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Introducing Macro-Financial Variables into a Semi-Structural Model

Dominika Ehrenbergerová and Simona Malovaná *

Abstract

This paper outlines a flexible and consistent model-based framework suitable for forecasting selected macro-financial variables of the Czech economy and conducting policy analysis to support the decision-making process. We enhance an existing semi-structural model of the Czech economy in order to replicate some of the characteristics of the financial cycle, i.e. co-movement between credit and house prices, higher persistence of respective macro-financial variables and a pronounced impact of shocks on the business cycle.

Abstrakt

Tento článek popisuje flexibilní a konzistentní modelový rámec vhodný pro prognózování vybraných makrofinančních veličin v české ekonomice a provádění analýz na podporu rozhodovacího procesu. Rozpracováváme stávající semistrukturální model české ekonomiky, abychom replikovali některé charakteristiky finančního cyklu, např. souběžný vývoj úvěrů a cen rezidenčních nemovitostí, vyšší perzistenci makrofinančních veličin a výrazný dopad šoků do hospodářského cyklu.

JEL Codes: C32, E47, E58, G21.
Keywords: Financial cycle, forecasting, macro-financial variables, semi-structural model.

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1. Introduction

The aim of this paper is to provide a flexible but consistent tool for forecasting selected macro-financial variables of the Czech economy and conducting policy analysis to support the decision-making process. In order to do that, we enhance an existing semi-structural model of the Czech economy with several macro-financial variables, relevant relationships and a feedback loop between the non-financial and financial parts of the economy. The difficulty in predicting macroeconomic downturns (upturns) and conducting policy experiments in (semi-)structural models without financial variables and financial frictions is well known (see, for example, Tovar, 2008; Trichet, 2010; Negro et al., 2015). These models usually fail to predict strong movements because, at the forecasting horizon, the variables converge relatively quickly to their steady-state (equilibrium) levels. Thus, our extension aims to introduce some aspects of the domestic financial cycle which should help to strengthen the response of the business cycle to certain shocks and to predict the evolution of macro-financial variables and their turning points. Nevertheless, the extended model is intended to be used as a complementary tool rather than a main forecasting model.

We have chosen to build on the semi-structural model (quarterly projection model, QPM) that the Czech National Bank (CNB) used before switching to a fully structural dynamic stochastic general equilibrium (DSGE) framework in 2008. The reasons are twofold. Firstly, the QPM proved to match the stylised facts of the Czech economy. Secondly, it is a flexible tool compared to fully structural models. Modelling financial frictions within a DSGE model is a complex and time-consuming task leading often to a less flexible solution with high demands on operating resources. Moreover, a vast amount of research has been devoted to introducing financial frictions into DSGE models, but no clear conclusion has been reached about which approach should be used; combining frictions is often not possible or yields a black-box solution that is not applicable in central banks. Therefore, even after the global financial crisis many central banks opted to continue using their pre-crisis frictionless models.

The remainder of this paper is organised as follows. Section 2 provides further motivation and a brief review of related literature. Sections 3 and 4 present the model extension and the calibration of parameters. Sections 5 and 6 report the simulation results. Section 7 concludes.

2. Motivation and Literature

Since the global financial crisis, the demand for more comprehensive modelling of the interactions between the real economy and the financial sector has increased markedly and the related literature has expanded. Various approaches to incorporating financial frictions into dynamic structural general equilibrium (DSGE) models have emerged (see, for example, Gertler and Kiyotaki, 2010; Gerali et al., 2010; Angeloni and Faia, 2013; Angelini et al., 2014; Bruha and Tonner, 2014; Chen and Columba, 2016; Gertler et al., 2016; Boissay et al., 2016). These models usually try to capture some important aspects of the financial cycle or to model the interactions between monetary policy and financial stability policies. Even though this can be considered progress in the right direction, high computational demands and low flexibility limit their potential to be used by policy institutions in practice. A flexible and "easy-to-operate" model seems to be a more appropriate tool for such a job. A semi-structural model (like the one we employ) fulfils these requirements while still maintaining the important theoretical relationships established in the minds of many economists and policy-makers.

In our quest to capture some aspects of the domestic financial cycle, we follow the definition and stylised facts of the financial cycle provided by Drehmann et al. (2012). According to these authors, the financial cycle can be characterised by joint fluctuation of credit and house prices,[1] higher persistence and amplitude than the traditional business cycle and potential “dis-synchronisation” with the business cycle, as not all business cycle recessions necessarily coincide with financial cycle contractions. However, when they do, the recessions tend to be especially severe (Drehmann et al., 2012).

It is still relatively rare to find a semi-structural model with a (full) financial sector in the literature. Attempts have been made in this area, but the researchers usually end up incorporating only some specific elements of the financial sector. For example, Benes et al. (2017) introduce a bank lending tightening variable into a semi-structural model of India; this variable is supposed to capture the credit market conditions and their impact on the real economy. Ravnik et al. (2018) introduce a rather more complex relationship in a semi-structural model of Croatia; in their case, the short-term bank lending rate is a function of change in non-performing loans and their deviation from the steady state. The evolution of non-performing loans then depends on output dynamics, the real lending rate and the exchange rate. However, credit and house prices are not part of this model. Last but not least, the relevant literature includes Juselius et al. (2017), who incorporate a leverage gap into a version of the model by Laubach and Williams (2003). In their work, the leverage gap is defined as the interest rate gap plus the debt service gap, which depends on the credit-to-GDP ratio and the lending rate. In this way, the authors allow financial factors to affect the business cycle and thus account for the relationship between financial and non-financial variables. However, their model is not a complete model of the economy and is not closed, in the sense that it does not include equations specifying the debt service gap and the lending rate.

In order to build our model, we examine a wide range of empirical literature focusing on the determinants of the macro-financial variables we want to incorporate into our model. Firstly, we search for the determinants of credit growth. Plašil et al. (2013) suggest that the volume of loans depends on GDP and the loan interest rate, typical variables used to control for credit demand factors, and the default rate. Determinants of the loan volume are estimated together with another two cointegrating relationships: one for the loan interest rate and one for non-performing loans (NPLs), where the loan interest rate depends on the monetary policy rate and NPLs, and NPLs depend on the loan volume, GDP and the default rate. Guo and Stepanyan (2011) analyse the determinants of bank credit in emerging markets. They find that GDP growth, the deposit rate, the NPL ratio, inflation, change in the monetary policy rate and change in the exchange rate may be significant determinants of private credit growth. Calza et al. (2003) assert that real loans are affected positively by real GDP and negatively by both short- and long-term interest rates. The literature on the determinants of credit demand or credit growth is vast; here we only present few examples pointing to the most important relationships.

Secondly, we are interested in the determinants of house prices. Égert and Mihaljek (2007) assert that house prices depend negatively on real interest rates, positively on real GDP and, in one specification, also positively on housing loans. Tsatsaronis and Zhu (2004) use bank credit, the nominal interest rate, inflation and the term spread as the determinants of house prices. Hlaváček et al. (2016) in empirical work for the Czech Republic suggest that housing prices depend on potential GDP, the GDP gap, the credit-to-GDP ratio and inflation. Last but not least, we examine the determinants of NPLs. Among others, Radivojevic and Jovovic (2017) suggest that the NPL ratio

[1] See also, for example, Schüler et al. (2015) and Stremmel (2015).

depends mostly on macroeconomic variables such as GDP, inflation and the unemployment rate, but also on bank-specific variables.

The literature also shows that most of these relationships are not unidirectional, but there exist loops between the variables: real activity affects credit and credit affects real activity in a feedback loop (Cappiello et al., 2010, and see also the literature on the credit and bank lending channel of monetary policy). There is also evidence of a similar feedback loop between NPLs and real activity (see, for example, Petkovski et al., 2018). The spiral between house prices and credit is a topic of utmost interest in CNB (2018) and CNB (2019), as it has been identified and evaluated as a source of systemic risk in the Czech Republic.

3. Model

We build on the quarterly projection model (QPM; known also as the gap model) proposed originally by Beneš et al. (2002)[2] and then adjusted by Hlédik and Vlček (2018) to account for relative price trends and purchasing power parity in the long run. All the model variables except prices are divided into a trend (equilibrium) and a gap (cycle) using Kalman filtration. The model is linear and calibrated to match the business and financial cycle properties of the Czech economy. The model is written in IRIS.

The model is a standard New-Keynesian model of a small open economy with a floating exchange rate and no financial frictions. We extend this model with a set of macro-financial variables and relationships intended to capture some aspects of the Czech financial sector and its financial cycle. In particular, we introduce

- four new macro-financial variables: real credit to the non-financial sector, real house prices, real non-performing loans (a proxy for credit risk) and the bank lending rate,
- a spiral between house prices and credit,
- a feedback loop between the non-financial and financial parts of the economy via credit and credit risk,
- a credit risk premium, a term premium and a term structure premium as components of the bank lending rate,
- an impact of monetary policy on the financial sector via credit, house prices and credit risk.

The risk of a spiral between property prices and property financing loans was identified as a potential source of systemic risk in CNB Financial Stability Report 2017/2018 and later. The feedback loop is a key feature allowing for transmission of macro-financial shocks, reinforcement processes and the existence of a few crucial monetary policy transmission channels identified by the empirical literature (see Section 2). The impact of monetary policy on financial sector variables has been proved by numerous studies (see Section 2) and has been discussed by the Czech National Bank in its Financial Stability Reports and minutes of monetary policy meetings (for more details, see the CNB's website). By incorporating these particular features, we are able to replicate some of the characteristics of the domestic financial cycle, i.e. co-movement between credit and house prices, higher persistence of relevant macro-financial variables and a pronounced impact of shocks on the

[2] The original QPM described in Benes et al. (2002) was used by the CNB as its key forecasting model during 2001–2008.

