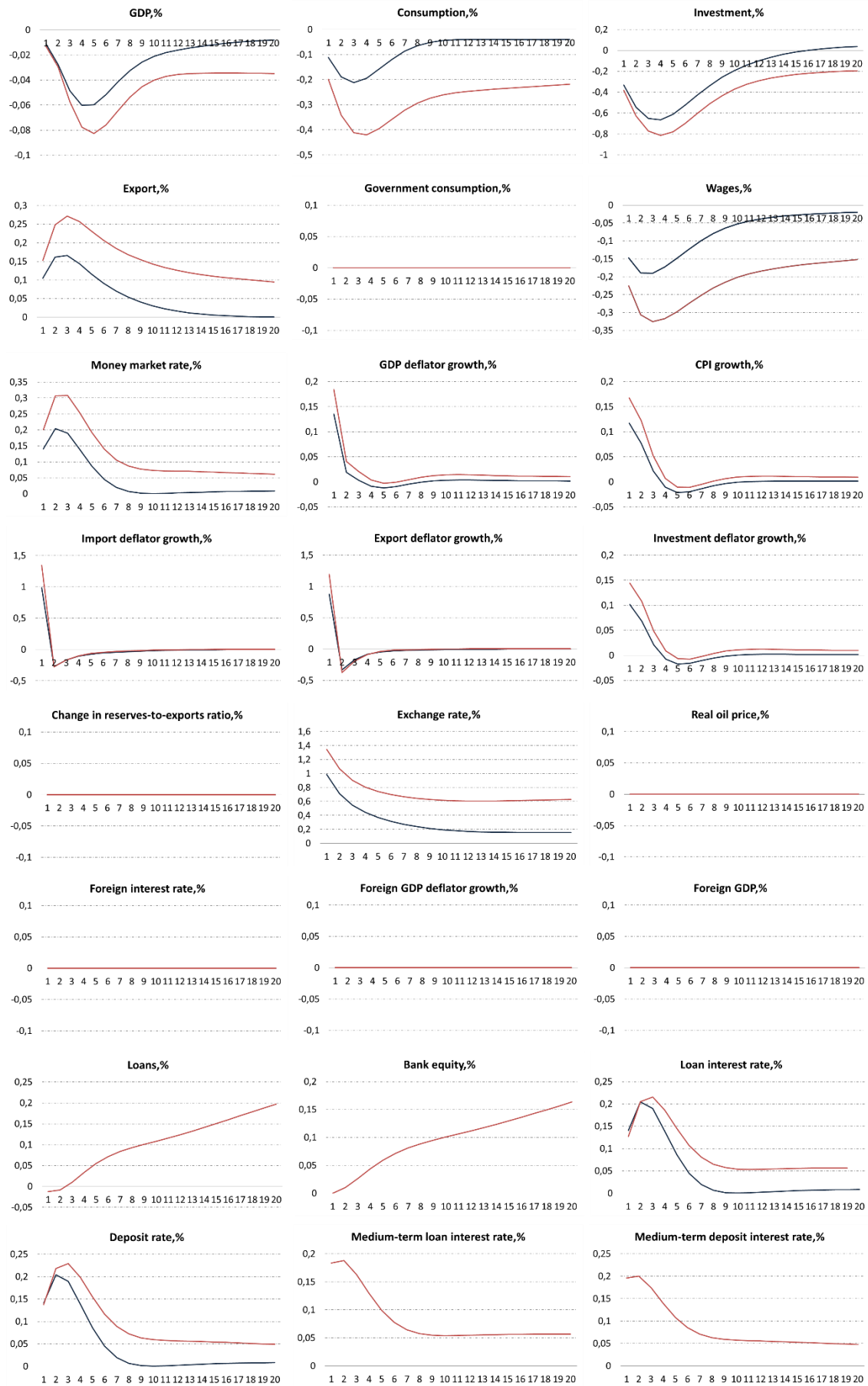
*Figure 2c. Monetary policy shock (baseline model – blue line; model with the banking sector – red line)*
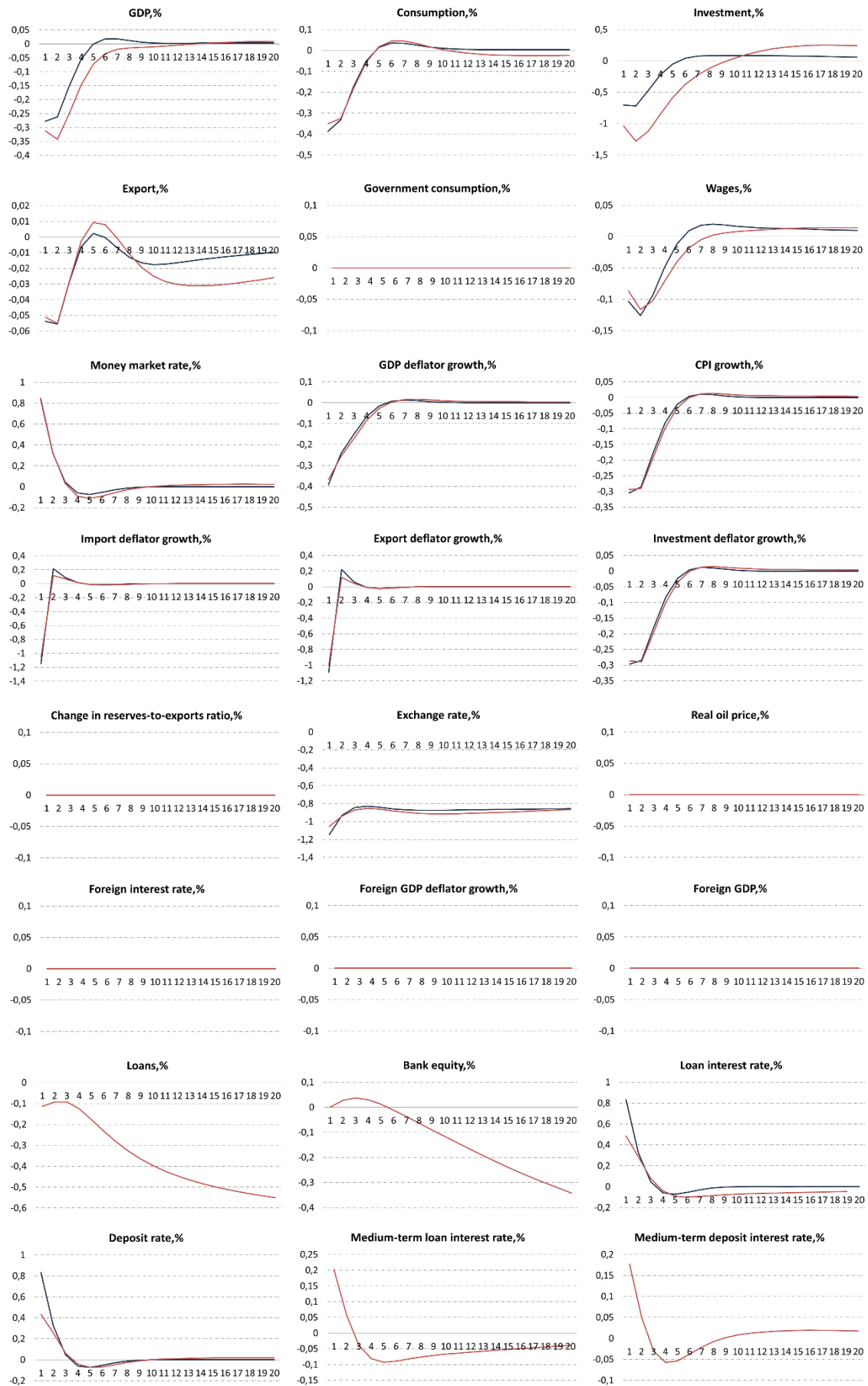
Figure 3a. Monetary policy shock (blue line) and capital dynamics shock (red line) in the model with the banking sector
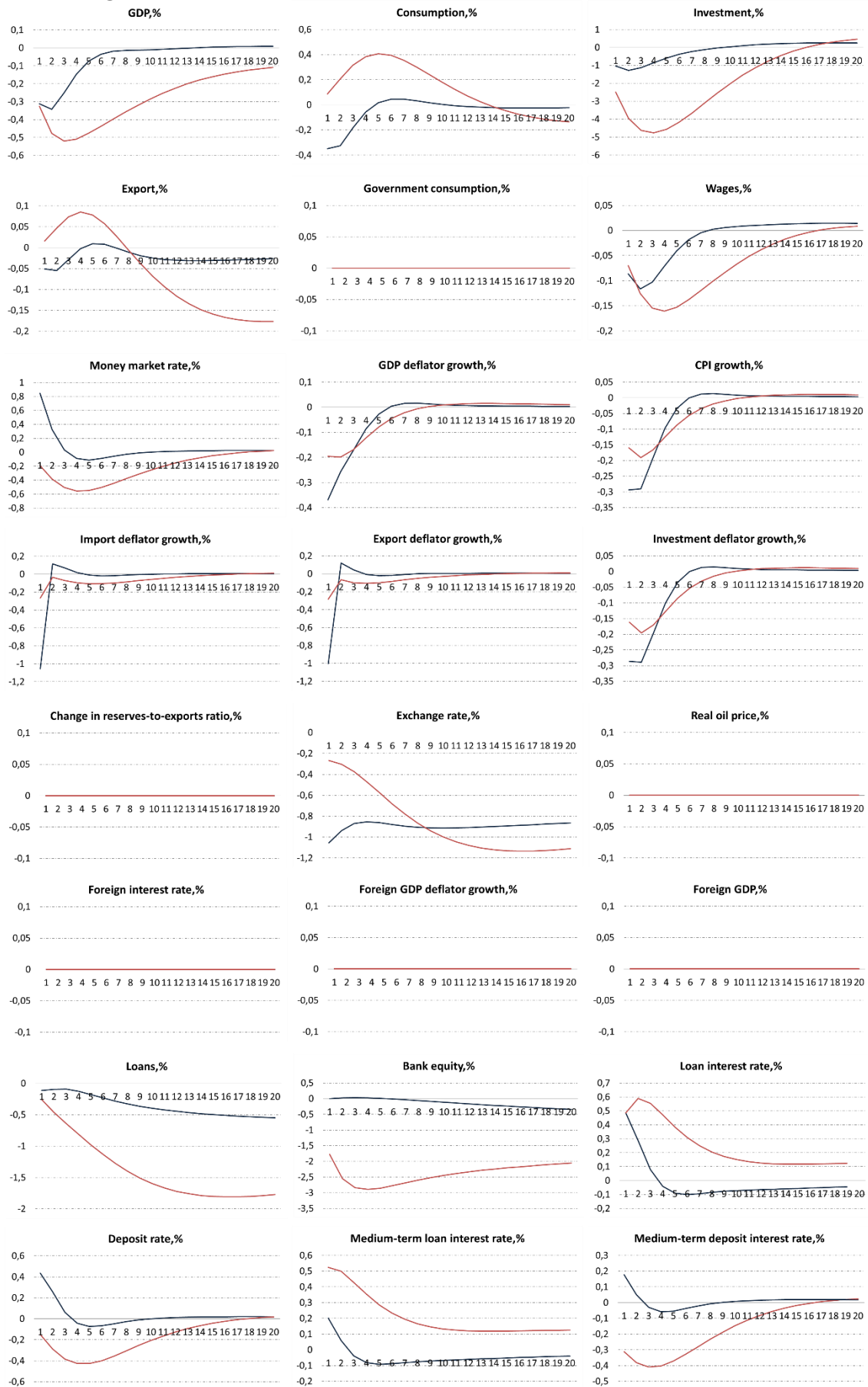
Figure 3b. Risk shock (blue line) and markup shock for deposit rates (red line in the model with the banking sector
