Check for updates

Special Collection: Modelling and Analysis of the Knowledge Society in Times of Crisis

INTERNATIONAL JOURNAL OF ENGINEERING BUSINESS MANAGEMENT

International Journal of Engineering Business Management
Volume 10: 1–11
© The Author(s) 2018
DOI: 10.1177/1847979018758740
journals.sagepub.com/home/enb
SAGE

The empirical evaluation of monetary policy shock in dynamic stochastic general equilibrium model with financial frictions: Case of Croatia

Irena Palić

Abstract

Large body of empirical literature points to the tight integration of financial and credit markets with real economic activity as well as the need for inclusion of financial frictions into macroeconomic modelling. After the recent mortgage loan crisis which spilled over into the global financial crisis, the assessment of relationship of monetary policy and house prices gained in importance. The aim of this article is to test the compliance of monetary policy shock in calibrated dynamic stochastic general equilibrium (DSGE) model which includes financial frictions with the empirical impact of monetary policy shock in Croatia estimated using vector autoregression (VAR) model. After the DSGE model is calibrated, the VAR model is estimated for Croatia. The comparative analysis of impulse response functions of DSGE and VAR model is conducted. In both models, monetary policy shock has positive initial impact on interest rate and negative initial impact on house prices and output gap. Results indicate that empirical impact of the monetary policy shock adequately reflects the impact of monetary shock in DSGE model with financial frictions.

Keywords

DSGE model, financial frictions, impulse response analysis, monetary policy shock, VAR model

Date received: 22 November 2017; accepted: 12 January 2018

Introduction

The recent global financial crisis that originated in summer 2007 from United States as subprime mortgage market crisis has pointed to the fact that change in credit supply can have key role in macroeconomic fluctuations. Banks have overestimated their assets, and together with the fragility of the financial system, the mortgage loan crisis emerged and spilled over into the global financial crisis. According to Gambacorta and Signoretti,[1] loose credit conditions in many developed economies have contributed to boosting the business cycle before the financial crisis, while the tightening of credit standards after the collapse of the 'Lehman Brothers' contributed to a sharp drop in production recorded in 2008 and 2009. The imbalance may arise in apparently calm period, after which the trigger causes a significant reduction in the wealth that flows into the real economy. While in the calm periods the financial sector can alleviate financial friction, in times of crisis the fragility of the financial sector leads to instability.[2]

Due to the tight integration of financial and credit markets with real economic activity, it is necessary to include financial frictions in macroeconomic models.[3] The term financial friction concerns financial market imperfections, namely, the fact that financial markets have costs and limitations on transactions. The research of Christiano et al.[4]

Faculty of Economics and Business, University of Zagreb, Zagreb, Croatia

Corresponding author:
Irena Palić, Faculty of Economics and Business, University of Zagreb, Trg J.F. Kennedy 6, Zagreb, 10000, Croatia.
Email: ipalic@efzg.hr

Creative Commons CC-BY: This article is distributed under the terms of the Creative Commons Attribution 4.0 License (http://www.creativecommons.org/licenses/by/4.0/) which permits any use, reproduction and distribution of the work without further permission provided the original work is attributed as specified on the SAGE and Open Access pages (https://us.sagepub.com/en-us/nam/open-access-at-sage).

indicated the need for an analysis of the five phenomena in macroeconomics and finance: asymmetry of information and agency problems in financial contracts, the possibility of sudden occurrence of significant market risk, adjusting credit supply as a critical channel through which market risk becomes systematic, terms of banks' financing as the main determinants of bank lending decisions and liquidity of the central bank as a substitute for market liquidity in the absence of funds. Furthermore, Mendoza[5] pointed out that recessions following the financial breakdowns are significantly different from the classic business cycles. After the financial crisis, developing economies witnessed the so-called 'sudden stop phenomenon'. Thus, there is the link between the financial collapse and the macroeconomic crisis. In the empirical assessment of financial frictions, the question is whether the inclusion of financial frictions offers a satisfactory explanation of the financial crisis. Such an explanation should reveal the sources of such a crisis as well as spreading mechanisms, which would help predict the spread of such crises in the future.[6]

The analysis and formulation of dynamic stochastic general equilibrium (DSGE) models have become the foundation of modern macroeconomic analysis. The combination of rich structural models, new algorithms of solving and powerful simulation techniques enabled researchers to transform the quantitative model implementation from a variety of procedures into a systematic perspective discipline. This interesting field of research greatly influences the way of thinking about models and recommendations for managing economic policy.[7] DSGE models are called *dynamic* because they address changes in macroeconomic variables over time, *stochastic* because they show the effect stochastic shocks on the economy. They are also referred to as *general equilibrium* models due to the fact that they describe macroeconomics as a combination of individual choices and decisions that companies, households and economic policymakers bring according to their own preferences and future expectations. Thus, DSGE models lead to the integration of macroeconomics and microeconomics by providing microeconomic basis for macroeconomic analysis. This approach provides a general framework for analysing economic policy and its implications used in recent economic research.[8]

The aim of this article is to assess whether the impact of monetary policy shock in Croatia, which is approximated by money market interest rate shock, fits the impact of interest rate shock in calibrated DSGE model with financial frictions for Croatian economy. Namely, the impact of monetary policy shock on selected variables is assessed.

The motivation to test the empirical implications of incorporating financial frictions into the DSGE model of the Croatian economy stems from the fact that the global financial crisis has shown the empirical weaknesses of previous macroeconomic models without financial frictions. Furthermore, DSGE models are not sufficiently explored in Croatian literature, which is explained in the next section. This research assesses the following hypothesis: The simulation of the DSGE model involving financial frictions matches the empirical effect of the interest rate shock on Croatian economy. After the literature review, the analysis of compliance of calibrated DSGE model and estimated VAR model is conducted. Firstly, the mentioned impact is assessed within the DSGE model with financial frictions in line with Iacoviello's study[9] on Croatian economy. Then the vector autoregression (VAR) model of Croatian economy is estimated in order to empirically examine the impact of monetary shock on selected variables.