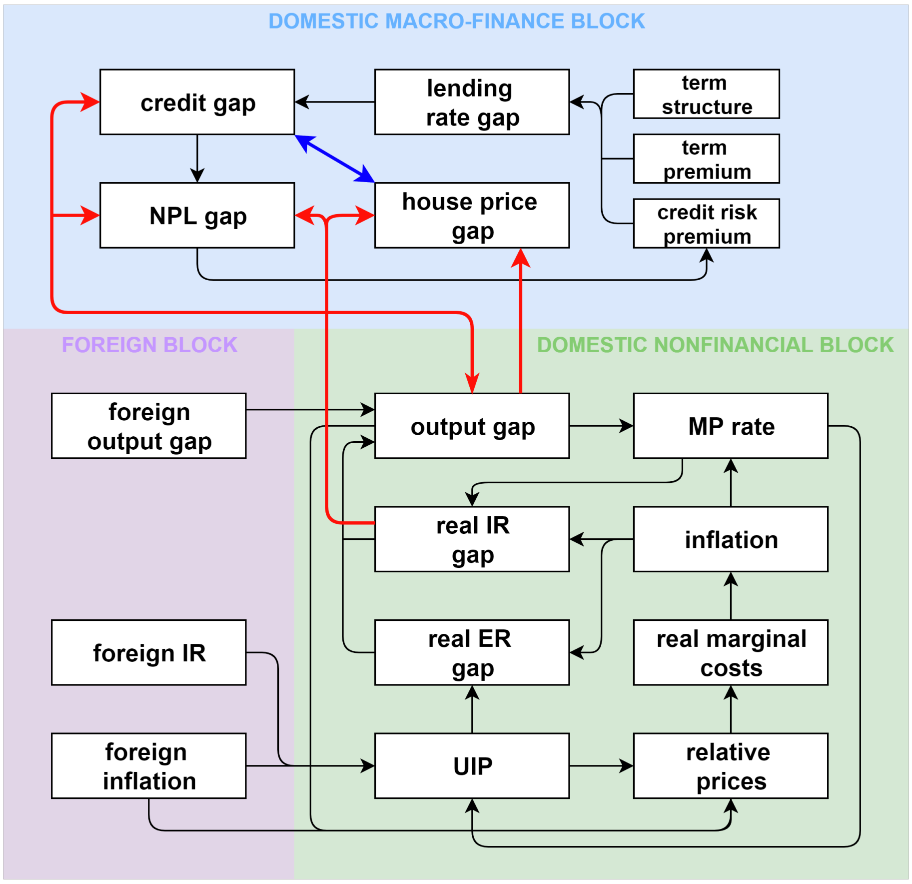
business cycle. The structure of the extended QPM is schematically depicted in Figure 1. Details on the macro-financial block are given below. For details on the model prior extensions employed, see Appendix A.

We use consistent labelling of the various groups of variables and parameters. Gap variables are indicated by a hat ($\hat{X}$), trend variables by a bar ($\bar{X}$), variables for the foreign or world economy by a star (X^*) and steady-state variables by the shortcut (X_{SS}). We use the Greek letters ρ for all persistence parameters and ε for all shocks. If not indicated otherwise, growth rates are calculated as annualised quarter-on-quarter changes and the variables are assumed to be in natural logarithm times 100 (except for interest rates):

$$\Delta X_t = 4(X_t - X_{t-1}) \tag{1}$$

where $X_t = 100(log(x_t))$.

Figure 1: Simplified Model Structure



Note: This figure is only a simplistic scheme. For a detailed structure, see Appendix A. Red lines represent the relationship between the non-financial and financial block and emphasise the feedback loop between non-financial and financial variables. The blue line represents the spiral between the credit gap and the house price gap. IR = interest rate, ER = exchange rate, UIP = uncovered interest rate parity.

3.1 Credit, House Prices and Non-Performing Loans

We introduce three new gap equations for the real credit gap $\hat{C}_t$, the real house price gap $\hat{H}_t$ and the real non-performing loans gap $\widehat{NPL}_t$:

$$\hat{C}_t = \theta_{C1}\hat{C}_{t-1} + \theta_{C2}\hat{Y}_t - \theta_{C3}\hat{rl}_t + \theta_{C4}\hat{H}_t + \varepsilon_{C,t} \tag{2}$$
$$\hat{H}_t = \theta_{H1}\hat{H}_{t-1} + \theta_{H2}\hat{Y}_t + \theta_{H3}\hat{C}_t - \theta_{H4}\hat{r}_t + \varepsilon_{H,t} \tag{3}$$
$$\widehat{NPL}_t = \theta_{NPL1}\widehat{NPL}_{t-1} - \theta_{NPL2}\hat{Y}_t + \theta_{NPL3}\hat{C}_t + \theta_{NPL4}\hat{r}_t + \varepsilon_{NPL,t} \tag{4}$$

where $\hat{rl}_t$ is the real lending rate gap, $\hat{r}_t$ is the real interest rate gap and $\hat{Y}_t$ is the real output gap.[3]

Total real credit, the real house price index and real non-performing loans are the sum of the relevant gap and trend (equilibrium value):

$$X_t = \hat{X}_t + \bar{X}_t \tag{5}$$

The respective identities for the growth rates of real credit, real house prices and real non-performing loans and their equilibrium values are defined as follows:

$$\Delta X_t = 4(X_t - X_{t-1}) \tag{6}$$
$$\Delta \bar{X}_t = 4(\bar{X}_t - \bar{X}_{t-1}) \tag{7}$$
$$\Delta X_{yoy,t} = X_t - X_{t-4} \tag{8}$$
$$\Delta \bar{X}_{yoy,t} = \bar{X}_t - \bar{X}_{t-4} \tag{9}$$

where ΔX_t and $\Delta \bar{X}_t$ are annualised quarterly growth rates, while $\Delta X_{yoy,t}$ and $\Delta \bar{X}_{yoy,t}$ are annual growth rates.

The growth rates of the equilibrium values are then defined as the weighted average of their lagged value and the steady-state value:

$$\Delta \bar{X}_t = \rho_X \Delta \bar{X}_{t-1} + (1-\rho_X)\Delta \bar{X}_{SS} + \varepsilon_{\bar{X},t} \tag{10}$$

3.2 Nominal and Real Lending Rate

The nominal lending rate is defined as follows:

$$l_t = \rho_l l_{t-1} + (1-\rho_l)(TS_t + TP_t + CP_t) \tag{11}$$
$$TP_t = \rho_{TP} TP_{t-1} + (1-\rho_{TP}) TP_{SS} \tag{12}$$
$$TS_t = \frac{1}{20}\sum_{k=1}^{20} i_{t+k} \tag{13}$$
$$CP_t = \rho_{CP} CP_{t-1} + (1-\rho_{CP})(\theta_{CP}\widehat{NPL}_t + CP_{SS}) + \varepsilon_{CP,t} \tag{14}$$

[3] The real credit gap equation and the real house price equation differ in the type of interest rate included; the real credit gap equation contains the real lending rate gap, and the real house price equation contains the real interest rate gap. These two differ in terms of the relevant lending premiums (the term premium and the credit premium), i.e. we assume that the real credit gap is affected by both the real risk-free rate gap determined by monetary policy and lending premiums, while house prices are affected predominantly by the real risk-free rate gap (accommodative monetary policy contributes to a higher real house price gap and restrictive monetary policy to a lower real house price gap).

where TS_t is the term structure, TP_t is the term premium and CP_t is the credit risk premium. The introduction of the term structure and term premium is inspired by Benes et al. (2017). Data limitations restrict the possibility to determine the exact average maturity of loans to the private non-financial sector. However, we estimated the average maturity to be between four and six years based on the available data. Therefore, we set the term structure to be an average of five years (twenty quarters) ahead of the short-term policy rate. The term premium is the weighted average of its past value and steady-state value; the credit premium is the weighted average of its past value and the sum of its steady-state value and real non-performing loans gap.

The real lending rate rl_t is defined as the nominal lending rate minus expected CPI inflation at $t+1$. The real lending rate gap is defined as the difference between the real lending rate and its trend (equilibrium) value, which is the weighted average of its lagged value and the sum of the steady-state values of the real lending rate components:

$$rl_t = l_t - \pi_{t+1} \tag{15}$$
$$\bar{rl}_t = \rho_{rl}\bar{rl}_{t-1} + (1-\rho_{rl})(\bar{r}_t + TP_{SS} + CP_{SS}) + \varepsilon_{rl,t} \tag{16}$$
$$\widehat{rl}_t = rl_t - \bar{rl}_t \tag{17}$$

3.3 Feedback Loop between the Non-Financial and Financial Parts of the Economy

We assume a feedback loop between the non-financial and financial parts of the economy through the real non-performing loans gap and the real credit gap:

$$\hat{Y}_t = \alpha_1\hat{Y}_{t-1} - \alpha_2\hat{r}_t + \alpha_2\hat{Q}_t + \alpha_3\hat{Y}^*_t + \alpha_4\hat{C}_t - \alpha_5\widehat{NPL}_t + \varepsilon_{\hat{Y},t} \tag{18}$$

where $\hat{r}_t = r_t - \bar{r}_t$ is the real interest rate gap and $r_t = i_t - \pi_{t+1}$ is the real interest rate, $\hat{Q}_t$ is the real exchange rate gap, $\hat{Y}^*_t$ is the foreign output gap and $\varepsilon_{\hat{Y},t}$ is a demand shock.

3.4 Measurement Variables

When deciding on the measurement variables we closely follow Hlédik and Vlček (2018). Similarly to these authors, our data set includes all key macroeconomic variables (headline inflation and its sub-components, real GDP, the 3M PRIBOR and the nominal CZK/EUR exchange rate and their foreign counterparts). In addition, we include macro-financial variables relevant to the proposed extensions (real loans to the private non-financial sector, real non-performing loans to the private non-financial sector, the real house price index and the real and nominal lending rates). Macro-financial variables are detrended out of the model. For more details on the measurement variables, see Appendix B.

4. Model Parameters

Regarding the original model parameters, we closely follow the calibration proposed by Hlédik and Vlček (2018) (for the actual values, see Appendix C). However, we need to set appropriate values for the newly introduced parameters. To our knowledge, we are among the first to introduce this particular set of macro-financial variables and relationships into the QPM, which limits our ability to rely on previous studies. Moreover, the history of the Czech data is relatively short – it includes a period of convergence and barely covers one whole financial cycle. We therefore rely on a combination of different approaches in our calibration.

We implement a three-step procedure. First, we combine the findings in the empirical literature on the various relationships with a simple correlation analysis using Czech data (see Table C3 in Appendix C). This information provides a basis for initial calibration. Second, we estimate selected parameters using the initial calibration as the starting and mean values of the corresponding prior distribution. Parameters affecting the dynamic properties of the model are estimated together with the standard deviations of newly introduced shocks. Finally, we check the forecasting performance of selected variables and impose expert judgement to reach the final calibration. The final calibration is presented below.

Steady-state parameters (Table 1). The steady-state parameters reflect the historical means and our judgement about the medium-term growth rates and levels of the variables. The steady-state growth of real credit and real house prices is calibrated such that it equals the steady-state growth of real GDP; this reflects the notion that the sustainable growth of real credit and real house prices should not exceed the steady-state growth of real income. Analogously, the steady-state growth of real non-performing loans is calibrated to the steady-state growth of real GDP. We assume that both the term premium and the credit risk premium equal 1% in the steady state; the term structure premium then equals 3% (the 1% natural real interest rate plus the 2% inflation target). In total, the steady-state value of the real lending rate is 3% and that of the nominal lending rate is 5%, which is close to the simple average of the nominal lending rate since 2003 (5.3% between 1Q2003 and 4Q2018).

Table 1: Steady-State Parameters

Parameter	Description	C/E	Value
$\bar{C}_{SS}$	Growth rate of domestic equilibrium real credit	C	3.00
$\bar{H}_{SS}$	Growth rate of domestic equilibrium real house prices	C	3.00
$N\bar{P}L_{SS}$	Growth rate of domestic equilibrium real NPL	C	3.00
$T\bar{P}_{SS}$	Equilibrium term premium	C	1.00
$C\bar{P}_{SS}$	Equilibrium credit premium	C	1.00

Note: C/E refers to calibrated/estimated.

