Bank i Kredyt 51(4), 2020, 317-366

BANK I KREDYT
BANK & CREDIT

Comparing business cycles in the Eurozone and in Poland: a Bayesian DSGE approach

Andrzej Cieślik*, Jan Teresiński#

Submitted: 15 January 2018. Accepted: 27 January 2020.

Abstract

In this article we compare business cycles in the Eurozone and in Poland using a DSGE approach. We estimate the Smets and Wouters (2007) model using Bayesian methods and analyze impulse response functions of model variables, as well as their variance decomposition. Although we do not find significant differences in structural parameters' estimates, it turns out that persistence and volatility of shocks differ among two economies. Impulse response functions are comparable and output fluctuations are driven by similar demand shocks, but we observe a significant effect of the exogenous spending shock in the Eurozone and the price markup shock in Poland. Our analysis also shows that the euro adoption in Poland is currently not recommended, unless relevant changes in macroeconomic and labour market policies are implemented.

Keywords: Bayesian estimation, business cycles, DSGE model, Eurozone, Poland

JEL: E32, E37, E63

* University of Warsaw, Faculty of Economic Sciences; e-mail: cieslik@wne.uw.edu.pl.
# European University Institute, Department of Economics; e-mail: Jan.Teresinski@EUI.eu.

1 Introduction

In this paper we compare business cycles in the Eurozone and in Poland and examine the structural features of their economies. The economy of the Eurozone is the largest European economy and constitutes the core of the European Union, while Poland is an emerging economy that after its successful economic transition aspires to catch up with Western Europe in terms of the level of *per capita* income and is obliged to adopt the euro in future. Our motivation to study business fluctuations of the Eurozone and Poland comes from the fact that their economies are interdependent and we investigate how strong these relations are. In particular, the Eurozone is the main foreign trade and investment partner for Poland. Therefore, it is important to explore to what extent Poland's economy and its business cycle is similar to that of the Eurozone. This issue has several important policy implications, not only concerning the possible euro adoption in Poland, but also the way that the relevant economic policy should deal with the shocks affecting key macroeconomic variables.

This paper has several goals. First, we compare business cycle properties in the Eurozone and Poland to find out which shocks are responsible for the business cycle development in their economies and how big the persistence of these shocks is. In addition, we simulate the model to see whether these economies react to exogenous shocks in the same way. The next objective is to estimate the structural parameters of the economies of the Eurozone and Poland in order to compare them with each other. The last aim is to check how the use of the observations from the Great Recession period affects the estimates of the model parameters.

The general hypothesis of our study is that business cycles in the Eurozone and in Poland are similar. The specific hypotheses to be validated are as follows: i) the structural parameters of their economies do not differ significantly, ii) the persistence of the shocks as well as their standard deviations is similar in the Eurozone and Poland, iii) crisis increases standard deviations of the shocks, iv) output fluctuations in both economies are driven by the same shocks to a similar degree, v) the impulse responses of macroeconomic variables are comparable between the Eurozone and Poland. These hypotheses are validated empirically using macroeconomic time series.

In our empirical study we employ the dynamic stochastic general equilibrium (DSGE) model based on the approach proposed by Smets and Wouters (2007). We estimate this model using quarterly data from the period 2001–2018 on seven macroeconomic time series: output, consumption, investment, hours worked, real wage, inflation, and interest rate for the Eurozone and for Poland, applying the Bayesian techniques. Next, we simulate the model to obtain impulse response functions, forecast error variance decomposition and historical decomposition of the times series on the exogenous shocks' influence. All the calculations, estimations and simulations are done using Dynare software.

The paper is organized as follows. In section 2 we review previous studies on business cycles in Poland based on the DSGE approach in the context of euro adoption and then specify the value added of our study. In section 3 we describe our analytical framework which is based on the theoretical DSGE model developed by Smets and Wouters (2007). In section 4 we describe the dataset and the estimation methodology. In section 5 we present the prior and the posterior distributions of structural parameters and of parameters describing the stochastic processes. In section 6 we compare estimates from the sub-periods: before and after the Great Recession started. In section 7 we run model simulations and analyse the Bayesian impulse response functions. In section 8 we report the forecast error variance decomposition. In section 9 we show the decomposition of macroeconomic variables from the dataset on the exogenous shocks included in the model. The paper ends with some concluding remarks.

2 Literature review

In this section we provide a literature review on a DSGE modelling focused on the potential effects of the euro adoption in Poland and potential benefits and costs associated with it. In particular, previous studies investigate how well Poland's economy can manage asymmetric shocks after giving up its independent monetary policy. As those issues are also crucial to our study, below we summarize the main results of the previous studies.