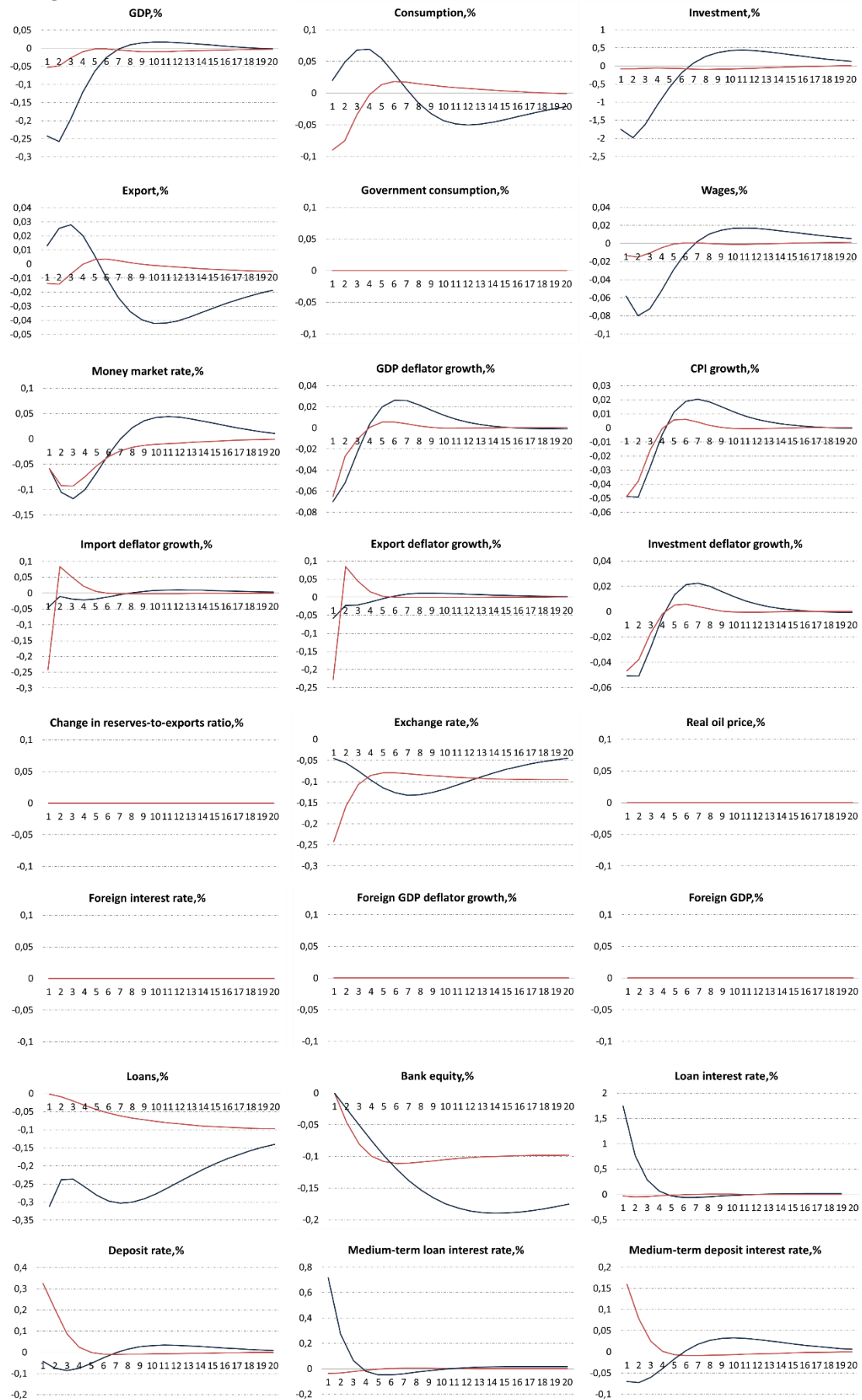
Figure 3c. Investment technology shock (blue line) and financial wealth shock (red line) in the model with the banking sector
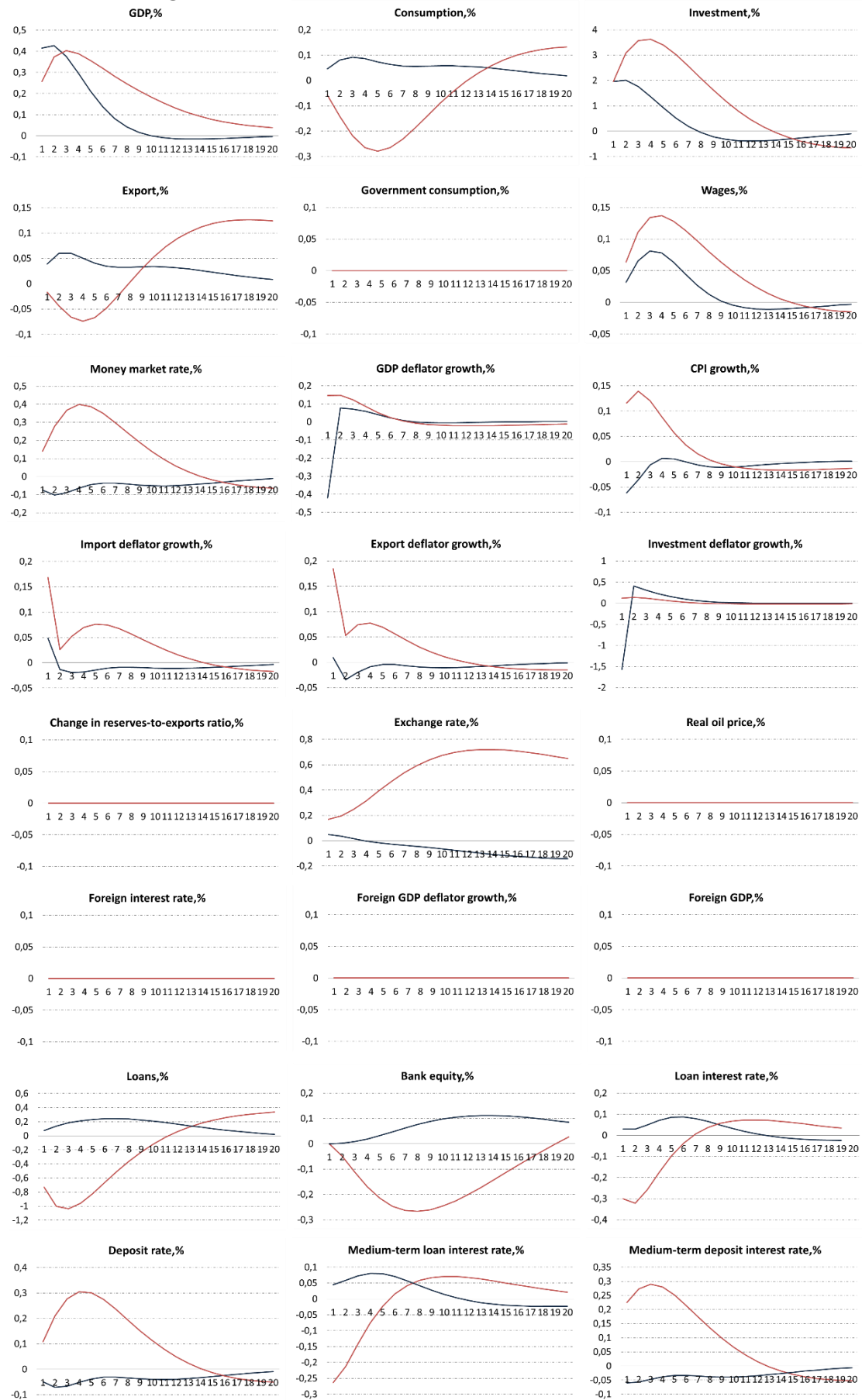
Figure 4a. Monetary policy shock in the model with the banking sector for a depreciation rate of 2.5% (blue line), 5% (red line), and 10% (green line)
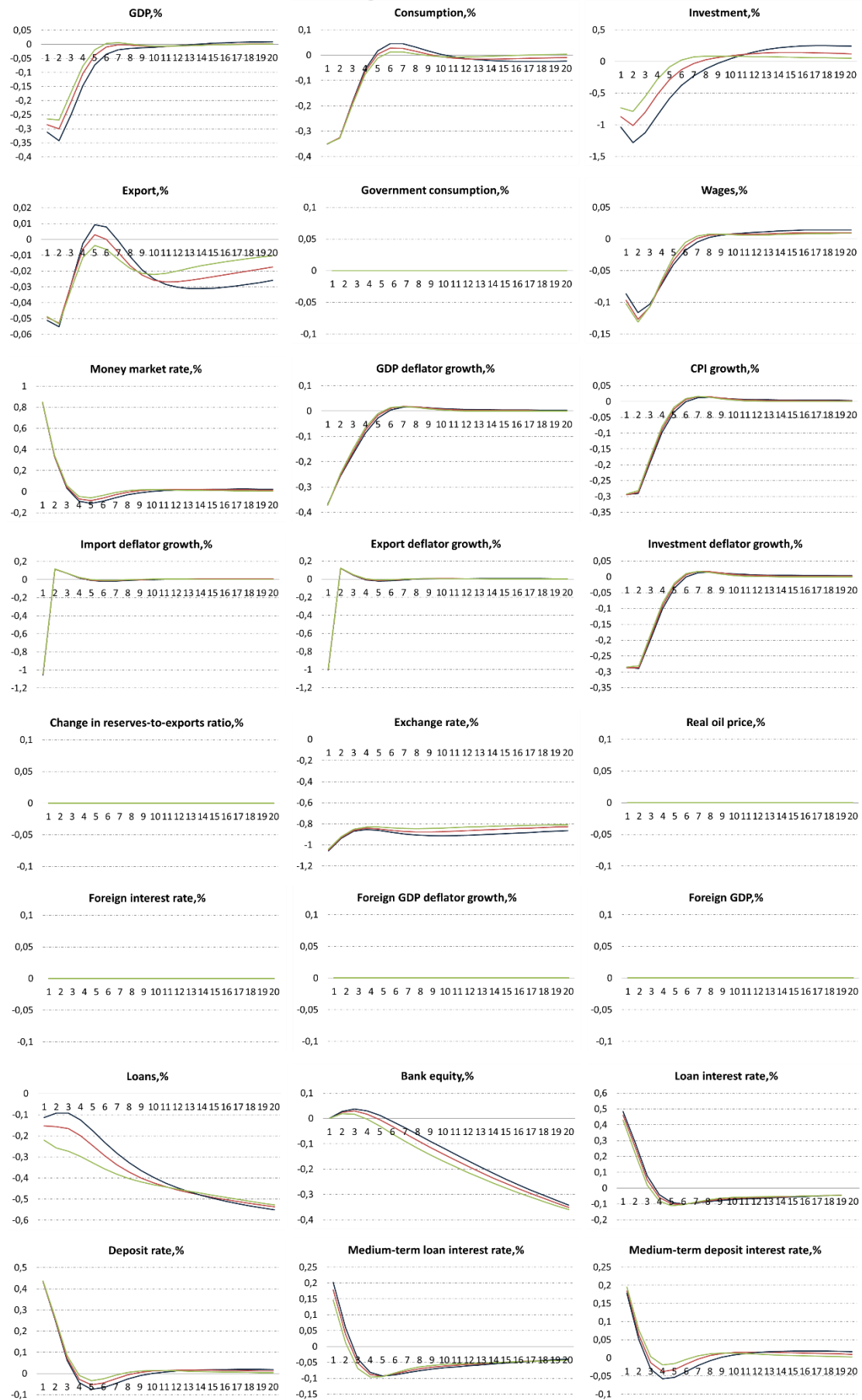