Parameters affecting the dynamic properties of the model (Table 2). The parameters affecting the dynamic properties of the model were estimated to be close to the initial calibration in most cases, with a slight deviation to one side or the other (of no more than 30%; see Table C4 in Appendix C). We impose expert judgement on four estimated parameters. Firstly, the persistence (autoregressive) parameter in the output gap equation is calibrated to be smaller than estimated and assumed in the calibration proposed by Hlédik and Vlček (2018). The reason is at least twofold. First, the Czech economy has undergone some structural changes and modernisation resulting in more flexible product and labour markets (see Hlédik and Vlček, 2018). Second, the macro-financial variables and the feedback loop help to explain some of the persistence in the dynamics and reinforce the relationships between variables and in the transmission processes. Secondly, we increase the values of the interaction parameters between the credit gap and the house price gap (θ_{H3}) and between the credit gap and the NPL gap (θ_{NPL3}) assuming stronger transmission. Finally, we reduce the value of the interaction parameter between the credit gap and the output gap (α_4), assuming that the feedback effect is driven mainly by changes in credit risk (the non-performing loans gap) and to a lesser extent by changes in credit.[4]

[4] Our calibration is broadly in line with the one proposed by our colleagues at the Central Bank of Chile, who are currently working on a similar model for the Chilean economy; they provided us with the preliminary results of their gap model extended to include financial sector variables and the corresponding calibration.

Table 2: Calibrated and Estimated Parameters

Parameter	Description	C/E	Value
Real credit gap equation			
θ_{C1}	Credit gap persistence	E	0.54
θ_{C2}	Impact of output gap	E	0.32
θ_{C3}	Impact of real lending rate gap	E	0.30
θ_{C4}	Impact of house price gap	E	0.40
Real house price gap equation			
θ_{H1}	House price gap persistence	E	0.58
θ_{H2}	Impact of output gap	E	0.38
θ_{H3}	Impact of credit gap	C	0.30
θ_{H4}	Impact of real interest rate gap	E	0.36
Real non-performing loans gap equation			
θ_{NPL1}	NPL gap persistence	E	0.38
θ_{NPL2}	Impact of output gap	E	0.38
θ_{NPL3}	Impact of credit gap	C	0.20
θ_{NPL4}	Impact of real interest rate gap	E	0.25
Real lending rate equation			
ρ_{l}	Lending rate persistence	E	0.95
ρ_{TP}	Term premium persistence	E	0.72
ρ_{CP}	Credit risk premium persistence	E	0.68
θ_{CP}	Impact of NPL gap	E	0.10
IS curve			
α_1	Output gap persistence	C	0.60
α_2	Impact of real interest rate	E	0.25
α_3	Impact of real exchange rate	E	0.44
α_4	Impact of external demand on domestic output	E	0.47
α_5	Impact of credit gap	C	0.10
α_6	Impact of NPL gap	E	0.29
Speed of convergence			
$\rho_{\bar{C}}$	Persistence in domestic equilibrium real credit growth	C	0.70
$\rho_{\bar{H}}$	Persistence in domestic equilibrium real house price growth	C	0.70
$\rho_{N\bar{P}L}$	Persistence in domestic equilibrium real NPL growth	C	0.70
$\rho_{\bar{l}}$	Persistence in domestic real lending rate	C	0.80

Note: C/E refers to calibrated/estimated.

Standard deviation of shocks (Table 3). The stochastic properties of the model are driven by the standard deviations of the shocks. In the calibration of those standard deviations, only the relative size (not the absolute value) matters. We propose an initial calibration following two rules. Firstly, the standard deviations of macro-financial variables are calibrated so that the dynamics of trends are smoother than those of gaps. Secondly, they are calibrated to be higher than the standard deviations of, for example, the aggregate demand shock due to higher volatility, but to be lower than the standard deviations of, for example, food price inflation and fuel price inflation due to lower volatility. The estimated standard deviations are smaller than the initial calibration but broadly in line with the intuition described above (i.e. the standard deviations of shocks to the gap equations remain higher than those of shocks to the trend equations).

Table 3: Standard Deviations of Exogenous Processes

Shock	Description	C/E	St.Dev.
$\varepsilon_{C,t}$	Shock to credit gap	E	1.25
$\varepsilon_{H,t}$	Shock to house price gap	E	1.31
$\varepsilon_{NPL,t}$	Shock to NPL gap	E	1.40
$\varepsilon_{CP,t}$	Shock to credit premium	E	1.34
$\varepsilon_{\bar{C},t}$	Shock to equilibrium credit growth	E	0.73
$\varepsilon_{\bar{H},t}$	Shock to equilibrium house price growth	E	0.71
$\varepsilon_{N\bar{P}L,t}$	Shock to equilibrium NPL growth	E	0.85
$\varepsilon_{rl,t}$	Shock to equilibrium real lending rate	E	0.85

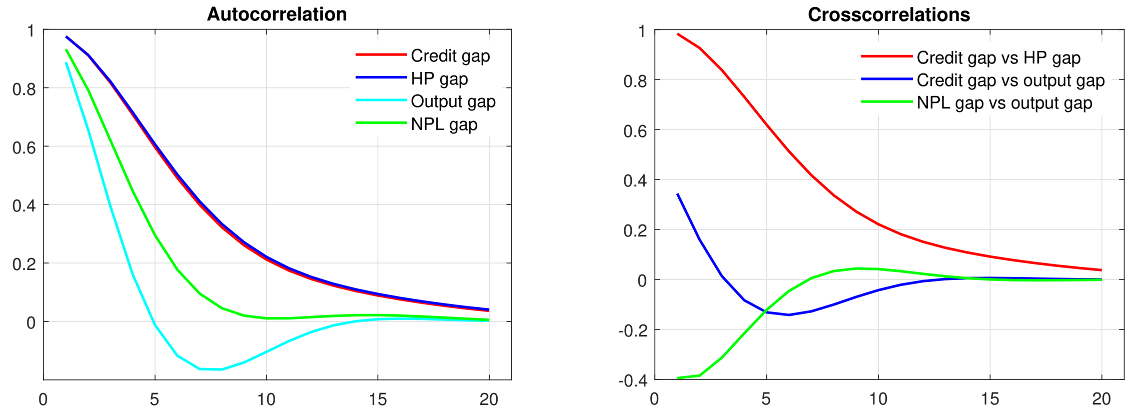
Note: C/E refers to calibrated/estimated.

5. Structural Analysis

5.1 Autocorrelations and Crosscorrelations

In this subsection, we provide autocorrelations and crosscorrelations of selected variables in order to access the second-order properties of our model (Figure 2). As discussed earlier, we aimed to capture some of the properties of the financial cycle, namely the co-movement of credit and house prices and the higher persistence of variables characterising the financial cycle than of variables characterising the business cycle. Firstly, the autocorrelations of the credit gap and the house price gap are much higher than the autocorrelation of the output gap. The autocorrelation functions (ACFs) of the credit gap and the house price gap die out after about five years, while the ACF of the output gap remains positive for only five quarters. This translates to higher persistence of the financial cycle. The ACF of the non-performing loans gap lies between the two, making credit risk a transmission variable/channel between the financial and non-financial parts of the model (see subsection 5.3). Secondly, the crosscorrelation between the credit gap and the house price gap is high, which again ticks our box for the characteristics of the financial cycle. This crosscorrelation is much higher than that between the credit gap and the output gap and between the non-performing loans gap and the output gap. This may eventually lead to dis-synchronisation between the two cycles.

Figure 2: Model-Based Autocorrelations and Crosscorrelations



Note: Estimated using the acf function in IRIS. Order 20 corresponds to 5 years.

5.2 Impulse Response Functions

We explore the dynamic properties of the model in response to three shocks: an aggregate demand shock, a monetary policy shock and a credit risk shock. Each shock is simulated as a positive 1 pp exogenous increase in the relevant gaps (the output gap and the non-performing loans gap) and the short-term nominal interest rate. We compare four model specifications: (i) an extended model with financial variables (the baseline), (ii) an extended model in which the spiral between house prices and credit is switched off, (iii) an extended model in which the feedback loop between financial and real variables is switched off, and (iv) the original model before any extensions. Figure 3 compares the impulse response functions of these specifications and allows us to identify differences in the transmission of each shock.

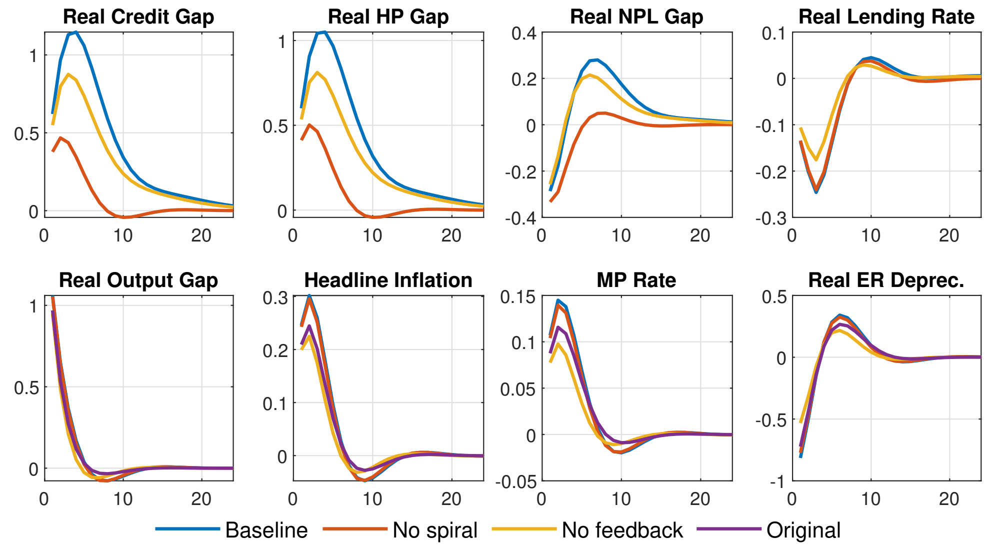
In response to a positive **aggregate demand shock**, i.e. a rise in the output gap (Panel 1), headline inflation, the credit gap and the house price gap increase, while the non-performing loans gap decreases. Both the output gap and the deviation of inflation from the target call for tighter monetary policy, i.e. a hike in the monetary policy rate, which then causes a temporary currency appreciation. The higher short-term interest rate pushes up the lending rate via the term structure premium, while the lower non-performing loans gap pushes down the lending rate via the credit premium. The tighter monetary conditions dampen aggregate demand, and over the medium term output returns to its potential level and inflation goes back to the target rate. With the elimination of excess aggregate demand, the credit gap, the house price gap and the non-performing loans gap close gradually and all variables return to their potential values. The persistence in the response of macro-financial variables is higher, in line with the observed data (showing that the financial cycle is longer than the business cycle). The response of all variables is pronounced in the specification with the feedback effect, implying that monetary policy must react more strongly in order to get inflation back on target and to close the output gap. On the other hand, the spiral between house prices and credit does not affect the monetary policy response, but is a key determinant of the shock transmission between macro-financial variables. With the spiral switched off, the response of the credit gap and the house price gap is two to three times weaker compared to the baseline.