In one of the earliest studies Kolasa (2009) compares Poland and the Eurozone using a two--country open-economy DSGE model with both tradable and non-tradable goods. His model is driven by fourteen stochastic shocks, seven for each of the countries. The purpose of his study is to assess the degree of heterogeneity between the two economies, i.e. differences in structural parameters and asymmetry of the shocks. He estimates the model using Bayesian techniques over the sample that ends at the second quarter of 2007, thus not taking into account observations from the 2008–2009 crisis. He argues that his results are rather inconclusive when it comes to the differences in structural parameters describing the behaviour of the economic agents in the two economies. Nevertheless, he finds that there are strong differences between the two economies in terms of volatility and synchronization of the shocks that hit them. His main conclusion is that it might be not optimal for Poland to join the Eurozone due to the high costs of losing monetary autonomy and adjustment of the exchange rate that helps to stabilize the economy.

In a more recent study Kolasa (2013) employs a simple DSGE model to compare business cycles between the Eurozone and the new member states of the European Union. He uses the business cycle accounting (BCA) framework and decomposes the fluctuations of output into the contributions of four economic wedges (efficiency, labour, investment and government consumption wedge) that correspond to production technology, intra- and intertemporal choices of the agents and the aggregate resource constraint. He studies the impact of each wedge on business cycles in different countries to find that the cycles in the Central and Eastern European countries differ from that of the Eurozone, although significant convergence of their economies is observed over time. The difference is mostly visible if one takes into account labour and investment wedges. This result suggests the need for tighter integration of capital and labour markets within the enlarged European Union.

Gradzewicz and Makarski (2013) also investigate the macroeconomic effects of losing the autonomy in monetary policy after the euro adoption in Poland. They construct a two-country open--economy DSGE model and study the effects of joining the Eurozone on the main macroeconomic variables in Poland. Their model features sticky prices to assure non-neutrality of money in the short run. They find that euro adoption in Poland is going to have significant effects on business cycles in Poland. In particular, they show that the volatility of Polish output would increase, while the volatility of inflation would drop. The changes in volatility are associated with the welfare loss as risk-averse consumption-smoothing agents dislike high variations in income and inflation. The overall welfare loss associated with the monetary policy regime change is found to be not particularly large. However, their model features fully flexible wages, which may lead to an underestimation of the costs of joining the Eurozone.

Brzoza-Brzezina, Makarski and Wesołowski (2014) investigate whether it would have paid for Poland to be in the Eurozone since 2007 using a small open economy DSGE model. They estimate the model and run a counterfactual simulation to find that the autonomous monetary policy and flexible exchange rate were crucial for stabilizing the Polish economy during the crisis period. If Poland had adopted the euro in 2007, the volatility of output and inflation would have increased significantly. The growth of GDP would have oscillated between -6% and +9% (under more extreme assumptions between -9% and +11%) instead of the actual interval of 1% and 7%. Hence, the euro adoption just before the crisis occurred would have led to the destabilization of Poland's economy. This makes them conclude that in the analysed period not giving up monetary independence was the right decision.

In another paper Brzoza-Brzezina, Jacquinot and Kolasa (2014) study boom-bust cycles in catching--up economies associated with the euro adoption. After joining the Eurozone, interest rates fall, which leads to an increase in spending and worsening of the current account. Over time, domestic prices increase, external competitiveness deteriorates, domestic demand decreases and boom is turned into bust. They study whether the right macroeconomic policy, i.e. cooling down the economy during the boom, may help to avoid this scenario using a four-country (Poland, the Eurozone, the US, and the rest of the world) EAGLE (Euro Area and GLobal Economy) model. They consider different policy experiments: revaluation of the exchange rate, increase in taxes and cuts in government expenditures. All of the changes in policy smooth the boom, but have different effects on other macroeconomic variables. They find that the best policy is the exchange rate revaluation, as it limits booms in output, consumption, investment and inflation, while causing the lowest costs in terms of welfare.

Most recently, Bielecki et al. (2019) investigate whether monetary or macroprudential policy could have prevented the European periphery's violent boom and bust after the euro adoption. They estimate a DSGE model for the two euro area regions, core and periphery, and conduct a series of historical counterfactual experiments in which monetary and macroprudential policies follow optimized rules that use area-wide welfare as the criterion. They show that a single monetary policy could have better stabilized output in both regions, but not the housing market or the periphery's trade balance. At the same time they argue that region-specific macroprudential policy could have substantially smoothed the credit cycle in the periphery and reduced the build-up of external imbalances.