Literature review

Dynamic stochastic models of the general equilibrium incorporate sectors of the economy and embody them in a coherent and interrelated entity and show the economy as a system that reflects the collective decisions of rational individuals through a series of variables that relate to the current and future periods. These individual decisions are then coordinated among economic agents to build a macroeconomic model using microeconomic foundations.[8]

While the topic of incorporating financial frictions into economic models has been present for many years in economic literature, the beginning of the inclusion of financial market imperfections in the DSGE models refers to Bernanke and Gertler,[10] whose research illustrates the modelling of financial frictions at company level. In the model of real business cycle exposed by Bernanke and Gertler,[10] companies' balance sheet is the source of dynamics in economic activity. Companies are limited by their net asset value when borrowing from financial intermediaries. The company's higher net worth reduces the agency cost of financing real capital investments. The increase in economic activity improves net value, reduces agency costs and increases investment. Hence, the mentioned paper points to conclusion that shocks that affect the net value of companies initiate economic fluctuations. In the mentioned model, agency costs foster the spread of technological shocks. Financial frictions at company level in DSGE models are also analysed by Bernanke et al.,[11] Christensen and Dib,[12] Graeve.[13] On the other hand, modelling of financial frictions at the level of financial intermediaries was originally presented by Kiyotaki and Moore,[14] where frictions arise due to limitations of financial intermediaries for borrowing funds to enterprises. The study by Kiyotaki and Moore exposes the dynamic model in which financial intermediaries cannot force companies to repay debts if debts are not secured.[14] In this model, long-term assets have a dual role: the role of production factors and the role of collateral. The research by Kiyotaki and Moore[14] indicates that the dynamic interaction of credit limits and asset prices is a strong transmission mechanism through which the effects of shock spill over to other sectors. Moreover, small technology or income shocks can generate persistent fluctuations in production

and housing prices. Modelling financial frictions at financial intermediaries' level is also analysed in the previous studies.[15–17]

In the aftermath of recent global financial crisis, the DSGE model of United States is estimated by Del Negro et al.,[18] combining models of financial frictions developed by Bernanke et al.[11] and Smets and Wouters.[19] Using quarterly data from the first quarter of 1964 to the third quarter of 2008, the research by Del Negro et al.[18] outlines that their model successfully forecasts the contraction of economic activity in 2008 and 2009 in the United States.

Although the studies by Bernanke and Gertler[10] and Kiyotaki and Moore[14] are influential papers cited by most of the research related to the inclusion of financial frictions in DSGE models, formal macroeconomic models did not include financial frictions until the global financial crisis that began to spread in the summer of 2007. Prior to that, New Keynesian models involving market frictions, namely, inflexible prices and wages, prevailed in general equilibrium analysis. However, these models were formed with the assumption of complete financial markets, and the emergence of the global financial crisis indicated that economic models lacked an essential element of the economic system's behaviour.[20] In addition to the fact that financial frictions played a significant role in the aforementioned financial crisis, Quadrini[20] notes that credit flows are procyclical, that is, the liabilities of households and companies on loans are in line with the economic cycle. Large body of empirical research has shown that financial frictions can boost production fluctuations in response to aggregate disturbances. The previous research[3,4,18,21–24] highlight the importance of financial factors for macroeconomic fluctuations.

The research by Iacoviello[9] systematically examines the extent to which a general equilibrium model with financial frictions can empirically explain macroeconomic fluctuations on the one hand and be used for monetary policy analysis on the other. The starting point is the New Keynesian model[11] in which endogenous variations in companies' balance sheets create a financial accelerator that amplifies business cycles. Two main features are added to the mentioned model of Iacoviello[9]: collateral limitations related to the value of company's real estate, as shown in Kiyotaki and Moore,[14] and collateral limitations related to household debts. The reason for incorporating collateral in the form of residential housing is empirically grounded, as much of the debt is secured by real estate. Involving collateral in the form of housing is significant, given that the housing market plays a significant role in business cycles' fluctuations. The transmission mechanism of the model can be described in the following way: The positive demand shock leads to an increase in consumer and property prices. The rise in housing prices increases the borrowing capacity of lenders, allowing them to spend and invest more. The rise in consumer prices reduces the real value of the debt, which has a positive impact on their net value. If debtors have a greater propensity to spend than creditors, the net effect on demand is positive and the mentioned effect is even more pronounced. However, consumer price inflation reduces shocks and causes negative correlation between income and inflation: negative supply shocks, namely, price increases, increase the net value of debtors if the liabilities are given in nominal terms. The financial accelerator depends on the source of shocks: there is an accelerator of demand shocks and a shock-absorber accelerator in the model. The mentioned transmission mechanism satisfactorily explains the empirical characteristics of the US economy. In order to assess the mentioned mechanism, Iacoviello[9] estimates VAR model, which includes interest rate, inflation, real estate prices and income.

Regarding Croatia, previous research using DSGE approach is scarce. The research by Bokan et al.[25] simulates the impact of financial crisis on Croatian economy using DSGE model, but authors indicate that paper is not simulated and evaluated in line with standard literature on DSGE models. Instead, the results are solely the impulse response functions of calibrated DSGE model. Furthermore, Palić[8] evaluated various DSGE models for the Croatian economy, and among other features of DSGE models, the inclusion of financial frictions was also analysed[8] for the period from 2000 to 2013. However, the choice of variables in this article differs substantially from Palić's.[8] The research[8] has shown that index of financial conditions as a measure of stance of monetary policy in Croatia impacts house prices, output gap and inflation in Croatia, and the mentioned impact is in line with the impact of interest rate shock in DSGE model with financial frictions. The main contribution of this research is that monetary shock is approximated using money market interest rate, while Palić[8] uses financial conditions index. Furthermore, in this research, house prices are differently approximated and VAR model is estimated with smaller number of variables, which is explained in detail within data description in third section of this article.

The analysis of compliance of DSGE model which includes financial frictions with estimated VAR model of Croatian economy

This section, divided into three subsections, provides the analysis of both calibrated DSGE model with financial frictions and estimated VAR model of Croatian economy and finally offers the results and discussion through the empirical evaluation of calibrated model using impulse response functions approach. VAR models are generally used to analyse the relationship of economic variables, to test economic theories and to compare actual data with time series generated by the DSGE models.

Both DSGE and VAR models have significant advantages but also some drawbacks. The VAR model can be directly estimated from data and after estimation it can be

used for statistical hypothesis testing and for forecasting. However, since VAR models do not rely heavily on economic theory, they often cannot detect structural parameters and may be unstable for analysing economic policy changes.[26] On the other hand, DSGE models are firmly based on economic theory and formalize the behaviour of economic agents using microeconomic foundations and are less sensible to Lucas critique exposed in the study[27] than traditional econometric models. DSGE models enable the design of a wide spectrum of scenarios and can cover a range of economic issues while at the same time offer a structured interpretation of scenarios and simulation results.[8] Structural parameters should not be influenced by changes in the economic policy. However, because of their strong reliance on economic theory, DSGE models are often considered too stylized to be able to apply concrete data because of the inability to carry out traditional econometric estimations. Therefore, DSGE and VAR models are often used together to obtain broad insight into impacts of shocks hitting the economy.