A positive **monetary policy shock**, i.e. a monetary policy tightening (Panel 2), leads to a fall in the output gap, exchange rate appreciation and a fall in headline inflation via the interest rate channel. The negative output gap induces a drop in the credit gap and the house price gap and a rise in the non-performing loans gap. The higher monetary policy rate transmits gradually to a higher lending rate. In order to return to its equilibrium level, the initial exchange rate appreciation is compensated by subsequent depreciation; this creates a stimulus for an increase in net exports, which helps to close the negative output gap and neutralise the disinflationary pressures. Over the short-to-medium term, all the gaps close. Similarly to the previous case, the impact of the shock to macro-financial variables is significantly weaker if the transmission via the spiral between credit and house prices is impaired; it is also less pronounced if the feedback effect is switched off. The reaction of aggregate demand to the monetary policy shock is significantly stronger in the specification with the feedback effect, in line with the empirical literature showing that monetary policy transmission via traditional channels (i.e. the interest rate channel and the exchange rate channel) is reinforced by the credit channel or, in general, by the interaction with the financial sector (for a comprehensive review, see, for example, Adrian and Liang, 2016). Hence, by omitting the transmission channel in the monetary policy decision-making process, the level of the monetary policy rate may not be appropriate to the situation.

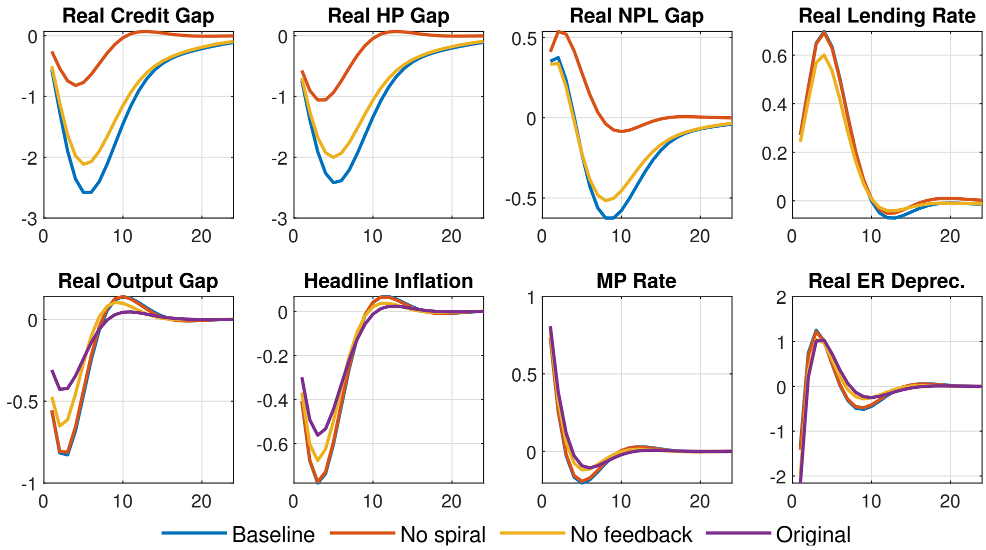
In response to a positive **credit risk shock**, i.e. a rise in the non-performing loans gap (Panel 3), aggregate demand falls, inducing disinflationary pressures and a temporary exchange rate depreciation. In order to bring inflation back to the target, the monetary authority reacts by lowering the monetary policy rate. The higher credit risk premium outweighs the lower monetary policy rate and transmits to a higher lending rate. The negative output gap and higher lending rate lead to a decrease in the credit gap and the house price gap, reinforcing the impact on aggregate demand. The accommodative monetary conditions help to mitigate the disinflationary pressures and to close the negative output gap. The exchange rate completes its cycle by appreciating and returning to the equilibrium level. The impact of the credit risk shock to the credit gap and house price gap is reinforced by the spiral between the two; the existence of the feedback effect is vital for the existence of any transmission at all.

Figure 3: Impulse Response Functions – Alternative Scenarios

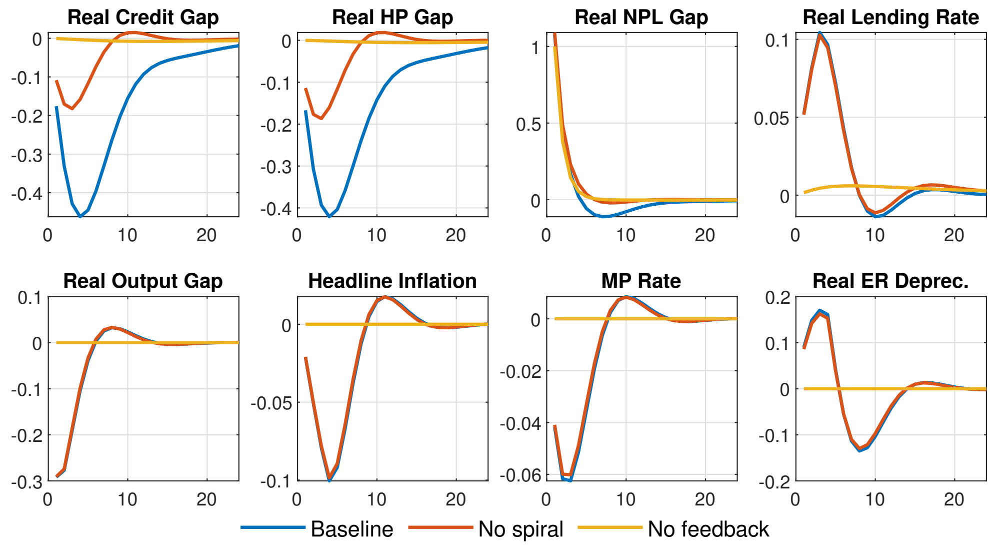
Panel 1: Aggregate Demand Shock



Panel 2: Monetary Policy Shock



Panel 3: Credit Risk Shock



Note: Gaps are in % of trend; the monetary policy (MP) rate and real lending rate are in % pa; inflation and real exchange rate (ER) depreciation are in % quarter-on-quarter annualised changes.

5.3 Historical Decomposition

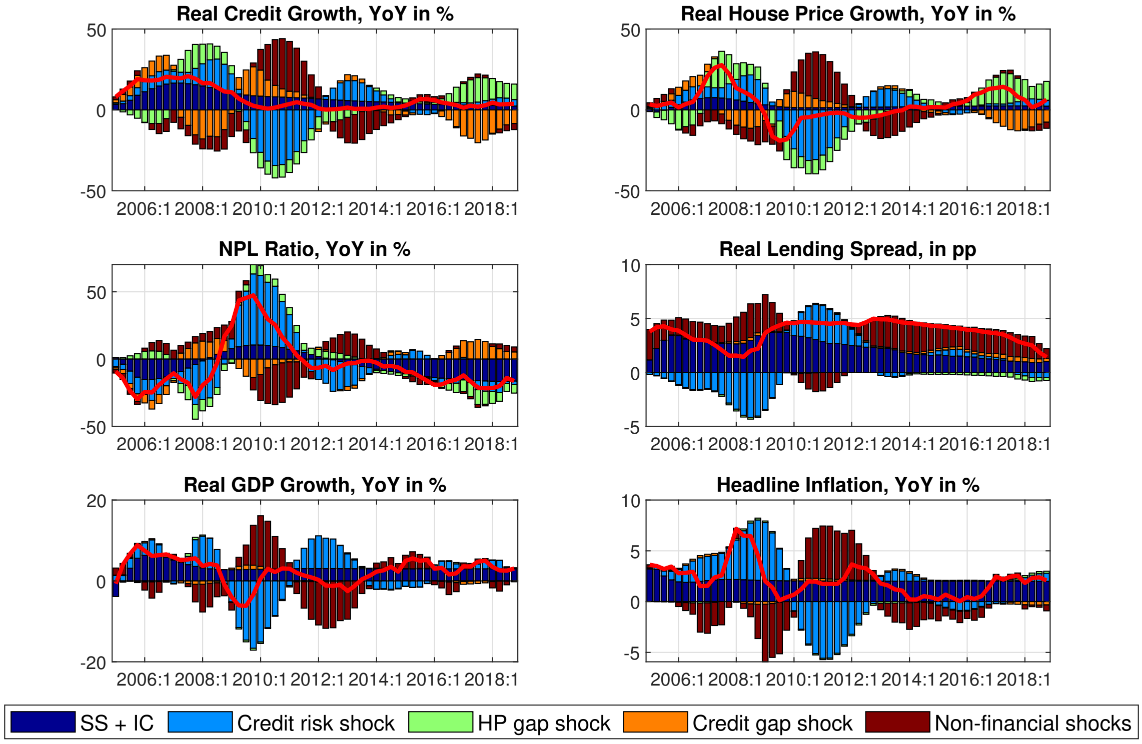
In this subsection, we provide historical decompositions of selected variables; this should help to identify sources of movements. We focus primarily on the newly introduced macro-financial block and the corresponding shocks, while we group together all the non-financial shocks of the original model. For the decomposition, the Kalman filter identifies the structural shocks and initial conditions and the shocks are then used to generate impulse response functions. Due to the model linearity, we can sum these impulse response functions, which allows us to construct the decomposition and to represent each variable as a combination of the shock contributions and its steady state. Figure 4 provides the decompositions of the variables of interest, where the shocks are added up to form groups.[5]

The newly introduced macro-financial shocks help to explain both the pre-crisis boom and the subsequent correction. This is in line with intuition and with the literature discussed in section 2. The pre-crisis growth in real credit and house prices and decrease in non-performing loans was fuelled by a combination of overvalued house prices and undervalued credit risk. The subsequent financial crisis led to a sharp increase in credit risk, which pushed down aggregate demand, credit growth and house price growth and pushed up the lending spread. Credit risk is the primary source of transmission between the financial and non-financial parts of the economy, as it is prone to react faster than credit. In other words, a credit risk shock is more likely to affect aggregate demand than a credit gap shock, because credit cycles are more persistent. Also, no credit crunches, which would drag output down further, were observed in the Czech economy in our historical sample.

In the most recent period, both house price growth and credit growth are pushed up by the overvaluation of house prices (the positive shock to the house price gap) and pushed down by the credit gap shock. This indicates that the recent tightening of macroprudential measures might have weakened the link between house prices and credit and contributed to mitigating excessive credit growth in an environment of high and overvalued house prices.

[5] The decomposition can also be applied to other endogenous variables in the model (not reported, available upon request).