Our contribution to the literature is the application of the Smets-Wouters model to the comparative study of the economies of the Eurozone and Poland. The value added of our study comes from the comparison of the business cycles in the Eurozone and Poland in the post-2008–2009 crisis period. We estimate the structural parameters of the two economies to demonstrate that the estimated persistence and volatility of the shocks hitting these two economies show some important differences. The new element with respect to previous studies is the investigation of the influence of the Great Recession on the stability of the estimates, as we have a sufficient number of crisis observations to perform a subsample estimation. Our general finding is that the recent crisis affected these two economies in a different way.

Another contribution of our study is the comparison of business cycle driving forces using the variance decomposition and the comparative analysis of the main macroeconomic variables' reactions to various shocks in the Eurozone and Poland, which has not been done before. We simulate the model for the two economies to obtain Bayesian impulse response functions. We show that reactions of model variables to exogenous shocks are comparable, although deviations from the steady state in the case of Poland are larger. We calculate the forecast error variance decomposition and we perform historical decomposition of the actual time series from the sample to find that output developments are driven by similar demand shocks. However, we also find a considerable importance of the exogenous spending shock in the Eurozone and the price markup shock in Poland. Finally, we derive some policy implications from our findings. In particular, we show that a relevant policy may help to make the two economies more similar to decrease the risk of the asymmetric shock that may hit them.

3 Analytical framework

In this paper we study the business cycle development by analysing the effects of various shocks on the economic fluctuations in the Eurozone and Poland. We also compare the structural features of these economies by estimating their structural parameters. The DSGE approach seems to be the best way to perform such a task. It should be emphasized that there is a variety of New Keynesian models one can find in the DSGE literature.[1] We decide to base our study on the Smets-Wouters framework, as it features a sufficiently sophisticated structure and a significant number of shocks, which confirmed its effectiveness in the business cycle analysis. We perform an international comparison of the two economies – the Eurozone and Poland, by estimating two independent models of them, similarly to what Smets and Wouters (2005) did for the Eurozone and the United States. However, we do not use their original model, but we apply the more developed version described in detail in Smets and Wouters (2007). As their model has no features specific to the US economy, it can be used for any other economy in the world.[2]

In this section we summarize our analytical framework that builds on the theoretical DSGE model developed in Smets and Wouters (2007), which is a development of the earlier framework presented in Smets and Wouters (2003). This is a New Keynesian DSGE model that is characterized by both price and wage stickiness, which allow for backward inflation indexation. The setup is based on the previous work by Christiano, Eichenbaum and Evans (2005), which includes habit formation in consumption and investment adjustment costs, that result is observed in practice hump-shaped responses of aggregate demand, as well as variable capital utilization and fixed costs in production. In addition to these ingredients, Smets and Wouters' (2007) setup features seven orthogonal shocks that drive the stochastic dynamics. The model contains a steady-state deterministic growth path driven by labour-augmenting technological progress.

The model features a continuum of households that maximize a non-separable utility function with two arguments: consumption and labour effort over an infinite life horizon. Consumption is relative to a time-varying external habit variable, depending on aggregate past consumption. Each household supplies a differentiated type of labour, which results in a monopolistic power over the supply of labour. This leads to a wage setting by households.[3] Wages are set with a markup over the ratio of the marginal disutility of an additional unit of labour and the marginal utility of an additional unit of consumption.

The wages set by households are not fully flexible. They follow the so-called Calvo (1983) scheme. Each household may reset its wage only with probability $1 - \xi_w$ in any given period, independent of the time passed since the last adjustment. Hence, in each period only a measure $1 - \xi_w$ of households

---

[1] There are several models considered canonical in the contemporary macroeconomic literature. For example, Romer (2012, p. 312) indicates three models that seek to find the ingredients which are crucial to capture the essence of modern economic fluctuations: Erceg, Henderson Levin (2000), Smets and Wouters (2003), and Christiano, Eichenbaum and Evans (2005).

[2] The example of application of the Smets-Wouters framework for countries other than the two big common currency areas is the study by Sin and Gaglianone (2006) for Brazil.

[3] It can be also seen as if labour is represented by the union with a monopolistic power that sets wages.

adjust their wages, while a fraction ξ_w keep their wages unaffected. As a result, the average duration of a wage is given by $1/(1 - \xi_w)$. Thus, ξ_w becomes a natural index of wage stickiness (see Galí 2008, p. 43). In addition to this it is assumed that wages that are not adjusted are partially indexed to past inflation rates, which makes wage dynamics dependent on past inflation.