DSGE models describe the impact of macroeconomic shocks on economic variables. However, the empirical impacts are often assessed by the estimation of VAR models. Both of these models have significant advantages but also some drawbacks. The VAR model can be directly analysed because it is easy to evaluate and after estimation the models can be used for statistical hypothesis testing and prognostic purposes. However, since VAR models rely weakly on economic theory, they often cannot detect structural parameters and may be unstable in economic policy changes.[9] On the other hand, DSGE models are firmly based on economic theory and formalize the behaviour of economic entities using microeconomic bases and are less vulnerable to Lucas critique exposed in the study[27] than traditional econometric models. DSGE models enable design of a wide spectrum of scenarios and can cover a range of economic issues while at the same time offering a structured interpretation of scenarios and simulation results.[28] DSGE models link structural parameters that describe preferences and technology with the behaviour of endogenous variables. In principle, structural parameters should not be influenced by changes in the economic policy regime. However, because of their strong reliance on economic theory, DSGE models are often considered too stylized to be applied on concrete data because of the inability to carry out traditional econometric assessments. Taking into consideration the advantages and disadvantages of both approaches, VAR approach is frequently used for the evaluation of DSGE models in order to econometrically assess the nature and characteristics of economic variables.

According to Bache,[29] the general approach to the DSGE model evaluation is to compare the impulse response functions of DSGE and VAR models. The impulse response functions of the VAR model relying on the minimal set of theoretical restrictions are interpreted as stylized facts that the DSGE model should reproduce. Data used in the conducted analysis are described in detail separately for each subsection, namely, for DSGE model calibration and for VAR model estimation. However, all variables and data sources used in empirical analysis are listed and explained in Table 1A of Appendix 1.

The calibration of DSGE model with financial frictions for Croatia

The DSGE model with financial frictions which is exposed in detail by Iacoviello[9] is calibrated in this section using Dynare 4.4.2 developed by Adjemian et al.[[30] and MATLAB R2014a. The mentioned model is a combination of previously mentioned models,[11,14] whereas Iacoviello[9] adds financial frictions of household sector to these features. Households in the model can be divided into patient and impatient households. Patient households are working, spending, buying housing, lending capital and land to businesses and lending funds to impatient households. Impatient households are limited by credit: they work, spend, buy housing and borrow, where housing is a collateral for borrowing, and they are limited by the value of housing when they borrow.

Whenever possible, the values of the parameters are set using data related to the Croatian economy and in accordance with the empirical characteristics of Croatian economy. However, if individual parameters cannot be determined from data, their value is taken from existing empirical studies.

In order to calibrate the stochastic properties of productivity in the model, productivity denoted by a_t is modelled as autoregressive process in line with standard literature.[9,31,32] Productivity refers to the cyclical component of seasonally adjusted logarithmic values of productivity, which is initially denoted by *PROD*. The cyclical component is extracted using Hodrick–Prescott filter developed by Hodrick and Prescott.[33] Original productivity *PROD* is calculated as the ratio of gross value-added *GVA* in million euro available at Eurostat[34] and number of employed persons *N* provided by Eurostat[35] from first quarter of 2002 to first quarter of 2017. Seasonal adjustment is conducted using X-13 ARIMA SEATS method developed by US Census Bureau.[36] The following autoregression, AR (1) process for labour productivity is estimated (with t value in parentheses):

$$\underset{(7.83)}{a_t = 0.73a_{t-1}} + e_t, \tag{1}$$

with standard deviation of productivity $\sigma_a = 8.26* 10^{-14}$. In this equation AR (1) parameter equals 0.73. It is necessary that AR (1) parameter is less than 1 to satisfy the condition of AR (1) process stationarity.[37]

The discount factor of patient households denoted by β is calibrated using the equation for intertemporal discount rate r given by Galì[31]:

$$r_{\text{quarterly}} \equiv -\ln\beta \tag{2}$$

The intertemporal discount rate is calculated as the equilibrium interest rate on the Croatian government bonds approximated by European monetary union (EMU) convergence criterion bond yields denoted by *rfb* available at Eurostat,[38] which is a proxy for risk-free bond for Croatia. The average EMU convergence criterion bond yield from 2007 to 2016 is 5.352%. The quarterly effective rate is calculated using the following equation[39]:

$$r_{\text{quarterly}} = (1 + r_{\text{annual}})^{1/4} - 1 \quad (3)$$

Thus, in line with equation (3), the equivalent quarterly rate equals 1.31196%. In line with the previous findings[29,37] the discount factor is $\beta = e^{-r_{quarterly}} = e^{-0.0131196} = 0.987$. The discount factor of entrepreneurs is denoted by β_e and calculated using internal rate of return for enterprises, which Iacoviello[9] approximates by double-value equilibrium risk-free interest rate. Hence, the double value of previously calculated quarterly interest rate is used. Discount factor β_e is calculated as $\beta_e = e^{2(-0.0131196)} = 0,974$. Then, it is necessary to calibrate the discount factor of impatient households. The research by Lawrance[40] uses quarterly data to estimate the value of the discounting factor of poor households in the United States, which are more likely to be debtors, and estimates the discount factor between 0.95 and 0.98, depending on the specification. In line with Iacoviello,[9] in this research the discount factor of impatient households is equal to 0.95. The standard deviation of the nominal interest rate σ_i is calculated as the standard deviation of the nominal interest rate on the overnight money market *MMIR* available at Zagreb Money Market[41] and is 2.53%.

Given that the estimation elasticity of labour supply for the Croatian economy is insufficiently explored, the standard values in DSGE modelling are used for calibration of inverse elasticity of labour supply. In line with Bokan et al.[25] and Galì and Monacelli,[32] the calibrated inverse of the elasticity of labour supply is equal to 3. Regarding the risk aversion parameter, the research[42] uses the data on the satisfaction and personal well-being of individuals in 80 countries and classify Croatia as the developed country. The average risk aversion coefficient is 1.01, and the conclusion[42] is that their result supports logarithmic utility function. Accordingly, the parameter of risk aversion is 1, which is in line with the calibration of Galì and Monacelli.[32]

Furthermore, it is necessary to calibrate the price stickiness parameter θ. The price stickiness is one of the key differences between New Keynesian model and real business cycle model. The average price duration equals $(1-\theta)^{-1}$. The only currently available research of price stickiness at companies' level in Croatia is conducted by Pufnik and Kunovac,[43] and the conclusion is that medial company in Croatia changes the price of its main product less frequently than once a year. The value $\theta = 0.90$ is used for the calibration of the Croatian economy DSGE model, what points to the average price duration of 10 months and is consistent with Pufnik and Kunovac[43].