Figure 4: Historical Decomposition



6. Conditional Forecasts

As mentioned in the introduction, the extended model is intended to be used not as a main forecasting model, but rather as a complementary tool in forecasting macro-financial variables. In particular, we have no ambition to compete with the existing official DSGE model of the Czech National Bank (CNB, 2019; Andrle et al., 2009) in forecasting non-financial variables. Therefore, we produce conditional forecasts of the newly introduced macro-financial variables, knowing the paths of the non-financial variables.[6] In our forecasting exercise, we assume that, at the forecasting horizon, the paths of foreign variables and domestic non-financial variables are known (the variables are treated as observed). Firstly, we identify the initial conditions at each point in time in the past using the Kalman filter and impose the conditions. Then we use the model to generate the forecast of financial variables. The model finds the most likely combination of all financial shocks to reproduce a given path for the macro-financial variables. These forecasts are produced iteratively at each point between 1Q2006 and 4Q2018; the forecasting horizon is 8 quarters. The model-based forecasts are then compared with the actual data, and normalised root-mean-square errors (RMSEs) are calculated; the RMSEs are normalised using the maximum-minimum range of the observed variables to facilitate comparison between variables with different scales. The normalised RMSE at forecasting

[6] Specifically, the model will be used to produce forecasts of credit growth, house price growth, the NPL ratio and the lending rate conditional on the forecasts of real and nominal variables produced by the CNB's core DSGE model.

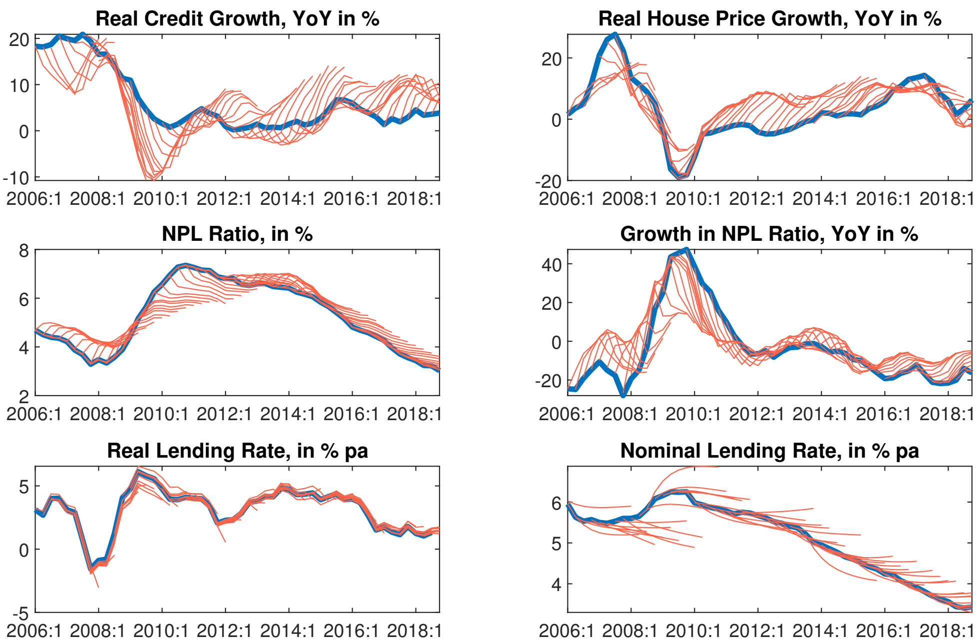
horizon h is calculated as follows:

$$RMSE_h = \sqrt{\frac{\sum_{t=1}^{T}(X_t^{h,forecast} - X_t)^2}{T}} \tag{19}$$

$$NRMSE_h = \frac{RMSE_h}{X_{MAX} - X_{MIN}} \tag{20}$$

A comparison of the model-based forecasts with the actual data is presented in Figure 5. The normalised RMSEs of different model specifications are presented in Table D1 in Appendix D.

Figure 5: Conditional Forecast – Baseline Specification



Note: The NPL ratio, the change in the NPL ratio and the lending spread are not variables defined within the model; the predictions for them are calculated using predictions of the components (NPLs, credit and the lending rate); the risk-free rate (monetary policy rate) used to calculate the lending spread is observed (its path is known).

The in-sample predictions show that the model is capable of correctly anticipating turning points in the financial cycle. Specifically, it was able to capture the reversion in the growth of house prices and credit in 2008 (the peak of the cycle) and in 2009 (the bottom of the cycle). From a simple visual inspection, it is apparent that the model-based predictions capture the dynamics of house prices very well (both the directions and the magnitudes of changes). The model is also capable of predicting well the direction of changes in credit growth, the lending rate and the NPL ratio, while it is less precise in capturing their magnitudes; this is especially true for credit growth.

The normalised RMSE suggests that the model is capable of relatively precise prediction of all the macro-financial variables in the short term. The forecasting performance of house price growth is also very high at longer horizons.[7] The worst relative forecasting performance is achieved for

[7] The normalised RMSE generally increases with longer forecasting horizon. However, in some specifications and for some variables, RMSE is declining with the forecast horizon. This may indicate that the sample is too short to test the model.

credit growth. This is a result of the spiral between credit and house prices. The spiral improves the prediction of house prices but worsens the prediction of credit growth. There may be several reasons for this. Firstly, credit comprises all loans to non-financial corporations, mortgages and consumer loans to households, while in the Czech Republic house prices mainly fuel growth of mortgages and other loans linked to residential property (such as loans for reconstruction and loans provided by building societies). Including the effect of house prices on credit may therefore exaggerate the forecasts for credit, especially in the recent period of extremely high house price growth.[8] Secondly, the less precise forecast of credit growth at the end of the sample may be due to the introduction of tighter macroprudential measures.[9] This might contribute to weakening the link between house price growth and credit growth. Both these issues may potentially be resolved by extending the model even further; it is our intention to do in future research work. Finally, we cannot forget the convergence issues of the Czech Republic. The model steady-state values are calibrated so as to provide the best possible estimate of the current equilibrium values, while the conditional in-sample predictions are made for the period of the last 12 years. The higher credit growth at the beginning of our sample suggests that the economy was undergoing convergence.

7. Conclusions

This paper outlines a flexible and consistent model-based framework suitable for forecasting selected macro-financial variables of the Czech economy and conducting policy analysis to support the decision-making process. We enhance an existing semi-structural model of the Czech economy by incorporating the following key features:

- four new macro-financial variables: real credit to the non-financial sector, real house prices, real non-performing loans (a proxy for credit risk) and the bank lending rate,
- a spiral between house prices and credit,
- a feedback loop between the real and financial parts of the economy via credit and credit risk,
- a credit risk premium, a term premium and a term structure premium as components of the bank lending rate,
- an impact of monetary policy on the financial sector via credit, house prices and credit risk.

Model simulations show that the response of both non-financial and financial variables to shocks is pronounced in the specification with the feedback loop and/or with the spiral between credit and house prices; this implies that monetary policy must react more strongly in order to get inflation back on target and to close the output gap. Moreover, historical decomposition shows that the newly introduced macro-financial variables help to explain both the pre-crisis boom and the following correction. Conditional forecasts then illustrate that the model is capable of correctly anticipating turning points in the financial cycle given information about the real economy and prices.

[8] There is some recent evidence that higher house price growth may also contribute to higher growth of consumer loans, but this seems to be a phenomenon observed in the Czech data only recently (see, for example, Malovaná, 2018). The share of housing loans in total credit provided to the domestic private non-financial sector was 42% as of 4Q2018; the share of all loans to households was 52%.

[9] Since 2014, the Czech National Bank's recommended limits for selected macroprudential tools have related mainly to the loan-to-value (LTV), debt-to-income (DTI) and debt service-to-income (DSTI) ratios (for more information, see the CNB's website).

References

ADRIAN, T. AND N. LIANG (2016): "Monetary Policy, Financial Conditions, and Financial Stability." Staff Report No. 690, Federal Reserve Bank of New York.

ANDRLE, M., T. HLÉDIK, O. KAMENÍK, AND J. VLČEK (2009): "Implementing the New Structural Model of the Czech National Bank." CNB Working Papers 2/2009, Czech National Bank.

ANGELINI, P., S. NERI, AND F. PANETTA (2014): "The Interaction Between Capital Requirements and Monetary Policy." *Journal of Money, Credit and Banking,* 46(6):1073–1112.

ANGELONI, I. AND E. FAIA (2013): "Capital Regulation and Monetary Policy with Fragile Banks." *Journal of Monetary Economics,* 60(3):311–324.

BENES, J., K. CLINTON, A. GEORGE, P. GUPTA, J. JOHN, O. KAMENIK, D. LAXTON, P. MITRA, G. NADHANAEL, R. PORTILLO, H. WANG, AND F. ZHANG (2017): "Quarterly Projection Model for India: Key Elements and Properties." IMF Working Paper WP/17/33, International Monetary Fund.

BENEŠ, J., D. VÁVRA, AND J. VLČEK (2002): "Střednědobá makroekonomická predikce: Makroekonomické modely v analytickém systému ČNB (available only in Czech)." *Finance a úvěr,* (4):197–231.

BOISSAY, F., F. COLLARD, AND F. SMETS (2016): "Booms and Banking Crises." *Journal of Political Economy,* 124(2):489–538.

BRUHA, J. AND J. TONNER (2014): "The Czech Housing Market Through the Lens of a DSGE Model Containing Collateral-Constrained Households." CNB Working Papers 9/2014, Czech National Bank.

CALZA, A., C. GARTNER, AND J. SOUSA (2003): "Modelling the Demand for Loans to the Private Sector in the Euro Area." *Applied Economics,* 35(1):107–117.

CAPPIELLO, L., A. KADAREJA, C. KOK, AND M. PROTOPAPA (2010): "Do Bank Loans and Credit Standards Have an Effect on Output? A Panel Approach for the Euro Area." ECB Working Paper No. 1150, European Central Bank.

CHEN, M. J. AND M. F. COLUMBA (2016): "Macroprudential and Monetary Policy Interactions in a DSGE Model for Sweden." IMF Working Paper WP/16/74, International Monetary Fund.

CNB (2019): "The CNB's Projection Model gets a New Plus." cnBlog, 25.7.2019, Czech National Bank.

CNB (2018): "Financial Stability Report 2017/2018." Czech National Bank.

CNB (2019): "Financial Stability Report 2018/2019." Czech National Bank.

DREHMANN, M., C. E. BORIO, AND K. TSATSARONIS (2012): "Characterising the Financial Cycle: Don't Lose Sight of the Medium Term!" BIS Working Papers 380, Bank for International Settlements.

ÉGERT, B. AND D. MIHALJEK (2007): "Determinants of House Prices in Central and Eastern Europe." *Comparative Economic Studies,* 49(3):367–388.

GERALI, A., S. NERI, L. SESSA, AND F. M. SIGNORETTI (2010): "Credit and Banking in a DSGE Model of the Euro Area." *Journal of Money, Credit and Banking,* 42:107–141.

GERTLER, M. AND N. KIYOTAKI (2010): *Financial Intermediation and Credit Policy in Business Cycle Analysis.* In Friedman, B. M. and M. Woodford, editors, *Handbook of Monetary Economics,* chapter 11, pages 547–599. Elsevier.