Households own capital and rent capital services to firms. The supply of capital services can be increased in two ways. The first is to invest in an additional capital, which takes one period to be installed – then we deal with investment adjustment. The second way is to change the utilization rate of already installed capital – then we talk about capital utilization adjustment. Both options are costly. Households need to decide how much capital to accumulate given investment adjustment costs and how to adjust the capital utilization rate given capital utilization adjustment costs. Thus, we deal not only with the investment adjustment decisions, but also with a variable capital utilization.

Final output that is used for consumption and investment by households is produced in a perfectly competitive way, out of a continuum of intermediate differentiated goods. Each of these intermediate inputs is produced by a single firm which has a monopolistic power. Thus, a monopolistically competitive continuum of firms produce their own goods, decide on labour and capital inputs and set prices. The latter depend on marginal costs and also past inflation rates. Marginal costs depend on wages and the rental rate of capital.

Similarly to wages, prices are not fully flexible and set according to the Calvo (1983) scheme. Each firm is able reset its price only with a probability of $1 - \xi_p$ in any given period, independent of the time since the last adjustment. Therefore, each period a number $1 - \xi_p$ of producers adjust their prices, while a fraction ξ_p keep their prices unchanged. Consequently, the average duration of a price is given by $1/(1 - \xi_p)$ and ξ_p becomes a natural index of price stickiness (see Galí 2008, p. 43). Prices that are not reoptimized are partially indexed to past inflation rates. Implied inflation depends thus on its past rates and the New Keynesian-Phillips curve is not only forward, but also backward looking (hybrid scheme).

The model features exogenous spending that is associated with both government spending and net exports. Thus, the international openness of the economy is only implicit. The model is, in fact, estimated as a closed economy model. There is also no financial sector included in the model setting, while it can appear important taking into a recent financial crisis. Despite these problems, we strongly believe that the model has a sufficiently rich structure for our purpose, i.e. business cycle analysis and international comparison between the Eurozone and Poland.

We present the equations of the Smets and Wouters (2007) model in a log-linearized form.[4] The variables in these equations are log-linearized around their steady-state balanced growth path. Thus, they should be interpreted as the deviations from the steady state.

The aggregate resource constraint of the economy is given by

$$y_t = c_y c_t + i_y i_t + z_y z_t + \varepsilon_t^g \tag{1}$$

where y_t is an output, which is absorbed by consumption c_t, investment i_t, capital-utilization costs $z_y z_t$ (where z_t is a capital utilization rate) and exogenous spending ε_t^g (including government spending and net exports). The parameter c_y is a steady-state share of consumption in output (equal to $1 - i_y - g_y$), i_y is a steady-state investment-output ratio (equal to $(\gamma - 1 + \delta) k_y$ in which γ is a steady-state growth

[4] We do not derive the equations here, as it is not the purpose of this paper. The derivation can be found in the on-line appendix to the aforementioned paper.

rate of the model, δ is a depreciation rate of capital, while k_y is a steady-state capital output ratio), g_y is a steady-state exogenous spending-output ratio, z_y is a coefficient in capital utilization costs equal to $R^k k_y$, where R^k is a steady-state rental rate of capital.

The equation (1) can be then rewritten as

$$y_t = \left(1-(\gamma-1+\delta)k_y - g_y\right)c_t + (\gamma-1+\delta)k_y i_t + R^k k_y z_t + \varepsilon_t^g$$

Exogenous spending ε_t^g follows AR(1) process with an IID-Normal error term of the form

$$\varepsilon_t^g = \rho_g \varepsilon_{t-1}^g + \eta_t^g + \rho_{ga}\eta_t^a \tag{E1}$$

where η_t^g is an exogenous spending shock, while η_t^a is a productivity shock. The latter is present here, as net exports might be influenced by the innovation in productivity.

Consumption dynamics is given by

$$c_t = c_1 c_{t-1} + (1-c_1)E_t c_{t+1} + c_2\left(l_t - E_t l_{t+1}\right) - c_3\left(r_t - E_t\pi_{t+1} + \varepsilon_t^b\right) \tag{2}$$

where l_t are hours worked, r_t is a nominal interest rate, $E_t\pi_{t+1}$ is an expected future inflation rate, while ε_t^b is a risk premium disturbance term.