Figure 4b. Oil price shock in the model with the banking sector for a depreciation rate of 2.5% (blue line), 5% (red line, and 10% (green line)
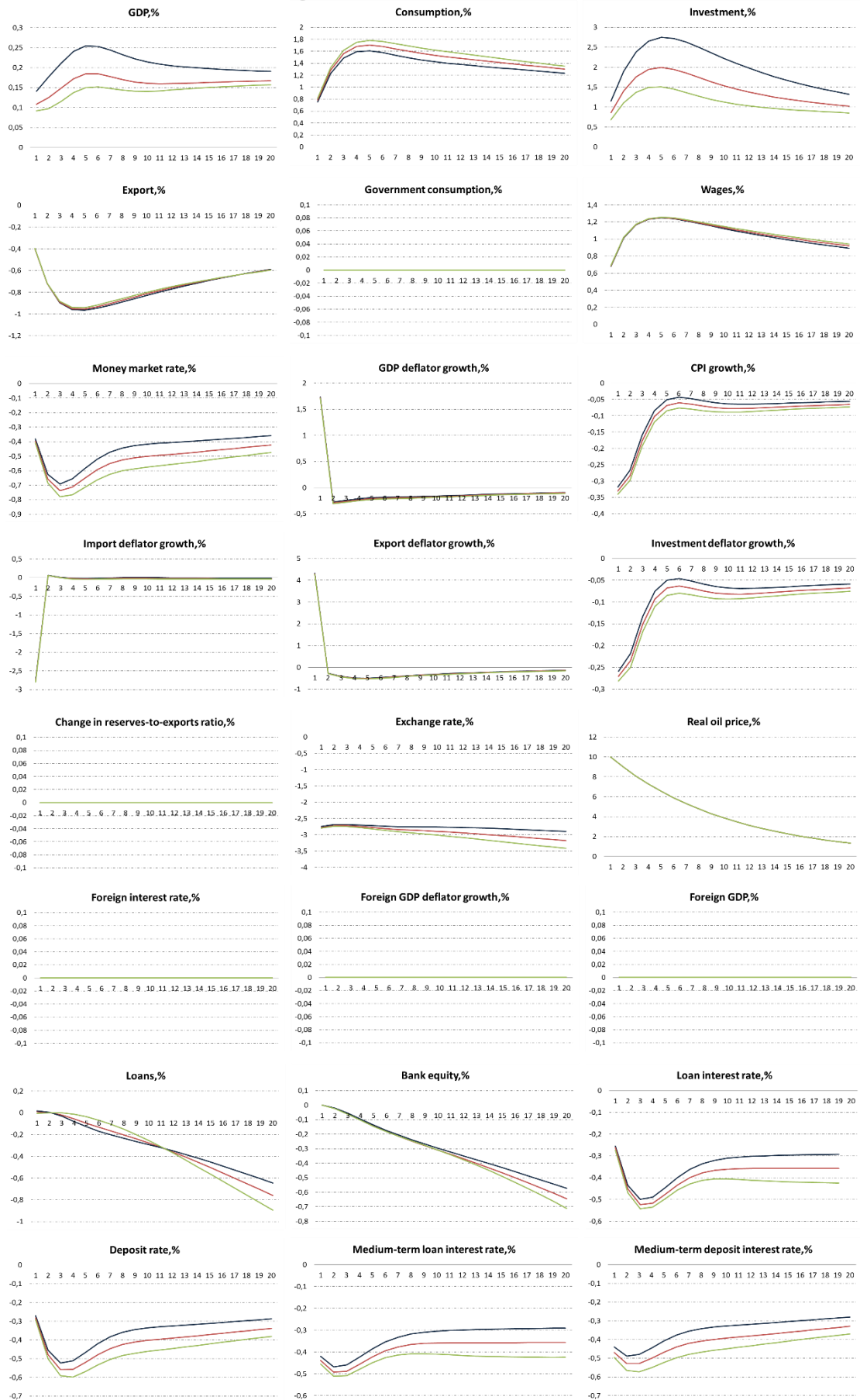
Рисунок 4c. Capital dynamics shock in the model with the banking sector for a depreciation rate of 2.5% (blue line), 5% (red line), and 10% (green line)
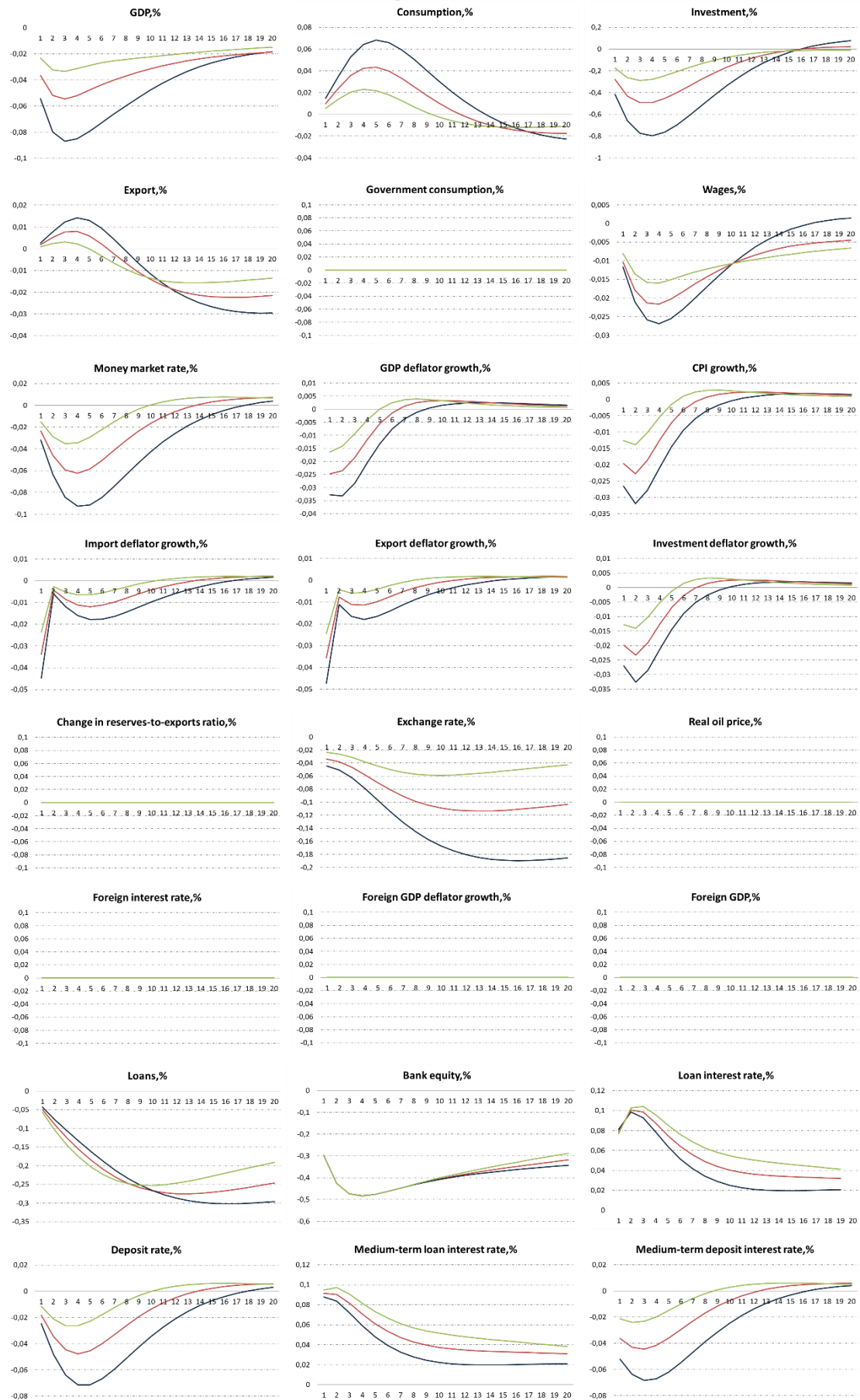
Figure 5a. Oil price shock, 68% credible interval (the baseline model – blue line, the model with the banking sector – red line)