The share of capital is calibrated for Croatia by Palić,[8] and the calibration is done in line with the mentioned research where share of capital $\alpha = 0.35$. In the calculation of capital,[8] the annual depreciation rate equal to 5% is used. Therefore, the quarterly depreciation rate is calculated in line with equation (2), so the quarterly depreciation equals 1.2275%.

Furthermore, it is necessary to estimate the AR (1) parameter of inflation. Inflation is calculated using harmonized consumer price index (*HICP*), 2010 = 100 available at Croatian National Bank (CNB) statistics.[44] The following AR (1) process is estimated using the quarterly seasonally adjusted inflation rate values from the first quarter of 2005 to the first quarter of 2017 (with t value in parentheses):

$$\underset{(2.98)}{\pi_t = 0.40\pi_{t-1}} + e_t, \quad (4)$$

with standard deviation of inflation $\sigma_\pi = 0.53$. Furthermore, AR (1) parameter of household preferences ρ_j and associated standard deviation σ_j is taken from Iacoviello.[9]

The remaining parameters are calibrated in line with the study by Iacoviello.[9] Thus, the markup of final goods in relation to intermediary goods denoted by X is set to 1.33. The weight of the housing construction in the utility function of the patient households denoted by j, namely, the parameter controlling the housing share in income, equals 0.1. Furthermore, elasticity of income to entrepreneurial real estate α_e is equal to 0.03 and the parameter of the cost of capital adjustment ϱ_K is 2, while the parameters of cost of housing adjustment ϱ_e and ϱ_h both equal zero. The relative proportion of the group of patient households equals 0.64. The share of debt in the total value of enterprises $m = 0.89$ and the share of debt in the total value of households $m'' = 0.55$. High values of m and m'' are necessary to generate strong and lasting effects of property price changes on aggregate demand.[9]

The estimation of VAR model for empirical evaluation of DSGE model

With the assumption that monetary policy can boost economic growth by lowering borrowing costs, together with the fact that the real estate market is heavily dependent on availability of loans, the question of the impact of monetary policy on real estate prices arises.[45] At the aggregate level, research[9] shows that restrictive monetary policy in the United States had negative impact on real estate prices and output, using New Keynesian DSGE model with collateral constraints that are related to the value of real estate, in line with Kiyotaki and Moore.[14] In order to evaluate DSGE model, using data from the first quarter of 1974 to the second quarter of 2003, Iacoviello[9] estimates VAR model of US economy, which includes the following variables: output, real estate prices, inflation and the nominal interest

rate. To approximate output, mentioned paper uses detrended real gross domestic product (GDP) with the removed trend component and detrended real estate prices. As the inflation approximation, he uses the first difference of the logarithmic values of the GDP deflator, and the nominal interest rate is the Fed Funds rate.

The VAR model in case of k variables $y_t = (y_{1t}, ...y_{kt})'$ is given by:

$$y_t = A_1 y_{t-1} + A_2 y_{t-2} + ... + A_p y_{t-p} + u_t \qquad (5)$$

where A_i are *(k x k)* matrices of coefficient, p is lag length and u_t is k-dimensional vector of innovations.[46] For detailed description of VAR model, see the literature.[37,46]

The choice of variables for the estimation of VAR model of Croatian economy is consistent with the previously calibrated DSGE model with financial frictions for Croatian economy. However, inflation is not included as separate variable in VAR model. Due to relatively short time span of house price index for Croatian economy (from first quarter of 2008 to second quarter of 2017), VAR model is estimated with smaller number of variables in order to preserve degrees of freedom and quality of econometric analysis. House price index is newly developed by the CNB and the Croatian Bureau of Statistics, and it replaced the hedonic real estate price index, which was used by Palić.[8] House price index is constructed taking into consideration harmonized indices of consumer prices, and output gap is constructed using GDP in constant prices. The interest rate is the standard part of the DSGE models as a proxy for monetary policy shock. Although the impact of interest rate to house prices has not been previously analysed in Croatian literature, the impact of monetary variables to the real sector in Croatia has been analysed in the literature.[47–51]

Previous research has shown that monetary policy in Croatia affects the real sector primarily through the direct channel and foreign exchange channel. It is important to note that Erjavec and Cota[48] and Vizek[51] have shown that the interest rate channel does not have the significant effect on the real sector. However, the results of the later research[47,49,50] pointed to different results, namely, the significance of interest rate channel in Croatia. According to Doležal,[50] possible reason is that the CNB introduced open market operations in 2005, which were supposed to establish the reference interest rate.

Furthermore, in DSGE model evaluation, it should be mentioned that solution for DSGE models is given for the equilibrium values of variables, and stochastic behaviour of variables is shown by temporary deviations from equilibrium values. Most DSGE models are formed for the analysis of cyclical behaviour of variables. However, a large number of macroeconomic time series contains a trend component, and cyclical characteristics of data are not directly visible.[52,53] Isolation of the cyclic component is closely related to the removal of the trend component. The cyclical component is commonly extracted using Hodrick–Prescott[33] and thus Hodrick–Prescott filter is also used in this research to extract cyclical component of selected variables. The value of the smoothing parameter is 1600, in line with the original value[33] for quarterly data. In this research, the cyclical component is obtained by removing the trend component, which is obtained using Hodrick–Prescott filter, from previous seasonally adjusted time series.

Therefore, the VAR model of Croatian economy includes following variables (see Table 1A in Appendix 1): cyclical seasonally adjusted overnight money market interest rate denoted by I (original data are available from Zagreb Money Market[41]) cyclical seasonally adjusted house price index, 2010 = 100 denoted by *HP* (original data are provided by CNB[44]) and cyclical seasonally adjusted values of GDP in million euro chain linked volumes, 2010 = 100, denoted by *GAP* (original data are available in Eurostat[54]). Since output gap is commonly defined as the deviation of actual output form equilibrium value, the cyclical component of seasonally adjusted output time series is referred to as output gap. The estimation period is conditioned by the availability of house price index time series, and thus model is estimated using data from first quarter of 2008 to second quarter of 2017. Augmented Dickey-Fuller (ADF) unit root test is conducted for all variables, and the variables are shown to be stationary at 5% significance.