GERTLER, M., N. KIYOTAKI, AND A. PRESTIPINO (2016): "Wholesale Banking and Bank Runs in Macroeconomic Modeling of Financial Crises." NBER Working Paper 21892, National Bureau of Economic Research.

GUO, K. AND V. STEPANYAN (2011): "Determinants of Bank Credit in Emerging Market Economies." IMF Working Paper WP/11/51, International Monetary Fund.

HLAVÁČEK, M., O. NOVOTNÝ, AND M. RUSNÁK (2016): "Analýza cen komerčních nemovitostí v zemích střední Evropy [Analysis of the Commercial Property Prices in the Central European Countries]." *Politická ekonomie,* 2016(1):3–18.

HLÉDIK, T. AND J. VLČEK (2018): "Quantifying the Natural Rate of Interest in a Small Open Economy – The Czech Case." CNB Working Papers 7/2018, Czech National Bank.

JUSELIUS, M., C. BORIO, P. DISYATAT, AND M. DREHMANNB (2017): "Monetary Policy, the Financial Cycle, and Ultra-Low Interest Rates." *International Journal of Central Banking,* 13(3).

LAUBACH, T. AND J. C. WILLIAMS (2003): "Measuring the Natural Rate of Interest." *Review of Economics and Statistics,* 85(4):1063–1070.

MALOVANÁ, S. (2018): "The Pro-Cyclicality of Risk Weights for Credit Exposures in the Czech Republic." CNB Working Papers 12/2018, Czech National Bank.

NEGRO, M. D., M. P. GIANNONI, AND F. SCHORFHEIDE (2015): "Inflation in the Great Recession and New Keynesian Models." *American Economic Journal: Macroeconomics,* 7(1): 168–196.

PETKOVSKI, M., J. KJOSEVSKI, AND K. JOVANOVSKI (2018): "Empirical Panel Analysis of Non-Performing Loans in the Czech Republic. What are their Determinants and How Strong is Their Impact on the Real Economy?" *Finance a Uver: Czech Journal of Economics & Finance,* 68(5).

PLAŠIL, M., ŠTĚPÁN RADKOVSKÝ, AND P. ŘEŽÁBEK (2013): "Modeling Bank Loans to Non-Financial Corporations." Chapter in Financial Stability Report 2012/2013, Czech National Bank.

RADIVOJEVIC, N. AND J. JOVOVIC (2017): "Examining of Determinants of Non-Performing Loans." *Prague Economic Papers,* 2017(3):300–316.

RAVNIK, R., N. BOKAN, ET AL. (2018): "Quarterly Projection Model for Croatia." Surveys S-34, The Croatian National Bank

SCHÜLER, Y. S., P. HIEBERT, AND T. A. PELTONEN (2015): "Characterising the Financial Cycle: A Multivariate and Time-Varying Approach." ECB Working Paper No. 1846, European Central Bank.

STREMMEL, H. (2015): "Capturing the Financial Cycle in Europe." ECB Working paper No. 1811, European Central Bank.

TOVAR, C. E. (2008): "DSGE Models and Central Banks." BIS Working Papers 258, Bank for International Settlements.

TRICHET, J. C. (2010): "Reflections on the Nature of Monetary Policy Non-standard Measures and Finance Theory." Speech given on the occasion of the ECB Central Banking Conference, Frankfurt, 18 November, European Central Bank.

TSATSARONIS, K. AND H. ZHU (2004): "What Drives Housing Price Dynamics: Cross-Country Evidence." *BIS Quarterly Review, March 2004.*

Appendix A: Semi-Structural Model of the Czech Economy

The original model is based on Hlédik and Vlček (2018). For consistency purposes, gap variables are indicated by a hat ($\hat{X}$), trend variables by a bar ($\bar{X}$), variables for the foreign or world economy by a star (X^*) and steady-state variables by the shortcut (X_{SS}). We use the Greek letters ρ for all persistence parameters and ε for all shocks. If not indicated otherwise, growth rates are calculated as annualised quarter-on-quarter changes and the variables are assumed to be in natural logarithm times 100 (except for interest rates):

$$\Delta X_t = 4(X_t - X_{t-1}) \tag{A1}$$

where $X_t = 100(log(x_t))$.

A.1 The Domestic Block

The real economy is represented by an IS curve, which is modified to include the feedback loop (see equation 18 in Section 3). The price block consists of the following four Phillips curves for core inflation $\pi_{C,t}$, food price inflation $\pi_{F,t}$, fuel price inflation $\pi_{Fu,t}$ and administered price inflation $\pi_{A,t}$:

$$\pi_{C,t} = \beta_{C1}\pi_{C,t-1} + (1-\beta_{C1})\pi_{C,t+1} + \beta_{C2}\left[\beta_{C3}\hat{Y}_{t-1} + (1-\beta_{C3})\hat{Q}_{C,t}\right] + \varepsilon_{C,t} \tag{A2}$$
$$\pi_{F,t} = \beta_{F1}\pi_{F,t-1} + (1-\beta_{F1})\pi_{F,t+1} + \beta_{F2}\left[\beta_{F3}\hat{Y}_{t-1} + (1-\beta_{F3})\hat{Q}_{F,t}\right] + \varepsilon_{F,t} \tag{A3}$$
$$\pi_{Fu,t} = \beta_{Fu1}\pi_{Fu,t-1} + (1-\beta_{Fu1})\pi_{Fu,t+1} + \beta_{Fu2}\left[\beta_{Fu3}\hat{Y}_{t-1} + (1-\beta_{Fu3})\hat{Q}_{Fu,t}\right] + \varepsilon_{Fu,t} \tag{A4}$$
$$\pi_{A,t} = \beta_{A1}\pi_{A,t-1} + (1-\beta_{A1})\pi_{A,t+1} + \beta_{A2}\left[\beta_{A3}\hat{Y}_{t-1} + (1-\beta_{A3})\hat{Q}_{A,t}\right] + \varepsilon_{A,t} \tag{A5}$$

where $\left[\beta_{X3}\hat{Y}_{t-1} + (1-\beta_{X3})\hat{Q}_{X,t}\right]$ are real marginal costs and $\hat{Q}_{X,t}$ are relative price gaps. The four relative price gaps are defined as follows:

$$\hat{Q}_{C,t} = e_t + P_t^* - P_{C,t} - \bar{Q}_{C,t} \tag{A6}$$
$$\hat{Q}_{F,t} = e_t + P_{F,t}^* - e_t^* - P_{F,t} - \bar{Q}_{F,t} \tag{A7}$$
$$\hat{Q}_{Fu,t} = e_t + P_{Fu,t}^* - e_t^* - P_{Fu,t} - \bar{Q}_{Fu,t} \tag{A8}$$
$$\hat{Q}_{A,t} = e_t + P_t^* - P_{A,t} - \bar{Q}_{A,t} \tag{A9}$$

where e_t is the domestic nominal exchange rate (CZK/EUR); e_t^* is the foreign nominal exchange rate (USD/EUR); $P_{C,t}$, $P_{F,t}$, $P_{Fu,t}$ and $P_{A,t}$ are, respectively, the core price index, the food price index, the fuel price index and the administered (regulated) price index; P_t^* is the foreign headline consumer price index; and $P_{F,t}^*$ is the world food price index and $P_{Fu,t}^*$ is the world fuel price index. $\bar{Q}_{X,t}$ are the equilibrium relative price indexes (trends in relative prices). Relative prices $Q_{X,t}$ are the sum of the relative price gaps and trends $Q_{X,t} = \hat{Q}_{X,t} + \bar{Q}_{X,t}$.

The domestic headline consumer price index P_t is a weighted sum of its price sub-components, and headline inflation π_t is an annualised quarter-on-quarter growth rate:

$$P_t = \omega_C P_{C,t} + \omega_F P_{F,t} + \omega_{Fu} P_{Fu,t} + \omega_A P_{A,t} \tag{A10}$$
$$\pi_t = 4(P_t - P_{t-1}) \tag{A11}$$

where $\omega_A = (1 - \omega_C - \omega_F - \omega_{Fu})$.

The nominal exchange rate of the koruna against the euro is determined by the staggered version of the uncovered interest rate parity (UIP) condition:

$$e_t = \rho_e\left[e_{t-1} + \frac{2}{4}(\pi^T - \pi^*_{NET,SS} + \Delta Q_{SS})\right] + (1-\rho_e)e_{t+1} - \frac{1}{4}(i_t - i^*_t) + \varepsilon_{e,t} \quad \text{(A12)}$$

where π^T is the 2% inflation target (in terms of the year-on-year growth rate of headline CPI), i_t is the domestic nominal interest rate and i^*_t is the foreign nominal interest rate. the UIP contains a backward-looking element $\rho_e\left[e_{t-1} + \frac{2}{4}(\pi^T - \pi^*_{NET,SS} + \Delta Q_{SS})\right]$ with the term $(\pi^T - \pi^*_{NET,SS} + \Delta Q_{SS})$ ensuring the right steady-state dynamics; if $\rho_e = 0$, the UIP becomes fully forward looking.[10] Net foreign steady-state inflation and growth in the trend value of the relative price are constructed as weighted sums based on the weights for the headline consumer price index:

$$\pi^*_{NET,SS} = \omega_{Fu}\pi^*_{Fu,SS} + \omega_F\pi^*_{F,SS} + \omega_C\pi^*_{SS} + \omega_A\pi^*_{SS} \quad \text{(A13)}$$

$$\Delta Q_{SS} = \omega_A\Delta Q_{A,SS} + \omega_{Fu}\Delta Q_{Fu,SS} + \omega_F\Delta Q_{F,SS} + \omega_C\Delta Q_{C,SS} \quad \text{(A14)}$$

The real exchange rate Q_t and its gap $\hat{Q}_t$ are calculated as follows:[11]

$$Q_t = e_t + P^*_{NET,t} - P_t \quad \text{(A15)}$$

$$\hat{Q}_t = Q_t - \bar{Q}_t \quad \text{(A16)}$$

The real exchange rate trend is based on the relative price trends:

$$\bar{Q}_t = \omega_C\bar{Q}_{C,t} + \omega_F\bar{Q}_{F,t} + \omega_{Fu}\bar{Q}_{Fu,t} + \omega_A\bar{Q}_{A,t} \quad \text{(A17)}$$

The short-term nominal policy rate follows a forward-looking, inflation forecast-based interest rate rule:

$$i_t = \rho_i i_{t-1} + (1-\rho_i)\left[\bar{i}_t + \phi_\pi(\pi_{yoy,t+4} - \pi^T) + \phi_{\hat{Y}}\hat{Y}_t\right] + \varepsilon_{i,t} \quad \text{(A18)}$$

where $\bar{i}_t$ is the natural (policy-neutral) interest rate and $\pi_{yoy,t} = CPI_t - CPI_{t-4}$. The nominal and real policy-neutral interest rates are defined as follows:

$$\bar{i}_t = \bar{r}_t + \pi_{yoy,t+4} \quad \text{(A19)}$$

$$\bar{r}_t = \rho_{\bar{r}}\bar{r}_{t-1} + (1-\rho_{\bar{r}})(\Delta\bar{Y}_{yoy,t} + \Delta\bar{Q}_{yoy,t}) + \varepsilon_{\bar{r},t} \quad \text{(A20)}$$

where $\Delta\bar{Y}_{yoy,t} = \bar{Y}_t - \bar{Y}_{t-4}$ is the year-on-year real GDP trend growth and $\Delta\bar{Q}_{yoy,t} = \bar{Q}_t - \bar{Q}_{t-4}$ is the year-on-year real exchange rate trend depreciation; $\bar{Y}_t$ is the real GDP trend and $\bar{Q}_t$ is the real exchange rate trend.