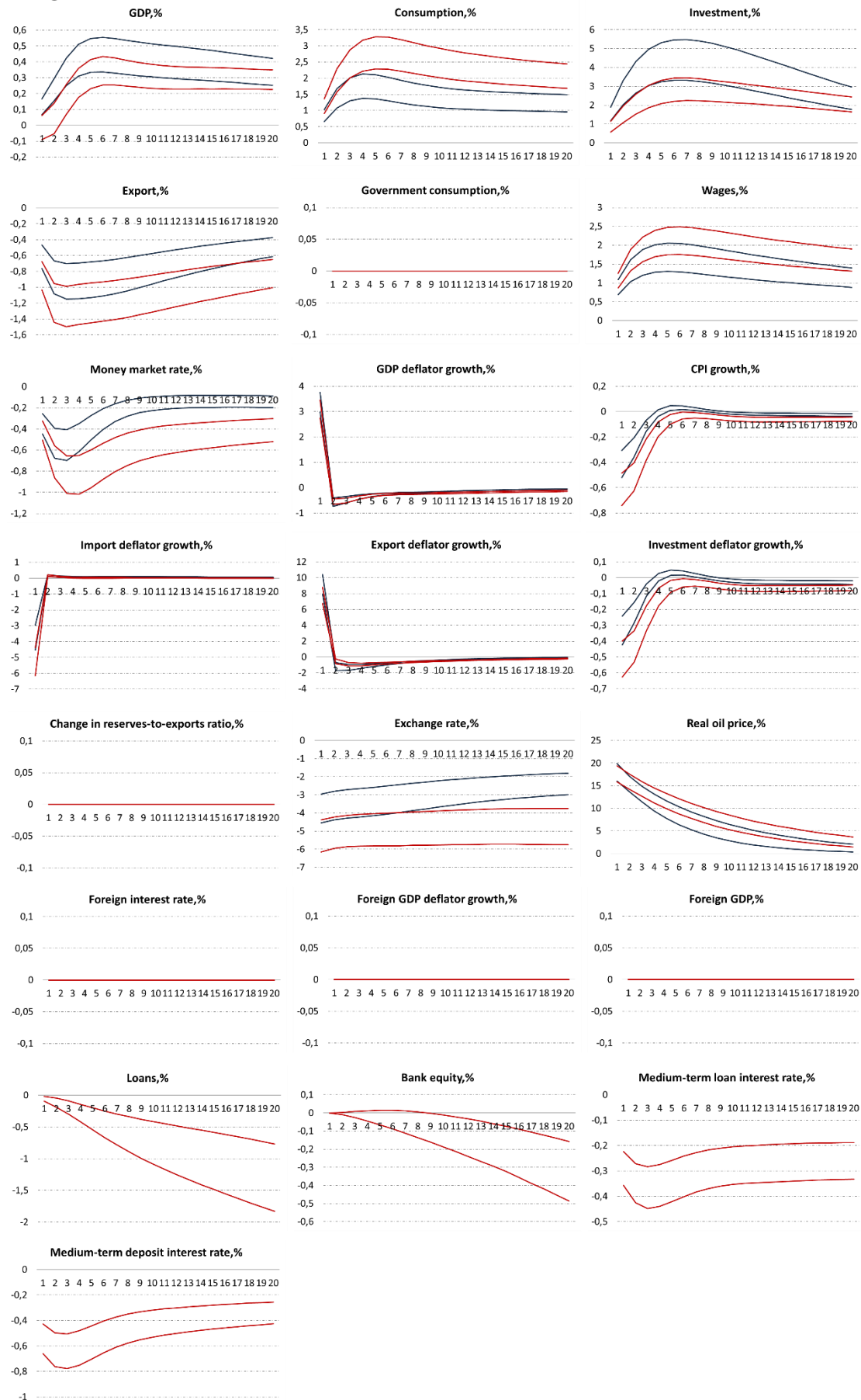
Figure 5b. Risk premium shock, 68% credible interval (the baseline model – blue line, the model with the banking sector – red line)

Figure5c. Monetary policy shock, 68% credible interval (the baseline model – blue line, the model with the banking sector – red line)
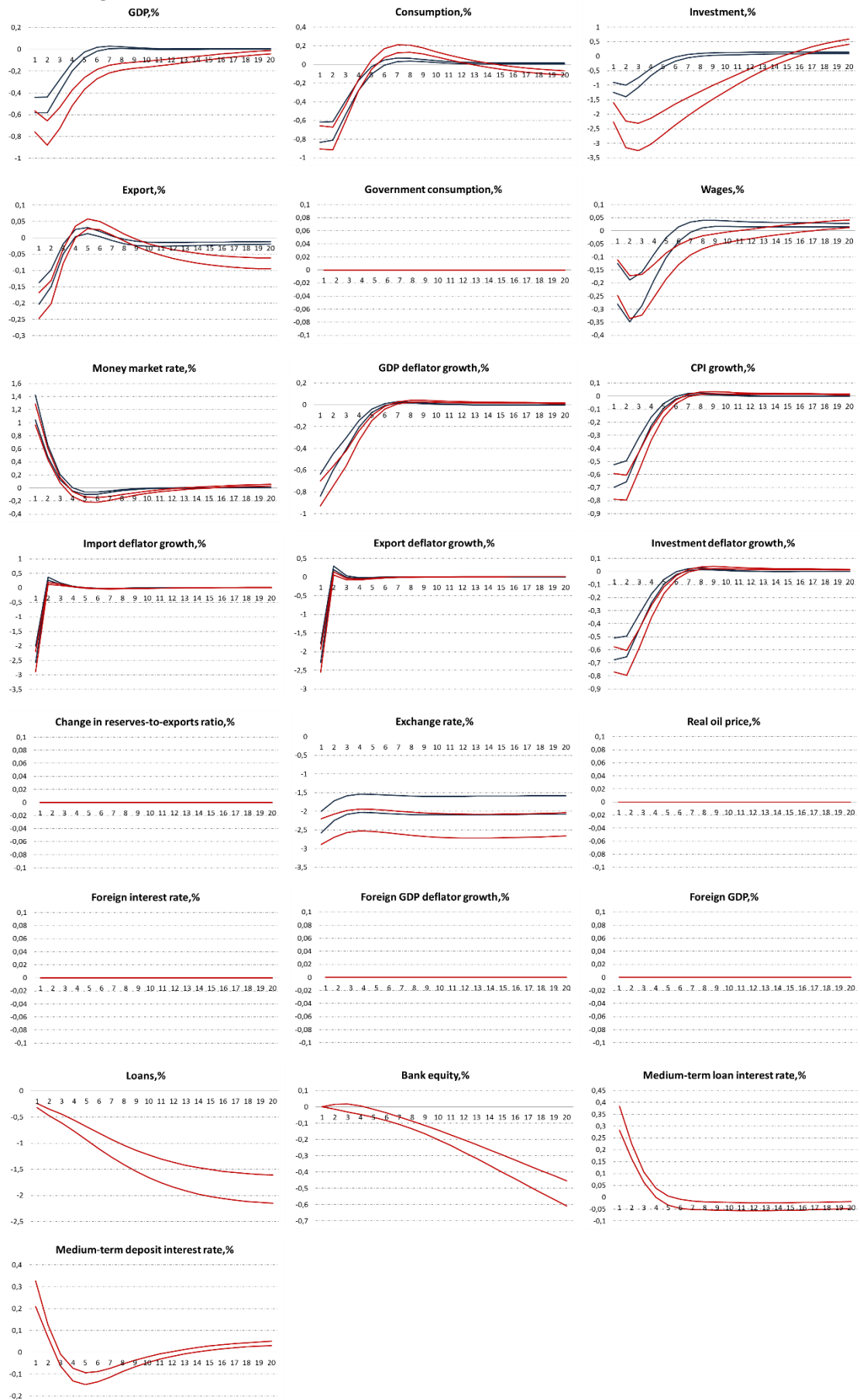
Figure 6a. Capital dynamics shock in the model with the banking sector, 68% credible interval