VAR model is estimated with seven lags in order to eliminate autocorrelation problem. The Lagrange multiplier autocorrelation test is conducted and it can be concluded that thw problem of residual autocorrelation is not present at 5% significance up to lag length 12, since all p values are higher than 0.05. Furthermore, White test for assessing residual heteroscedasticity is performed. The chi-square (χ^2) test statistic of White test 177.185, with p value of 0.5454, which points to conclusion that heteroscedasticity of residuals is not present. Moreover, VAR residual normality tests are conducted. The null hypothesis that residuals are multivariate normal cannot be rejected at 5% significance level, since χ^2 statistic for testing skewness of residuals equals 6.211 with p value of 0.1018, χ^2 statistic for testing kurtosis of residuals equals 5.341 with p value of 0.1484 and Jarque-Bera test statistic equals 11.553 with p value of 0.073.After conducting residual diagnostics tests, the stability of model is tested using inverse roots of characteristic AR polynomial calculated in EViews 9, as shown in Figure 1. Since all remaining roots have modulus less than one and lie inside the unit circle, the estimated VAR model is stable.

Results and discussion

The evaluation of the previously calibrated DSGE model with financial frictions is conducted using comparative impulse response analysis. Impulse response functions of calibrated DSGE model are compared to the impulse response functions of the estimated VAR of the Croatian

economy, which is a common approach to the evaluation of the DSGE models.

Figure 2 shows the impact of monetary shock on interest rate, inflation, house prices and output gap in DSGE model with financial frictions calibrated for Croatia using Dynare 4.4.2 and MATLAB R2014a. While the impact of monetary shock on the interest rate itself is initially positive, the impact on inflation, house prices and income is initially negative.

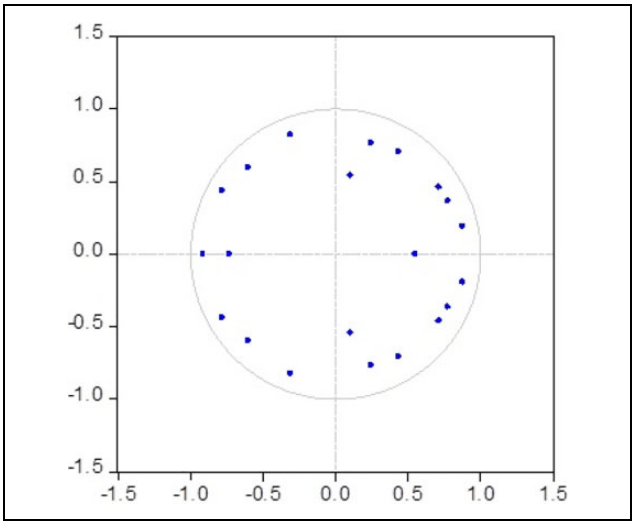


Figure 1. Inverse roots of AR characteristic polynomial. *Source*: Author's calculation, EViews 9. AR: autoregression.

Figure 3 shows the impact of monetary shock approximated by shock of *i* to interest rate *i*, house prices *HP* and output gap denoted by *GAP*. Inflation is not included as a separate variable into VAR model due to reasons mentioned earlier. The impact of monetary shock to interest rate *i* is initially statistically significant and positive. Initial positive impact is in line with the impact in calibrated DSGE model shown in Figure 2. Regarding the impact of *i* on house prices *HP*, although initially insignificant, the significant negative impact is recorded three-quarters after the initial shock. Negative impact is in line with the impact of *i* on *HP* in DSGE model shown in Figure 2. Finally, the impact of *i* on *GAP* is analysed. Figure 3 shows the significant negative impact of monetary policy shock to output gap, which is in line with the impact in calibrated DSGE model shown in Figure 3.

Based on the comparison of impulse response functions, it can be concluded that the empirical impact of monetary, namely, interest rate shock in Croatia matches the effect of the interest rate shock in calibrated DSGE model involving financial frictions. Therefore, the research hypothesis stated in the introductory part of the article cannot be rejected.

The obtained result sheds the light on impact of monetary policy on housing market. The analysis of mentioned impact gained in importance after the recent financial crisis. According to Tovar,[6] the financial crises around the world, for example, the Great Depression in the 1930s, the crisis in Japan and Latin America in the 1980s, the Asian