The unobserved equilibrium values X for non-stationary variables $X \in \{\bar{Q}_{C,t}, \bar{Q}_{F,t}, \bar{Q}_{Fu,t}, \bar{Q}_{A,t}, \bar{Y}_t\}$ are modelled as an AR(1) process:

$$\Delta\bar{X}_t = \rho^{\Delta\bar{X}} \cdot \Delta\bar{X}_{t-1} + (1-\rho^X) \cdot \Delta X^{SS} + \varepsilon^X_t \quad \text{(A21)}$$

[10] The shock is modelled as an AR(1) process in order to ensure its persistence: $\varepsilon_{e,t} = 0.65 * \varepsilon_{e,t-1} + \varepsilon_{e2,t}$.

[11] Alternatively, the real exchange rate may be calculated using the domestic net CPI: $Q_{NET,t} = e_t + CPI^*_{NET,t} - CPI_{NET,t}; \hat{Q}_{NET,t} = Q_{NET,t} - \bar{Q}_{NET,t}$, where the net consumer price index is calculated as follows: $CPI_{NET,t} = \frac{CPI_t - \omega_A CPI_{A,t}}{1-\omega_A}$.

A.2 The Foreign Block

The foreign output gap follows an AR(1) process:

$$\hat{Y}_t^* = \rho_{\hat{Y}}^* \hat{Y}_{t-1}^* + \varepsilon_{\hat{Y},t}^* \tag{A22}$$

The foreign net consumer price index is constructed based on the Czech weights:

$$P_{NET,t}^* = \omega_C P_t^* + \omega_F (P_{F,t}^* - e_t^*) + \omega_{Fu} (P_{Fu,t}^* - e_t^*) + \omega_A P_t^* \tag{A23}$$

World fuel and food price inflation are defined as follows:

$$\pi_{Fu,t}^* = \rho_{Fu}^* \pi_{Fu,t-1}^* + (1 - \rho_{Fu}^*) \pi_{Fu,SS}^* + \varepsilon_{Fu,t}^* \tag{A24}$$

$$\pi_{F,t}^* = \rho_F^* \pi_{F,t-1}^* + (1 - \rho_F^*) \pi_{F,SS}^* + \varepsilon_{F,t}^* \tag{A25}$$

where $\pi_{Fu,t}^* = 4(P_{Fu,t}^* - P_{FU,t-1}^*)$ and $\pi_{F,t}^* = 4 * (P_{F,t}^* - P_{F,t-1}^*)$.

The foreign headline consumer price index and inflation are defined as follows:

$$CPI_t^* = CPI_{t-1}^* + \frac{1}{4} \pi_t^* \tag{A26}$$

$$\pi_t^* = \rho_\pi^* \pi_{t-1}^* + (1 - \rho_\pi^*) \pi_{SS}^* + \varepsilon_{\pi,t}^* \tag{A27}$$

The foreign nominal interest rate is defined as follows:

$$i_t^* = \rho_i^* i_{t-1}^* + (1 - \rho_i^*)(\bar{r}_t^* + \pi_{NET,t}^*) + \varepsilon_{i,t}^* \tag{A28}$$

where $\bar{r}_t^*$ is the foreign real natural (policy-neutral) interest rate and $\pi_{NET,t}^* = 4(CPI_{NET,t}^* - CPI_{NET,t-1}^*)$.

The foreign real policy-neutral interest rate and the real interest rate gap are defined as follows:

$$\bar{r}_t^* = \rho_{\bar{r}}^* \bar{r}_{t-1}^* + (1 - \rho_{\bar{r}}^*) r_{SS}^* + \varepsilon_{\bar{r},t}^* \tag{A29}$$

$$\hat{r}_t^* = r_t^* - \bar{r}_t^* \tag{A30}$$

where $r_t^* = i_t^* - \pi_{NET,t}^*$ is the real interest rate.

Foreign nominal exchange rate depreciation (USD/EUR) is defined as follows:

$$\Delta e_t^* = \rho_e^* \Delta e_{t-1}^* + \varepsilon_{e,t}^* \tag{A31}$$

$$\Delta e_t^* = 4(e_t^* - e_{t-1}^*) \tag{A32}$$

Appendix B: Data Sources and Definitions

All the measurement equations are identities with appropriate state variables. Tables B1 and B2 present the data and their transformation as measurement variables in the Kalman filtration.

Table B1: Measurement Variables – Original Model

Name	Description
Y_t	Czech gross domestic product, constant prices, non-seasonally adjusted, source: Czech Statistical Office; transformation: seasonally adjusted (X13), log-transformed (taking natural log of variable) and multiplied by 100
P_t	Czech non-seasonally adjusted consumer price index, source: Czech Statistical Office; transformation: seasonally adjusted (X13), log-transformed and multiplied by 100
$P_{C,t}$	Czech CPI sub-index used for calculation of core inflation index, source: CNB calculation, transformation: seasonally adjusted (X13), log-transformed and multiplied by 100
$P_{F,t}$	Food price sub-index of Czech CPI, source: CNB calculation; transformation: seasonally adjusted (X13), log-transformed and multiplied by 100
$P_{Fu,t}$	Fuel price sub-index of Czech CPI, source: CNB calculation; transformation: seasonally adjusted (X13), log-transformed and multiplied by 100
$P_{A,t}$	Czech CPI sub-index measuring administered prices, source: CNB calculation; transformation: seasonally adjusted (X13), log-transformed and multiplied by 100
π_t^T	CNB's y-o-y inflation target, source: Czech National Bank
e_t	Nominal exchange rate of Czech koruna against euro, source: Czech National Bank, transformation: log-transformed and multiplied by 100
i_t	3M Pribor, source: Czech National Bank (online ARAD database)
$\bar{Y}_t$	Output trend, estimation: Hodrick-Prescott filter with lambda 1,600
Q_t	Domestic real exchange rate calculated as difference between nominal exchange rate of Czech koruna against euro and Czech CPI plus foreign net CPI; transformation: seasonally adjusted (X13), log-transformed and multiplied by 100; estimation: Hodrick-Prescott filter with lambda 1,600
$\bar{r}_t$	Domestic real interest rate trend; domestic real interest rate is calculated as difference between 3M Pribor and Czech CPI inflation; estimation: Hodrick-Prescott filter with lambda 1,600
Y_t^*	Euro area gross domestic product, constant prices, non-seasonally adjusted, source: Eurostat; transformation: seasonally adjusted (X13), log-transformed (taking natural log of variable) and multiplied by 100
P_t^*	Euro area HICP, non-seasonally adjusted, source: Eurostat; transformation: seasonally adjusted (X13), log-transformed (taking natural log of variable) and multiplied by 100
$P_{NET,t}^*$	Euro area HICP excluding administered prices; non-seasonally adjusted, source: Eurostat; transformation: seasonally adjusted (X13), log-transformed (taking natural log of variable) and multiplied by 100
$P_{F,t}^*$	World food and beverage price index, source: IMF commodity database, seasonally adjusted (X13), transformation: log-transformed and multiplied by 100
$P_{Fu,t}^*$	Global price of Brent crude oil in USD, transformation: log-transformed and multiplied by 100
e_t^*	Nominal exchange rate of euro against US dollar, source: Eurostat, transformation: log-transformed and multiplied by 100
i_t^*	3M Euribor, source: European Central Bank
$\bar{r}_t^*$	Foreign real interest rate trend; foreign real interest rate is calculated as difference between 3M Euribor and foreign net inflation; estimation: Hodrick-Prescott filter with lambda 1,600
$\hat{Q}_{Fu,t}$	Gap in price of energy relative to headline CPI, price of energy relative to headline CPI is calculated as sum of difference between domestic and foreign nominal exchange rate and difference between domestic and foreign fuel price index, log-transformed (taking natural log of variable) and multiplied by 100, estimation: Hodrick-Prescott filter with lambda 1,600

Table B2: Measurement Variables – Extended Model

Name	Description
C_t	Czech real credit to private non-financial sector, non-seasonally adjusted, source: Czech National Bank (online ARAD database); transformation: seasonally adjusted (X13), deflated by CPI, log-transformed (taking natural log of variable) and multiplied by 100
H_t	Czech real house price index, non-seasonally adjusted, source: Czech Statistical Office; transformation: seasonally adjusted (X13), deflated by CPI, log-transformed (taking natural log of variable) and multiplied by 100
NPL_t	Czech real non-performing loans to private non-financial sector, non-seasonally adjusted, source: Czech National Bank (online ARAD database); transformation: seasonally adjusted (X13), deflated by CPI, log-transformed (taking natural log of variable) and multiplied by 100
l_t	Czech nominal lending rate to private non-financial sector, source: Czech National Bank (online ARAD database)
rl_t	Czech real lending rate to private non-financial sector, deflated by CPI, source: Czech National Bank (online ARAD database)
$\bar{C}_t$	Real credit trend, estimation: Hodrick-Prescott filter with lambda 26,000
$\bar{H}_t$	Real house price trend, estimation: Hodrick-Prescott filter with lambda 26,000
$N\bar{P}L_t$	Real NPL trend, estimation: Hodrick-Prescott filter with lambda 1,600
$\bar{rl}_t$	Real lending rate trend, estimation: Hodrick-Prescott filter with lambda 1,600

Appendix C: Parameters

Table C1: Parameter Calibration of the Original Model (1)