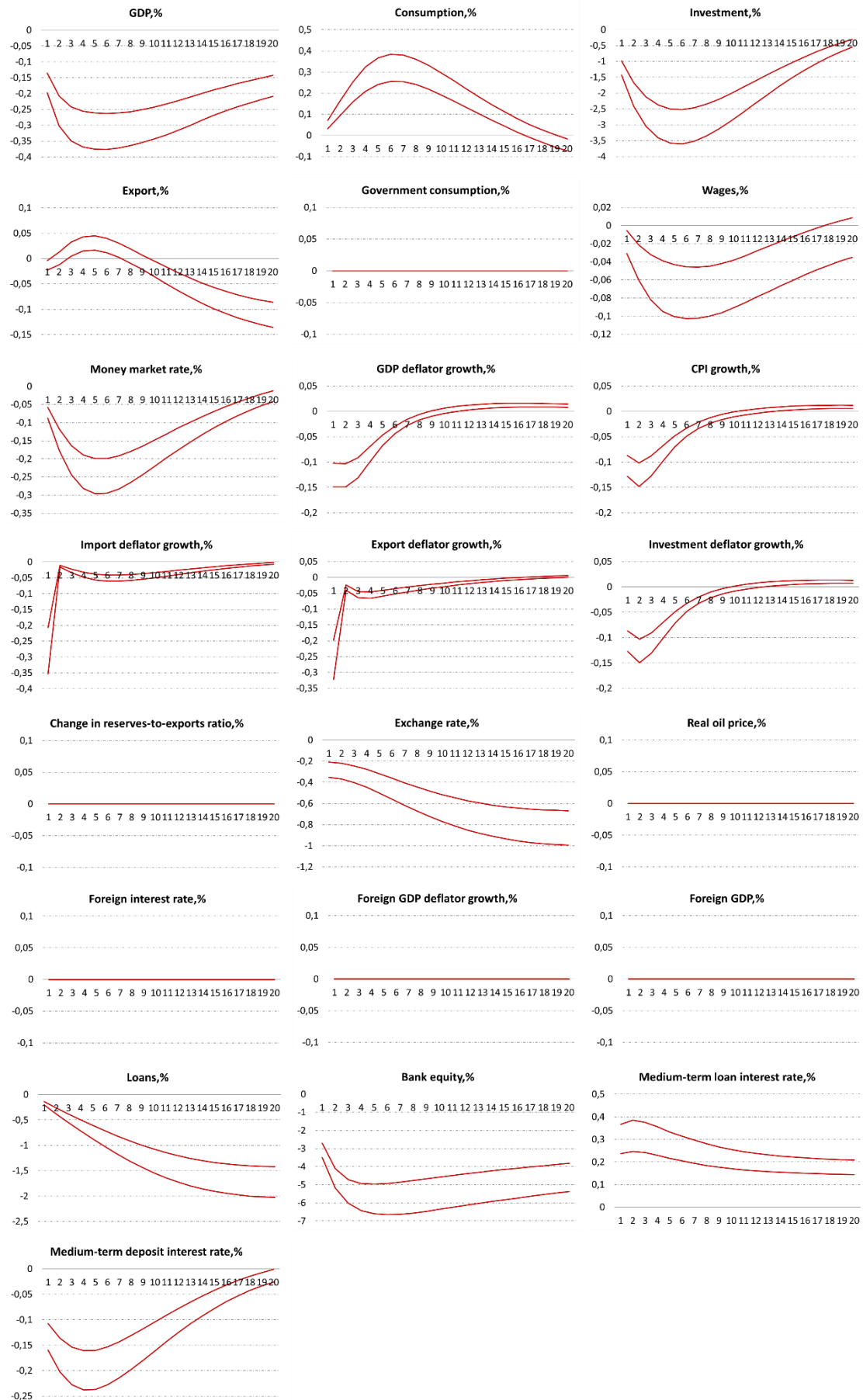
Figure 6b. Risk shock in the model with the banking sector, 68% credible interval

Figure 6c. Deposit rate markup shock in the model with the banking sector, 68% credible interval
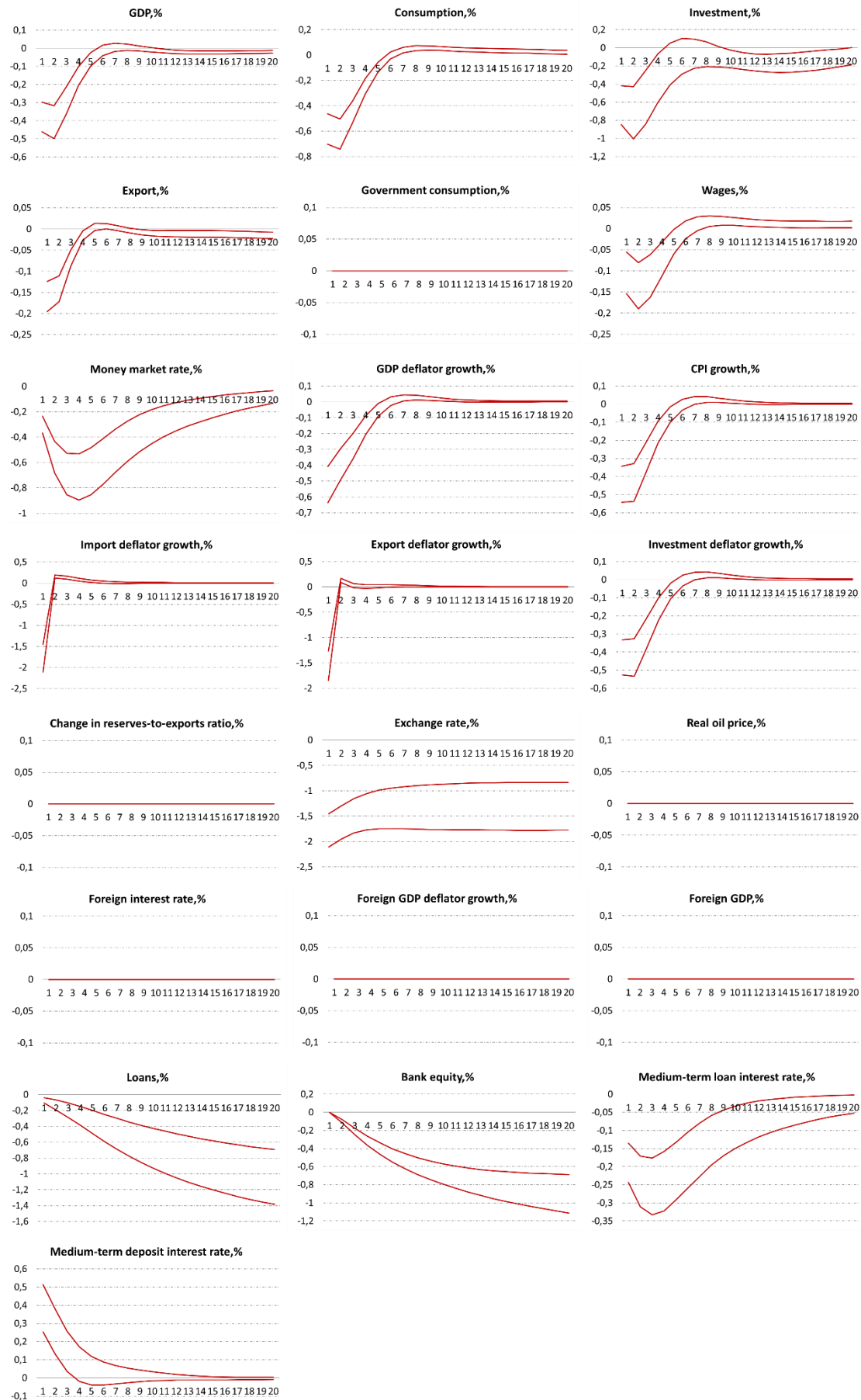
Figure 6d. Financial wealth shock in the model with the banking sector, 68% credible interval
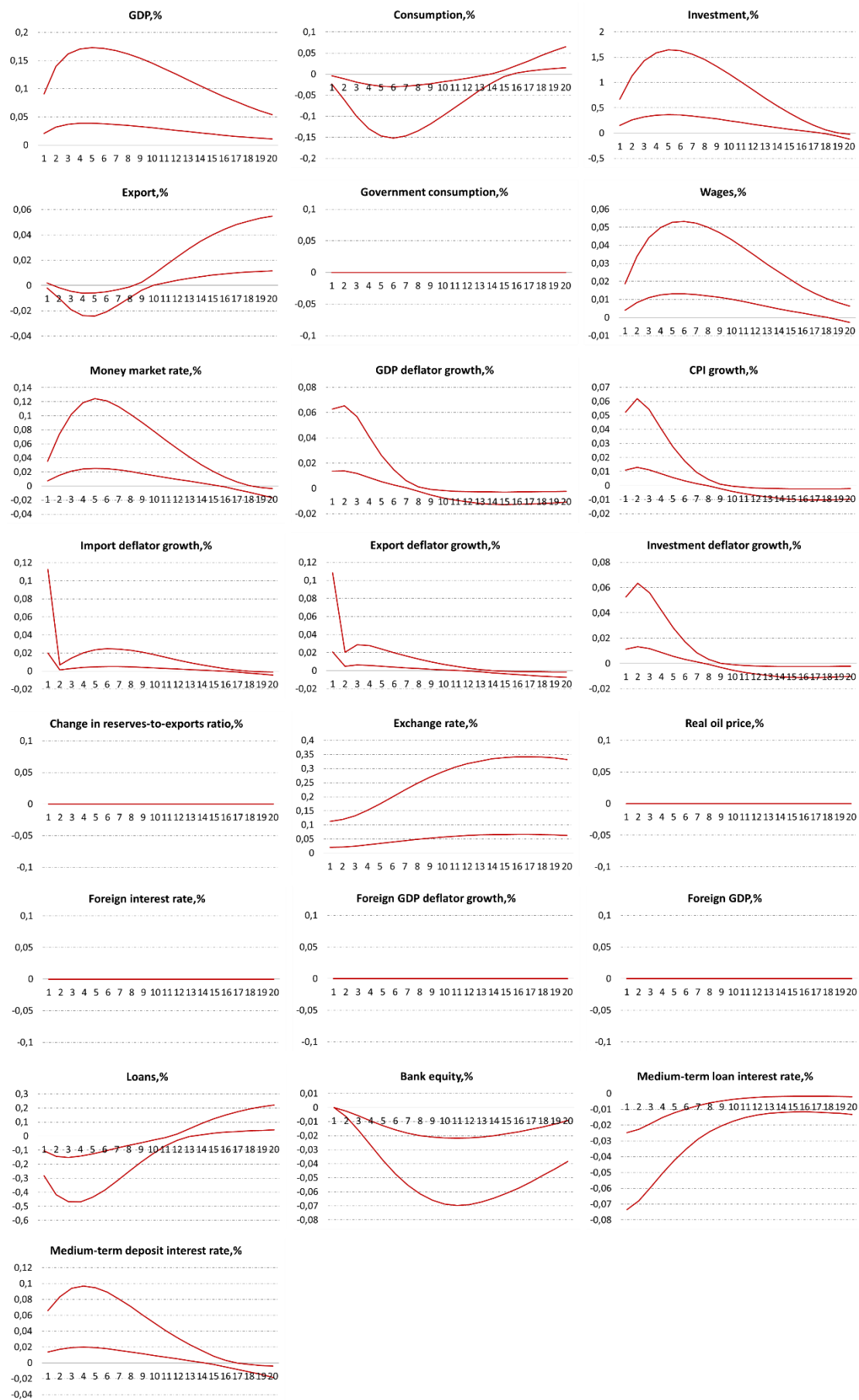