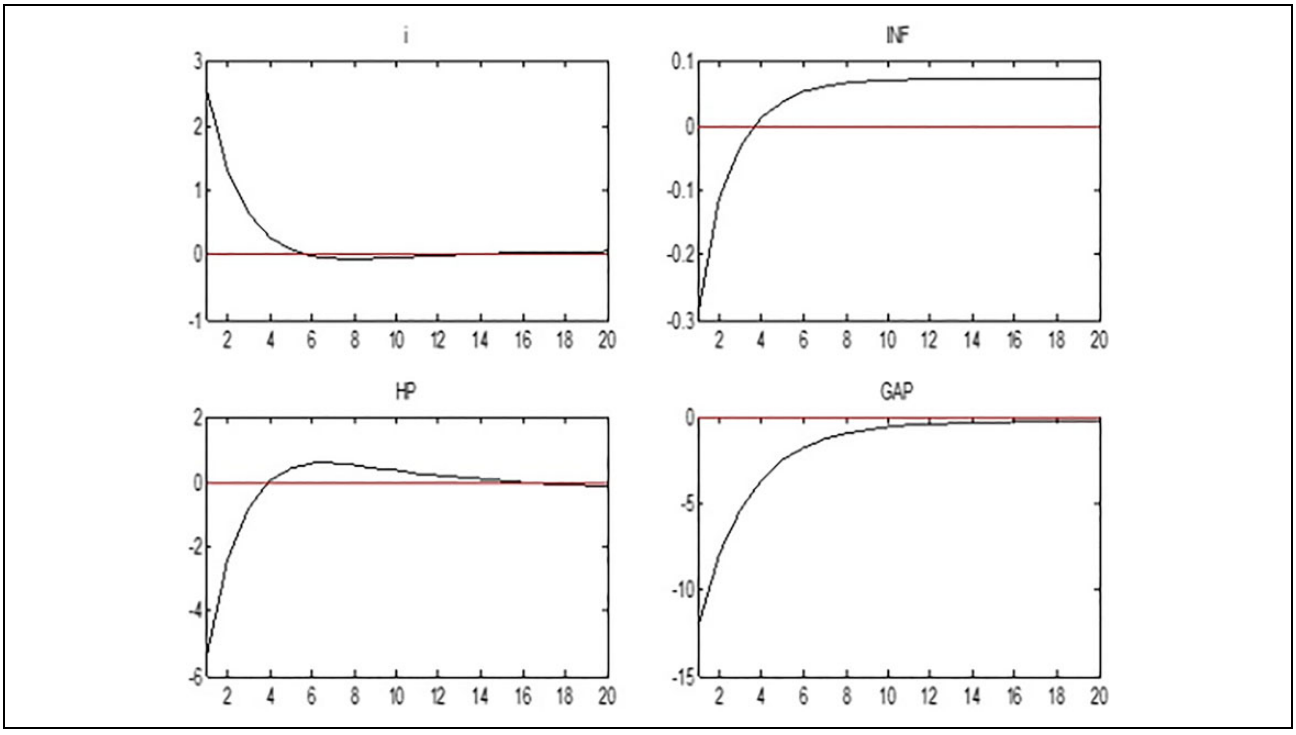


Figure 2. The impact of monetary shock in calibrated DSGE model with financial frictions. *Source*: Author's calculation, MATLAB R2014a and Dynare 4.4.2. DSGE: dynamic stochastic general equilibrium.

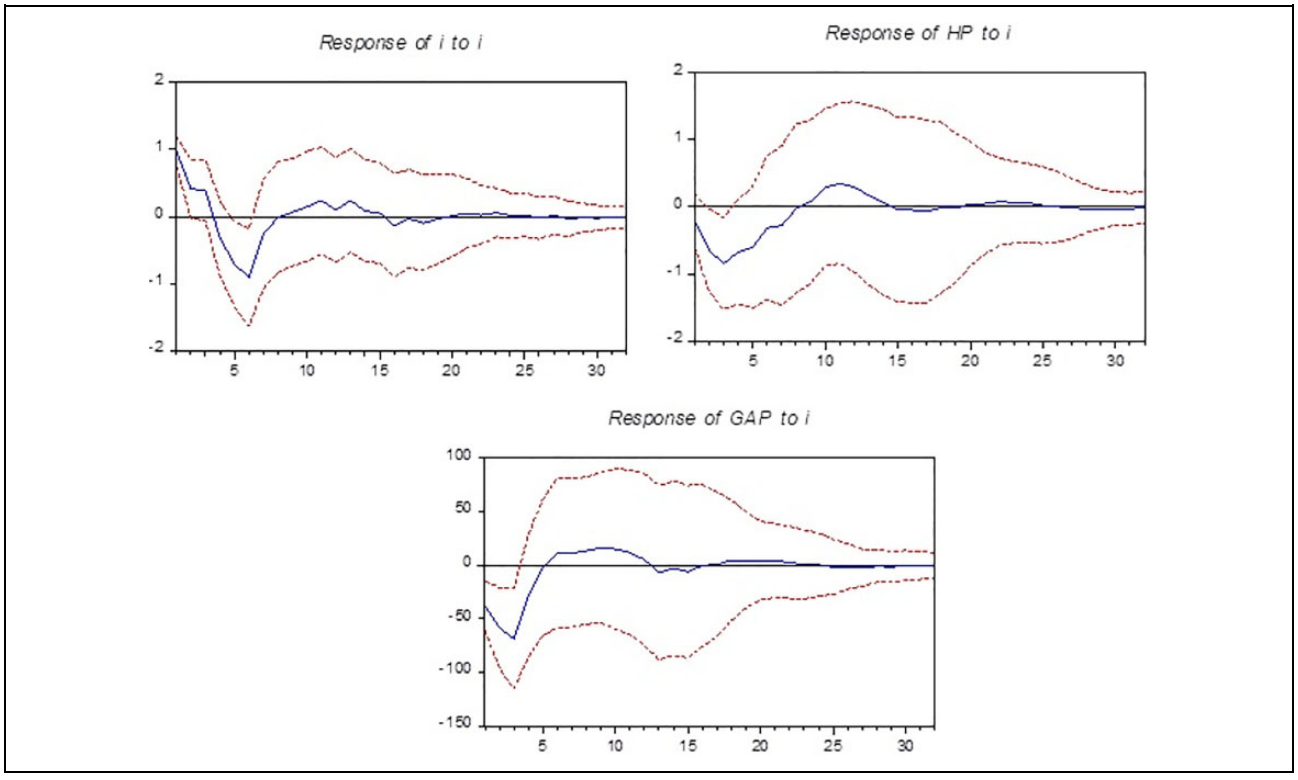


Figure 3. The impact of monetary shock in estimated VAR model of Croatian economy. The response to Cholesky One S.D. Innovations ± 2 standard errors. *Source*: Author's calculation, EViews 9. VAR: vector autoregression.

crisis in 1997 as well as the recent financial crisis triggered by the real estate crisis in the United States, pointed to the importance of the financial structure of the economy in macroeconomic modelling. If financial markets, or the existence of financial frictions, are not involved in formal modelling, DSGE models fail to explain economic fluctuations. The conducted econometric analysis has shown that inclusion of financial frictions in DSGE model explains the empirical characteristics of monetary shock in Croatian economy properly, which is important for monetary policymaking in Croatia. The conducted analysis indicates that monetary policy shock statistically significantly impacts house prices and output gap in Croatia. The restrictive monetary policy shock, namely, an increase in interest rate, will lead to decrease in house prices and output gap. In line with Ahearne et al.,[55] increased house prices are expected after expansive monetary policy of lowering interest rates. Although asset prices are commonly not the part of primary objectives of countries' monetary authorities, including CNB, after recent global financial crisis it is obvious that housing market fluctuations can have substantial consequences for overall economic activity. The finding about the significant impact of monetary policy conduct on house prices in Croatia is important for monetary policymaking in Croatia, taking into account the importance of housing market for overall financial stability that gained in importance in the aftermath of the recent global financial crisis. However, when interpreting the results of conducted empirical analysis, it should be noted that financial frictions modelling is conducted through examining the impact of interest rate shock on house prices, which is one possible way to include financial frictions in macroeconomic modelling. Other possible financial frictions modelling options are discussed in literature review.

Conclusions

The recent financial crisis that began in the summer of 2007 suggested that financial conditions could play a key role in macroeconomic developments. The macroeconomic analysts and the economic policymakers should also take into account financial frictions, namely, imperfections in financial markets that gained importance during the recent financial crisis that hit the world and the Croatian economy. The mortgage loan crisis emerged parallel with the fragile financial system and spilled over into the global financial crisis. The analysis of the relationship of monetary policy and housing prices thus gained in importance. Housing market obviously plays important role in the overall economic fluctuations. Consequently, the assessment of monetary policy impact on housing prices is captivating for both researchers and economic policymakers in Croatia.