Parameter	Description	Value
IS curve		
α_1	Output gap persistence	0.60
α_2	Impact of real interest rate gap	0.275
α_3	Impact of real exchange rate gap	0.275
α_4	Impact of external demand on domestic output	0.50
Phillips curves		
Core price inflation		
β_{C1}	Core price inflation persistence	0.50
β_{C2}	Pass-through (impact of world prices, exchange rate and output gap on domestic food prices)	0.10
β_{C3}	Ratio of imported goods in firms' marginal costs	0.75
Food price inflation		
β_{F1}	Food price inflation persistence	0.50
β_{F2}	Pass-through	0.10
β_{F3}	Impact of world food prices, exchange rate and output gap on domestic food prices	0.30
Administered price inflation		
β_{A1}	Administered price inflation persistence	0.50
β_{A2}	Pass-through	0.30
β_{A3}	Impact of world prices, exchange rate and output gap on domestic food prices	0.30
Fuel price inflation		
β_{Fu1}	Fuel price inflation persistence	0.50
β_{Fu2}	Pass-through	0.20
β_{Fu3}	Impact of world fuel prices, exchange rate and output gap on domestic fuel prices	0.60
Domestic headline consumer price index		
ω_F	Weight of food prices in CPI basket	0.24
ω_{Fu}	Weight of fuel prices in CPI basket	0.03
ω_A	Weight of administered prices in CPI basket	0.19
Uncovered interest rate parity		
ρ_e	Persistence of nominal exchange rate	0.40
Monetary policy reaction function (forward-looking Taylor rule)		
ρ_i	Persistence of nominal interest rate (policy persistence)	0.70
ϕ_π	Weight put on inflation by policy maker (policy reactiveness)	0.20
$\phi_{\hat{Y}}$	Weight put on output gap by policy maker (policy reactiveness)	0.10
Foreign block		
$\rho^*_{\hat{Y}}$	Persistence in foreign output gap	0.80
ρ^*_i	Persistence in foreign nominal interest rate	0.80
ρ^*_r	Persistence in foreign real interest rate	0.50
ρ^*_π	Persistence in foreign headline inflation	0.80
ρ^*_e	Persistence in cross exchange rate and world food and oil prices	0.50
ρ^*_{Fu}	Persistence in world fuel inflation	0.50
ρ^*_F	Persistence in world food inflation	0.50

Source: Hlédik and Vlček (2018)

Table C2: Parameter Calibration of the Original Model (2)

Parameter	Description	Value
Speed of convergence of remaining variables to their trend (steady-state) values		
$\rho^{\Delta\bar{Q}C}$	Persistence in eq. relative prices (core indices)	0.75
$\rho^{\Delta\bar{Q}F}$	Persistence in eq. relative prices (food prices)	0.75
$\rho^{\Delta\bar{Q}Fu}$	Persistence in eq. relative prices (energy prices)	0.75
$\rho^{\Delta\bar{Q}A}$	Persistence in eq. relative prices (administrative prices)	0.75
$\rho^{\Delta\bar{Y}}$	Persistence in domestic potential GDP growth	0.80
$\rho^{\bar{r}}$	Persistence in domestic short-term real interest rate	0.80
Inflation target and other observed economic trends (steady states)		
$\Delta\bar{Y}_{SS}$	Potential output growth	3.00
$\Delta\bar{Q}_{C,SS}$	Trend change in relative core prices	-1.50
$\Delta\bar{Q}_{F,SS}$	Trend change in relative food prices	-2.00
$\Delta\bar{Q}_{Fu,SS}$	Trend change in relative fuel prices	-1.50
$\Delta\bar{Q}_{A,SS}$	Trend change in relative administrative prices	-4.50
π^T	Domestic inflation target	2.00
r^*_{SS}	Trend level of foreign real interest rate	1.50
π^*_{SS}	Trend change in foreign CPI inflation rate	2.00
$\pi^*_{Fu,SS}$	Trend change in world fuel inflation rate	5.00
$\pi^*_{F,SS}$	Trend change in world food inflation rate	2.00

Shock	Description	St.Dev.
$\varepsilon_{\hat{Y},t}$	Aggregate demand shock	1.00
$\varepsilon_{C,t}$	Shock to core inflation	1.00
$\varepsilon_{Fu,t}$	Shock to fuel price inflation	7.00
$\varepsilon_{F,t}$	Shock to food price inflation	3.00
$\varepsilon_{A,t}$	Shock to administered price inflation	15.00
$\varepsilon_{e,t}$	Shock to nominal exchange rate	1.00
$\varepsilon_{i,t}$	Shock to nominal interest rate (monetary policy shock)	10.00
$\varepsilon_{\bar{r},t}$	Shock to real interest rate trend	0.50
$\varepsilon_{\bar{Y},t}$	Shock to potential output growth	0.60
$\varepsilon_{\hat{Y}^*,t}$	Shock to foreign output gap	1.00
$\varepsilon_{\pi^*,t}$	Shock to foreign CPI inflation	2.00
$\varepsilon_{i^*,t}$	Shock to foreign nominal interest rate	1.00
$\varepsilon_{QC,t}$	Shock to core inflation relative to headline inflation	1.75
$\varepsilon_{QF,t}$	Shock to food price inflation relative to headline inflation	2.00
$\varepsilon_{QFu,t}$	Shock to fuel price inflation relative to headline inflation	3.50
$\varepsilon_{QA,t}$	Shock to regulated price inflation relative to headline inflation	3.00

Source: Hlédik and Vlček (2018)

Table C3: Correlation Matrices, Gaps in % of Trends

	$\hat{Y}_t$	$\hat{C}_t$	$\hat{H}_t$	$\widehat{NPL}_t$	$\hat{rl}_t$	$\hat{r}_t$
$\hat{Y}_t$	1					
$\hat{C}_t$	0.51***	1				
$\hat{H}_t$	0.66***	0.74***	1			
$\widehat{NPL}_t$	-0.69***	-0.46***	-0.70***	1		
$\hat{rl}_t$	-0.49***	-0.05	-0.41***	0.37***	1	
$\hat{r}_t$	-0.27**	0.13	-0.17	0.17	0.92***	1

Note: Gaps in % of trends. All variables are in real terms

C.1 Model-Based Parameter Estimation

1,000,000 draws from the posterior distribution using an adaptive version of the random-walk Metropolis algorithm; 20% burn-in period; final acceptance ratio 0.224.

Table C4: Model-Based Parameter Estimation Results

Parameter	Description	Prior			Posterior	
		Distr.	Mean	St.Dev.	Mean	90% interval
Real credit gap equation						
θ_{C1}	Credit gap persistence	Beta	0.60	0.1	0.54	0.49 / 0.60
θ_{C2}	Impact of output gap	Gamma	0.35	0.1	0.32	0.30 / 0.34
θ_{C3}	Impact of real lending rate gap	Gamma	0.30	0.1	0.30	0.28 / 0.32
θ_{C4}	Impact of house price gap	Gamma	0.50	0.1	0.40	0.39 / 0.40
Real house price gap equation						
θ_{H1}	House price gap persistence	Beta	0.60	0.1	0.58	0.56 / 0.60
θ_{H2}	Impact of output gap	Gamma	0.40	0.1	0.38	0.36 / 0.40
θ_{H3}	Impact of credit gap	Gamma	0.30	0.1	0.13	0.12 / 0.14
θ_{H4}	Impact of real interest rate gap	Gamma	0.40	0.1	0.36	0.33 / 0.38
Real non-performing loans gap equation						
θ_{NPL1}	NPL gap persistence	Beta	0.30	0.1	0.38	0.34 / 0.41
θ_{NPL2}	Impact of output gap	Gamma	0.40	0.1	0.38	0.35 / 0.41
θ_{NPL3}	Impact of credit gap	Gamma	0.20	0.1	0.1	0.09 / 0.11
θ_{NPL4}	Impact of real interest rate gap	Gamma	0.30	0.1	0.25	0.23 / 0.27
Nominal lending rate equation						
ρ_{l}	Nominal lending rate persistence	Beta	0.90	0.1	0.95	0.95 / 0.95
ρ_{TP}	Term premium persistence	Gamma	0.70	0.1	0.72	0.68 / 0.74
ρ_{CP}	Credit premium persistence	Gamma	0.70	0.1	0.68	0.65 / 0.71
θ_{CP}	Impact of NPL gap	Gamma	0.10	0.1	0.10	0.06 / 0.20
IS curve						
α_1	Output gap persistence	Beta	0.60	0.1	0.80	0.78 / 0.82
α_2	Impact of real interest rate gap	Gamma	0.30	0.1	0.25	0.22 / 0.28
α_3	Impact of real exchange rate gap	Gamma	0.30	0.1	0.44	0.42 / 0.46
α_4	Impact of external demand on domestic output	Gamma	0.50	0.1	0.47	0.44 / 0.49
α_5	Impact of credit gap	Gamma	0.10	0.1	0.21	0.17 / 0.25
α_6	Impact of NPL gap	Gamma	0.40	0.1	0.29	0.26 / 0.32
St. dev. of shocks						
$\varepsilon_{C,t}$	Shock to credit gap	Inv. Gamma	2.00	0.2	1.25	1.21 / 1.30
$\varepsilon_{H,t}$	Shock to house price gap	Inv. Gamma	2.00	0.2	1.31	1.28 / 1.33
$\varepsilon_{NPL,t}$	Shock to NPL gap	Inv. Gamma	2.00	0.2	1.40	1.33 / 1.46
$\varepsilon_{CP,t}$	Shock to credit premium	Inv. Gamma	2.00	0.2	1.34	1.28 / 1.39
$\varepsilon_{\bar{C},t}$	Shock to equilibrium credit growth	Inv. Gamma	1.50	0.2	0.73	0.69 / 0.75
$\varepsilon_{\bar{H},t}$	Shock to equilibrium house price growth	Inv. Gamma	1.50	0.2	0.71	0.68 / 0.74
$\varepsilon_{N\bar{P}L,t}$	Shock to equilibrium NPL growth	Inv. Gamma	1.50	0.2	0.85	0.81 / 0.89
$\varepsilon_{rl,t}$	Shock to equilibrium real lending rate	Inv. Gamma	1.50	0.2	0.85	0.80 / 0.89

Appendix D: Additional Results

Table D1: Forecasting Performance of Different Model Specifications – Normalised RMSE

Period	Spec.		$\%\Delta C$	$\%\Delta H$	$\%\Delta NPL/L$
1Q2006–4Q2018*	Baseline	h=1	0.20	0.09	0.12
		h=6	0.28	0.14	0.18
		h=12	0.29	0.13	0.19
	No spiral	h=1	0.35	0.15	0.14
		h=6	0.29	0.17	0.20
		h=12	0.16	0.13	0.22
	No feedback	h=1	0.17	0.09	0.09
		h=6	0.29	0.16	0.16
		h=12	0.27	0.12	0.19
4Q2007–4Q2011**	Baseline	h=1	0.24	0.13	0.16
		h=6	0.34	0.15	0.24
		h=12	0.29	0.13	0.23
	No spiral	h=1	0.48	0.21	0.20
		h=6	0.41	0.20	0.28
		h=12	0.21	0.14	0.26
	No feedback	h=1	0.21	0.12	0.13
		h=6	0.33	0.16	0.22
		h=12	0.31	0.13	0.23
1Q2012–4Q2018*	Baseline	h=1	0.16	0.03	0.06
		h=6	0.19	0.14	0.06
		h=12	0.29	0.12	0.13
	No spiral	h=1	0.12	0.06	0.03
		h=6	0.05	0.13	0.09
		h=12	0.08	0.12	0.17
	No feedback	h=1	0.13	0.03	0.04
		h=6	0.24	0.15	0.06
		h=12	0.23	0.11	0.14

Note: * The last starting point of the forecast is 4Q2016. ** The last starting point of the forecast is 4Q2009. RMSE is normalised using the maximum and minimum values of the observed variable in the period 1Q2006–4Q2018.

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