Figure 7a. Decomposition of smoothed (in the model) change in the logarithm of GDP (the baseline model – the upper diagram, the model with the banking sector – the lower diagram)
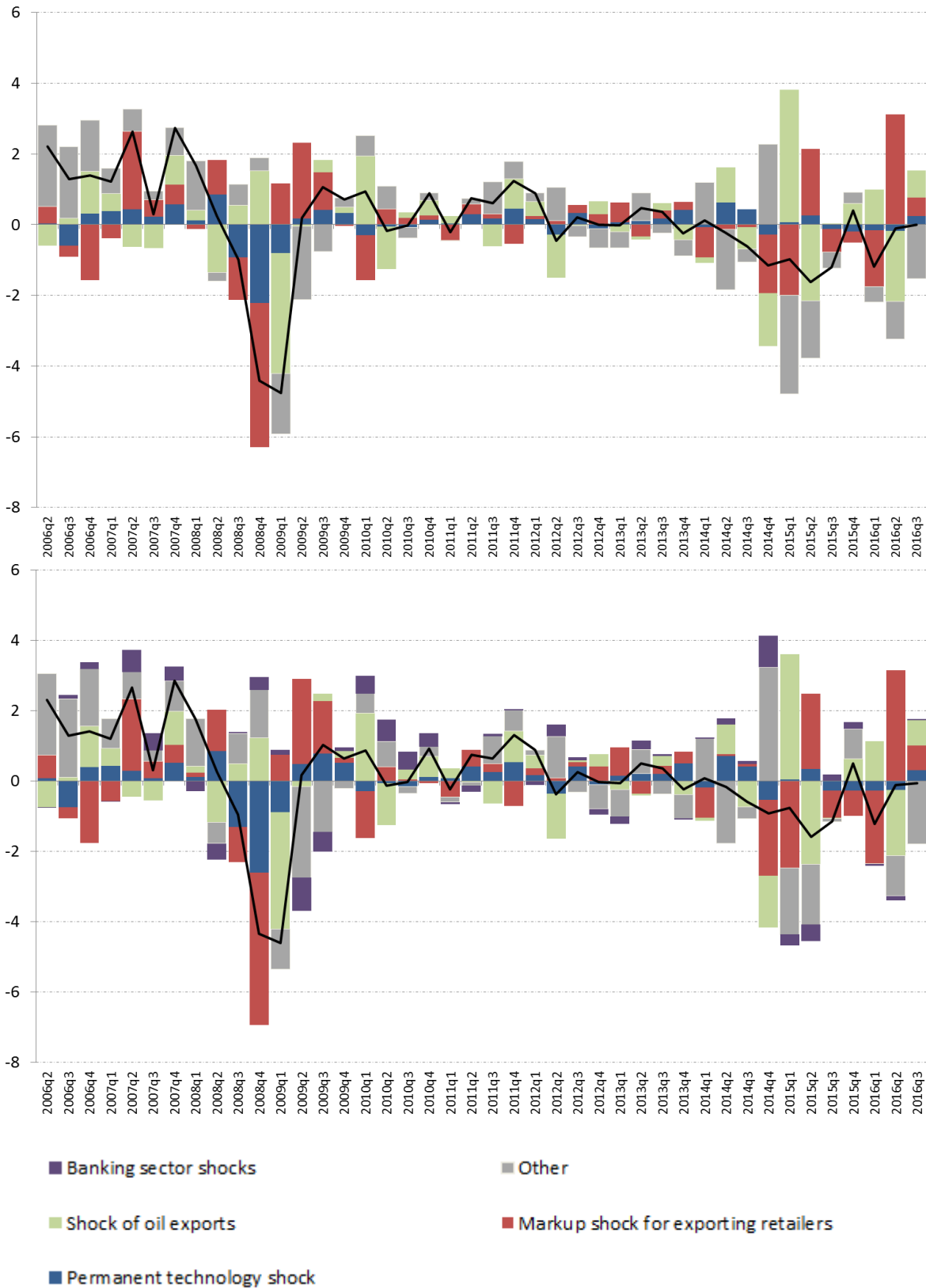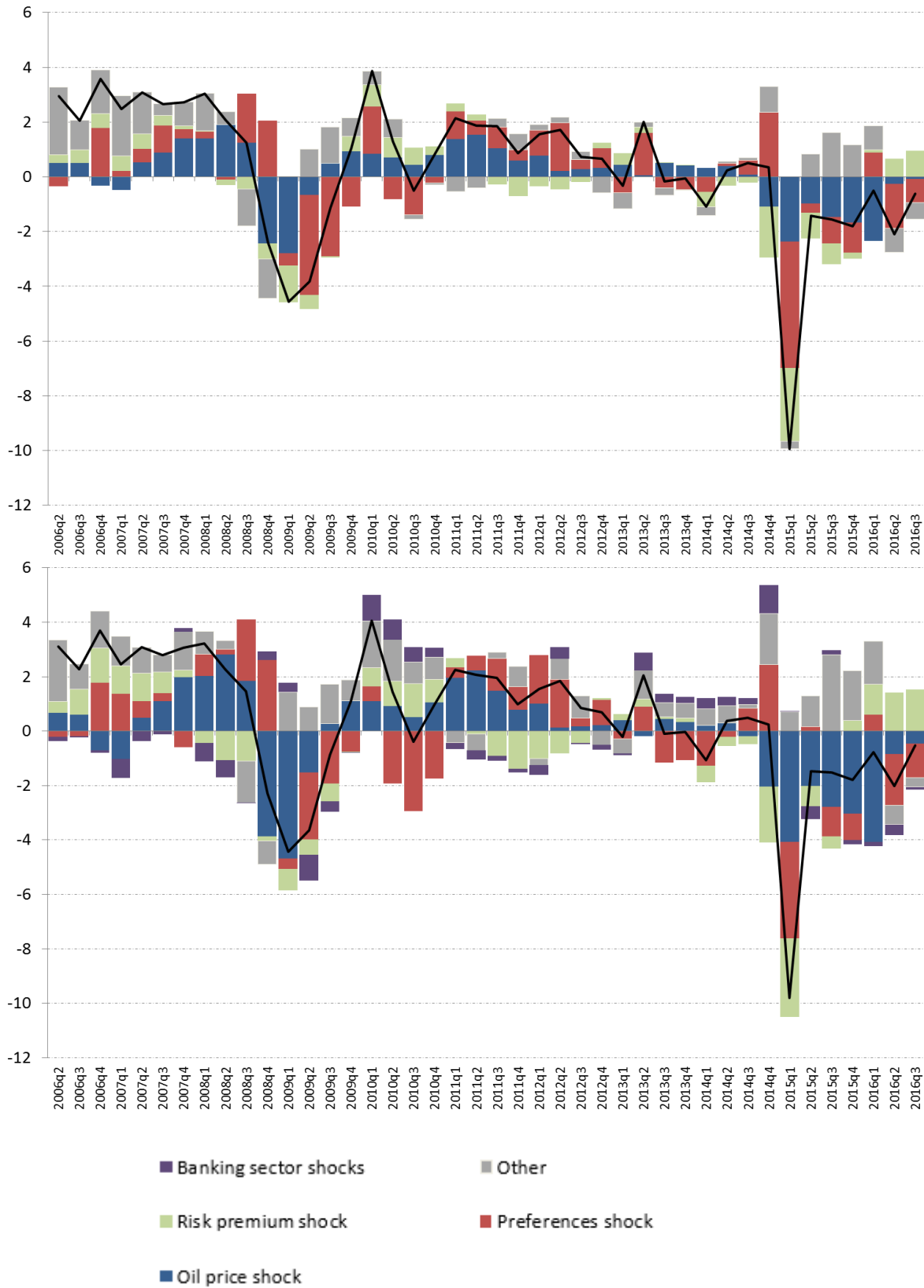
Figure 7b. Decomposition of smoothed (in the model) change in the logarithm of consumption (the baseline model – the upper diagram, the model with the banking sector – the lower diagram)