The empirical evaluation of the inclusion of financial frictions into DSGE model is conducted in this article. Firstly, the impact of monetary shock is assessed within the DSGE model with financial frictions which include

collateral limitations related to housing value. After calibration of DSGE model, the VAR model of Croatian economy is estimated in order to empirically evaluate the impact of monetary shock on selected variables. The estimated VAR model includes overnight money market interest rate, house price indices and output gap. The analysis of impulse response functions of both DSGE and VAR model has shown that restrictive monetary policy shock in VAR model reflects adequately the monetary shock in DSGE model. The conducted empirical analysis suggests that potential restrictive monetary policy in the form of an interest rate increase could lead to a decrease in house prices and output gap. Mentioned result is important for economic policymaking in Croatia, especially in the aftermath of recent global financial crisis, which originated from real estate market crisis in the United States.

The limitation of conducted research is that financial frictions in DSGE model are modelled in the form of collateral limitations related to the value of real estate, whereas the empirical impact of monetary policy shock on house prices is estimated in order to evaluate calibrated DSGE model. However, the empirical effects of the companies' and financial institutions' balance sheets on macroeconomic fluctuations, which are also important aspects of modelling financial frictions, are not analysed in this research. Mentioned limitation offers the perspective for future research in this field.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author disclosed receipt of the following financial support for the research, authorship and publication of this article: The publication of this article was fully funded by Croatian Science Foundation support for the project 'Statistical Modelling for Response to Crisis and Economic Growth in Western Balkan Countries (STRENGTHS)', IP-2013-9402.

References

1. Gambacorta L and Signoretti FM. Should monetary policy lean against the wind? An analysis based on a DSGE model with banking. *J Econ Dyn Control* 2014; 43: 146–174.
2. Brunnermeier MK, Eisenbach TM and Sannikov Y. Macroeconomics with Financial Frictions: a Survey. *NBER Working Paper Series*, No. 1810, National Bureau of Economic Research, http://www.nber.org/papers/w18102 (2012, accessed 4 September 2016).
3. Merola R.The role of financial frictions during the crisis: an estimated DSGE model. Dynare Working Papers, No. 33, Cepremap, Paris, http://www.dynare.org/wp-repo/dynarewp033.pdf (2013, accessed 28 January 2015).
4. Christiano LJ, Motto R and Rostagno M. Financial factors in economic fluctutations. *ECB Working Paper Series*, No. 1192, European Central Bank, http://www.ecb.europa.eu/pub/pdf/scpwps/ecbwp1192.pdf (2010, accessed 24 October 2012).
5. Mendoza E. Sudden stops, financial crises and leverage. *Am Econ Rev* 2010; 100(5): 1941–1966.
6. Tovar CE. DSGE Models and Central Banks. *Bank for International Settlements Working Papers*, No 258, https://www.bis.org/publ/work258.pdf (2008, accessed 8 April 2015).
7. Fernandez-Villaverde J. The econometrics of DSGE models. *SERIEs* 2009; 1(1): 3–49.
8. Palić I (2015). *Econometric analysis and calibration of dynamic stohastic general equilibrium models of Croatian economy*. PhD Thesis., Faculty of Economics and Business, University of Zagreb, Zagreb.
9. Iacoviello M. House prices, borrowing constraints, and monetary policy in the business cycle. *Am Econ Rev* 2005; 95(3): 739–764.
10. Bernanke B and and Gertler M. Agency costs, Net worth and Business Fluctuations. *Am Econ Rev* 1989; 79(1): 14–31.
11. Bernanke B, Gertler M and Gilchrist S. The financial accelerator in a quantitative business cycles framework. In: Taylor JB and Woodford M (eds) *Handbook of Macroeconomics*, 1A. North-Holland: Elsevier Science, 1999, pp. 1341–1393.
12. Christensen I and Dib A. The financial accelerator in an estimated New Keynesian model. *Rev Econ Dyn* 2008; 11(1): 155–178.
13. De Graeve F.The external finance premium and the macroeconomy: US Post-WWII evidence. *J Econ Dyn Control* 2008; 32(11): 3415–3440.
14. Kiyotaki N and Moore J. Credit Cycles. *J Political Econ* 1997; 105(2): 211–248.
15. Gerali A, Neri S, Sessa L, et al. Credit and banking in a DSGE model of the euro area. *J Money Credit Bank* 2010; 42(1): 107–141.
16. Curdia V and Woodford M. Conventional and unconventional monetary policy. *Fed Reserve Bank St Louis Rev* 2010; 92(4): 229–264.
17. Gertler M and Karadi P. A model of unconventional monetary policy. *J Monetary Econ* 2011; 58(1): 17–34.
18. Del Negro M, Giannoni MP and Schorfheide F. Inflation in the great recession and New Keynesian models. *Federal Reserve Bank of New York Staff Reports*, No. 618, https://www.newyorkfed.org/research/staff_reports/sr618.html (2013, accessed 10 June 2015).
19. Smets F and Wouters R. Shocks and frictions in US business cycles: a bayesian DSGE approach. *Am Econ Rev* 2007; 97(3): 586–606.
20. Quadrini V. Financial Frictions in Macroeconomic Fluctuations. *Fed Reserve Bank Richmond Econom Quar* 2011; 97(3): 209–254.
21. Goodfriend M and McCallum B. Banking and interest rates in monetary policy analysis. *J Monetary Econ* 2007; 54(5): 1480–1507.
22. De Walque G, Pierrard O and Rouabah A. Financial (in)stability, supervision and liquidity injections: a dynamic