Figure 7c. Decomposition of smoothed (in the model) change in the logarithm of investment (the baseline model – the upper diagram, the model with the banking sector – the lower diagram)
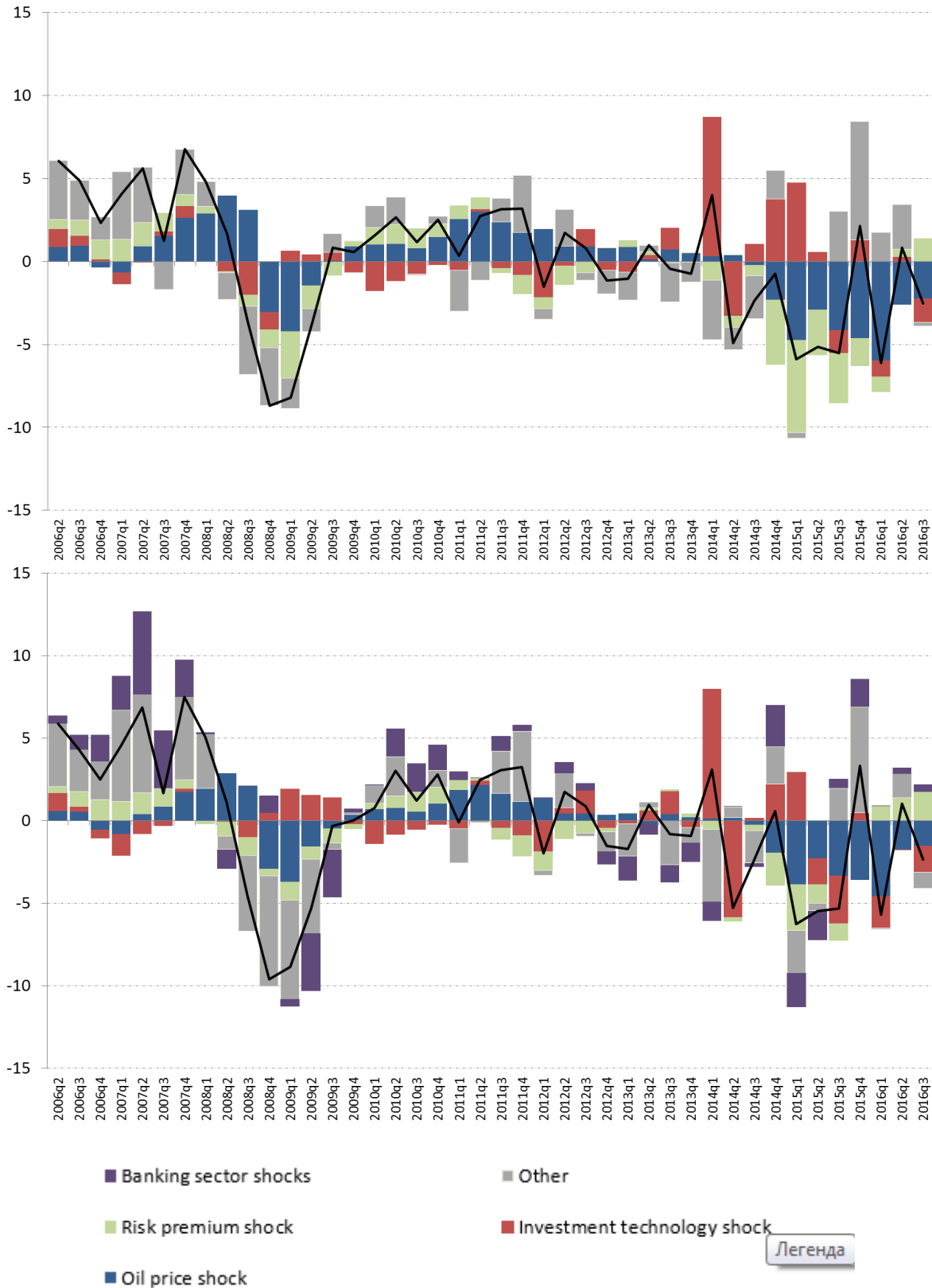
Рисунок 7d. Decomposition of smoothed (in the model) change in the logarithm of exchange rate (the baseline model – the upper diagram, the model with the banking sector – the lower diagram)
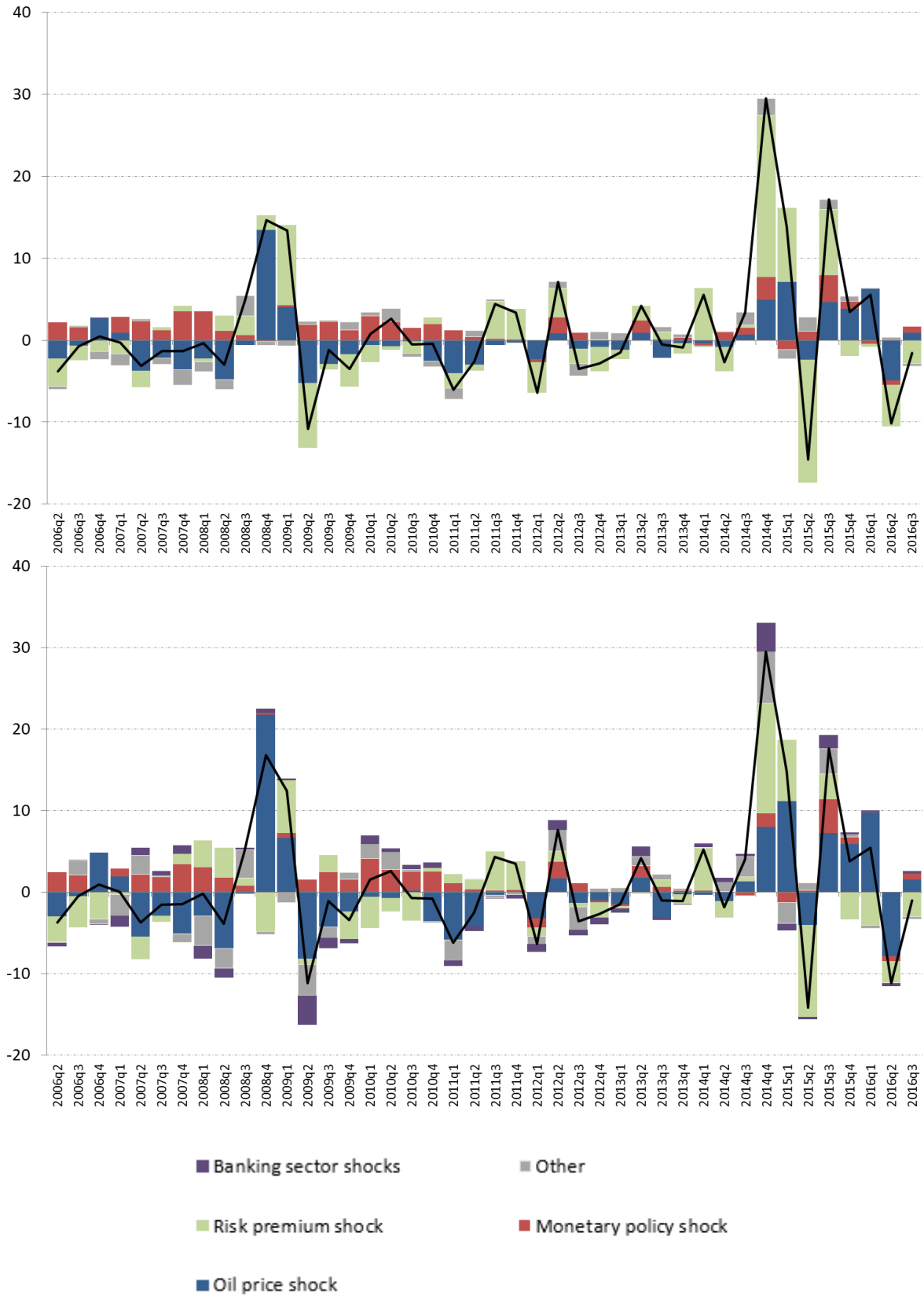
Figure 7e. Decomposition of smoothed (in the model) change in the logarithm of CPI (the baseline model – the upper diagram, the model with the banking sector – the lower diagram)
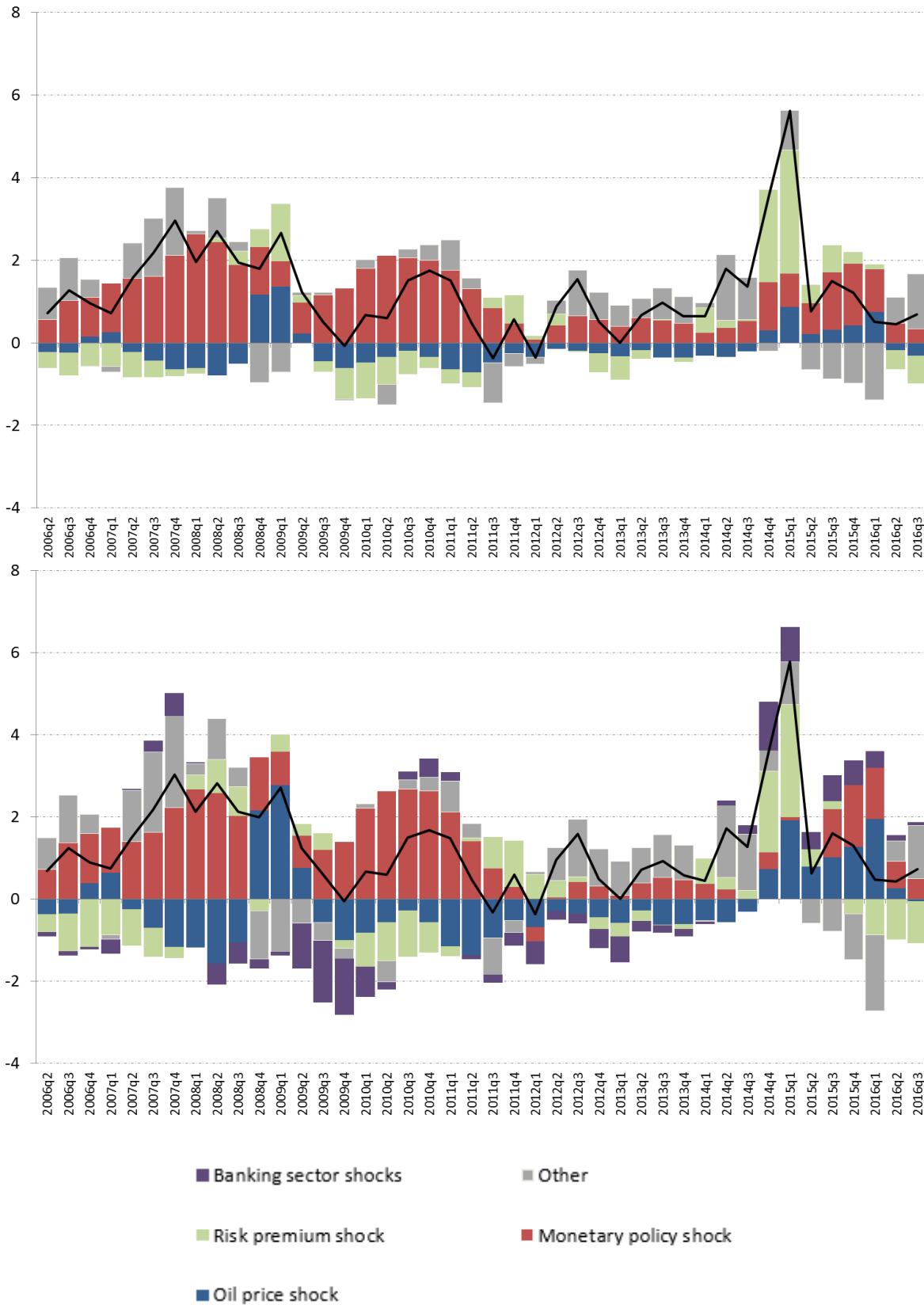
Figure 7f. Decomposition of smoothed (in the model) logarithm of MIACR (the baseline model – the upper diagram, the model with the banking sector – the lower diagram)

Legend:
- ■ Banking sector shocks
- ■ Other
- ■ Risk premium shock
- ■ Monetary policy shock
- ■ Oil price shock