general equilibrium approach. *Econ J* 2010; 120(549): 1234–1261.
23. Angeloni I and Faia E. Capital regulation and monetary policy with fragile banks. *J Monetary Econ* 2010; 60(3): 311–324.
24. Meh CA and Moran K. The role of bank capital in the propagation of shocks. *J Econ Dyn Control* 2010; 34(3): 555–576.
25. Bokan N, Grgurić L, Krznar I, et al. The impact of the financial crisis and policy responses in Croatia. *Croatian National Bank Working Papers*, No. 22, https://www.hnb.hr/documents/20182/121339/w-022.pdf/038c602a-8633-4638-b0c7-0b2a5dc52e8e (2009, accessed 29 January 2013).
26. Ireland PN. A method for taking Models to the Data. *J Econ Dyn Control* 2004; 28: 1205–1226.
27. Lucas RE.Econometric Policy Evaluation: A critique. *Carnegie-Rochester Conf Ser Public Policy* 1976; 1: 19–46.
28. Vetlov I, Félix RM, Frey L, et al. The Implementation of Scenarios using DSGE Models. *Central Bank of Cyprus Working Paper Series*, No 10, http://www.lb.lt/en/publications/no-8-the-implementation-of-scenarios-using-dsge-models (2010, accessed 8 May 2015).
29. Bache IW (2006). *Econometrics of exchange rate pass-through*. PhD Thesis. University of Oslo, Norway.
30. Adjemian S, Bastani H, Juillard M, et al. Dynare: Reference Manual, Version 4. *Dynare Working Papers*, No. 1, Cepremap, Paris, http://www.dynare.org/wp-repo/dynarewp001.pdf (2011, accessed 3 June 2013).
31. Galì J. *Monetary Policy, Inflation and Business Cycle: An Introduction to the New Keynesian Framework*. Princeton: Princeton University Press, 2008.
32. Galì J and Monacelli T. Monetary policy and exchange rate volatility in a small open economy. *Rev Econ Stud* 2005; 72(3): 707–734.
33. Hodrick R and Prescott EC. Postwar U.S. Business cycles: An empirical investigation. *J Money Credit Bank* 1997; 29(1): 1–16.
34. Eurostat. Gross value added and income A*10 industry breakdowns. http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=namq_10_a10and (2017, accessed 20 October 2017).
35. Eurostat. Employment and activity by sex and age. http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=lfsi_emp_qand (2017, accessed 20 October 2017).
36. U.S. Census Bureau. X-13ARIMA-SEATS Reference Manual, Time Series Research, Statistical Research Division. http://www.census.gov/ts/x13as/docX13ASHTML.pdf (2013, accessed 4 June 2014).
37. Enders W. *Applied Econometric Time Series*, 4th Ed. London: John Wiley and Sons, 2015.
38. Eurostat. EMU convergence criterion series. http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=irt_lt_mcby_a (2017, accessed 23 September 2017).
39. Steiner B. *Mastering Financial Calculations*, 3rd ed. Harlow: Pearson Education, 2012.
40. Lawrance EC. Poverty and the rate of time preference: evidence from panel data. *J Political Econ* 1991; 99(1): 54–77.
41. Zagreb Money Market. http://www.trzistenovca.hr/ (2017, accessed 10 October 2017).
42. Gandelman N and Hernandez-Murillo R. Risk aversion at the country level. *Federal Reserve Bank of St. Louis Working Paper*, No. 2014–005B, https://files.stlouisfed.org/files/htdocs/wp/2014/2014-005.pdf (2014, accessed 8 July 2016).
43. Pufnik A and Kunovac D. Pricing behaviour of Croatian companies: results of firm survey and a Comparison with the eurozone. *Croatian National Bank Working Papers*, No. 36, http://old.hnb.hr/publikac/istrazivanja/w-036.htm (2013, accessed 8 June 2015).
44. Croatian National Bank. Statistics (Price indices). https://www.hnb.hr/en/statistics/statistical-data/selected-non-financial-statistics/price-indices (2017, accessed 10 October 2017).
45. Ghysels E, Plazzi A, Valkanov R, et al.Forecasting real estate prices. In: Graham E and Timmermann A (eds) *Handbook of Economic Forecasting*. Vol. 2A. North-Holland: Elsevier, 2013, pp. 509–580.
46. Breitung J, Brüggemann R and Lütkepohl H. Structural vector autoregressive modelling and impulse responses. In: Lütkepohl H and Krätzig M (eds) *Applied Time Series Econometrics*. Cambridge: Cambridge University Press, 2004, pp. 159–196.
47. Dumičić K, Čibarić I and Horvat N. The analysis of monetary transmission mechanism in Croatia using cointegration approach. *Croat Oper Res Rev* 2010; 1–2010: 210–220.
48. Erjavec N and Cota B. Macroeconomic granger - causal dynamics in croatia: evidence based on a vector error - correction modelling analysis. *Econom Rev* 2003; 54: 139–156.
49. Borozan Dj. Granger causality and innovation accounting analysis of the monetary transmission mechanism in Croatia. *Post Commun Econ* 2011; 23: 517–537.
50. Doležal V. Efficiency of the monetary transmission mechanism in Croatia. *Economic Trends Econom Policy* 2011; 21(128): 27–55.
51. Vizek M. Econometric analysis of monetary transmission channels in Croatia. *Econom Trends Econom Policy* 2006; 10: 28–61.
52. Canova F. *Methods for Applied Macroeconomic Research*. Princeton: Princeton University Press, 2007.
53. De Jong D and Chetan D. *Structural Macroeconometrics*, 2nd ed. Princeton: Princeton University Press, 2011.
54. Eurostat. GDP and main components. http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=namq_10_gdpand (2017, accessed 12 October 2017)
55. Ahearne AG, Ammer J and Doyle BM. House prices and monetary policy: a cross-country study. *Board of Governors of the Federal Reserve System International Finance Discussion Papers*, No. 841, https://www.federalreserve.gov/pubs/ifdp/2005/841/ifdp841.pdf (2005, accessed 8 September 2017).

Appendix 1

Table 1A. Data description.

Variable	Notation	Data source
Variables for DSGE model calibration		
Productivity – calculated as the ratio of *GVA* and *N*	*PROD*	Author's calculation
Gross value added in million euro	*GVA*	Eurostat[34]
Number of employed persons	*N*	Eurostat[35]
EMU convergence criterion bond yields	*rfb*	Eurostat[38]
Nominal interest rate on the overnight money market	*MMIR*	Zagreb Money Market[41]
Inflation calculated as the rate of change in harmonized consumer price index (*HICP*), 2010 = 100 in relation to previous quarter	*INF*	Author's calculation using CNB statistics[44]
Harmonized consumer price index (*HICP*), 2010 = 100	*HICP*	CNB statistics[44]
Variables for VAR model estimation		
Cyclical seasonally adjusted overnight money market interest rate	*I*	Author's calculation[a], original data available from Zagreb Money Market[41]
Cyclical seasonally adjusted house price index, 2010 = 100	*HP*	Author's calculation[a], original data available from CNB statistics[44]
Cyclical seasonally adjusted values of gross domestic product in million euro chain linked volumes, 2010 = 100,	*GAP*	Author's calculation[a], original data available from Eurostat[54]

DSGE: dynamic stochastic general equilibrium; EMU: European monetary union; CNB: Croatian National Bank.
[a]Using X-13 ARIMA SEATS method developed by US Census Bureau[36] and Hodrick-Prescott filter.[33]