This is a kind of an Euler equation. Current consumption depends on a weighted average of past and expected future consumption. It is also influenced by an expected growth of hours worked and *ex ante* real interest rate, as well as a disturbance ε_t^b. We have three coefficients in the equation of consumption dynamics:

$$c_1 = \frac{\frac{\lambda}{\gamma}}{1+\frac{\lambda}{\gamma}},\quad c_2 = \frac{(\sigma_c - 1)\frac{W^h L}{C}}{\sigma_c\left(1+\frac{\lambda}{\gamma}\right)} \text{ and } c_3 = \frac{1-\frac{\lambda}{\gamma}}{\left(1+\frac{\lambda}{\gamma}\right)\sigma_c}$$

where γ is a steady-state growth rate, λ is a habit formation parameter, while σ_c is an inverse of the elasticity of intertemporal substitution (note that when $\lambda = 0$ and $\sigma_c = 1$, we have no external habit formation, as well as log utility in consumption and in turn $c_1 = c_2 = 0$, which leads to a traditional, purely forward looking consumption equation) and W^h is a steady-state wage, L are steady-state hours worked, while C is a steady-state consumption.

When $\sigma_c > 1$, consumption depends positively on current hours worked, but negatively on expected hours worked growth. The risk premium disturbance ε_t^b is a representation of a wedge between the interest rate that is set by the central bank and the return on assets faced by households. When a positive shock to this wedge (risk premium shock) occurs, there is an increase in the return on assets and a reduction in current consumption. The disturbance term ε_t^b follows AR(1) process with an IID-Normal error term of the form

$$\varepsilon_t^b = \rho_b \varepsilon_{t-1}^b + \eta_t^b \tag{E2}$$

where η_t^b is a risk premium shock.

Investment dynamics is given by

$$i_t = i_1 i_{t-1} + (1 - i_1) E_t i_{t+1} + i_2 q_t + \varepsilon_t^i \tag{3}$$

where q_t is a real value of an existing capital stock, while ε_t^i is a disturbance to the investment-specific technology.

Current investment depends on a weighted average of past and expected future investment, as well as the real value of capital stock and the disturbance to the investment-specific technology. The two coefficients in investment dynamics equation are given by

$$i_1 = \frac{1}{1 + \beta \gamma^{1-\sigma_c}} \text{ and } i_2 = \frac{1}{\left(1 + \beta \gamma^{1-\sigma_c}\right) \gamma^2 \varphi}$$

where β is a discount factor applied by households, σ_c is an inverse of the elasticity of intertemporal substitution, γ is a steady-state growth rate and φ is a steady-state elasticity of the capital adjustment cost function.

The higher the elasticity of adjusting capital, the lower the sensitivity of investment to the real value of existing capital stock. The disturbance to the investment-specific technology ε_t^i follows AR(1) process with an IID-Normal error term of the form

$$\varepsilon_t^i = \rho_i \varepsilon_{t-1}^i + \eta_t^i \tag{E3}$$

where η_t^i is an investment-specific technology shock.

The arbitrage equation for the value of capital is given by

$$q_t = q_1 E_t q_{t+1} + (1 - q_1) E_t r_{t+1}^k - \left(r_t - E_t \pi_{t+1} + \varepsilon_t^b\right) \tag{4}$$

where $E_t r_{t+1}^k$ is an expected real rental rate of capital, r_t is a nominal interest rate, $E_t \pi_{t+1}$ is an expected future inflation rate, while ε_t^b is again the risk premium disturbance term, described by the equation (E2).

The current real value of the existing capital stock depends positively on the expected future value of the capital stock, as well as the expected real rental rate of capital and negatively on the *ex ante* real interest rate and the risk premium disturbance. The coefficient in the equation of the value of existing capital equals

$$q_1 = \beta \gamma^{-\sigma_c} (1 - \delta) = \frac{1 - \delta}{R^k + (1 - \delta)}$$

where β is a discount factor applied by households, γ is a steady-state growth rate, σ_c is an inverse of the elasticity of intertemporal substitution, δ is a depreciation rate, while R^k is a steady-state rental rate of capital.

The aggregate production function is given by

$$y_t = \varphi_p\left(\alpha k_t^s + (1-\alpha) l_t + \varepsilon_t^a\right) \tag{5}$$

where k_t^s are capital services used in production, l_t are hours worked, and ε_t^a is a total factor productivity process. Output is produced using capital and labour with the shares α and $1 - \alpha$, respectively, while the production is also affected by the evolution of productivity. Parameter φ_p is reflecting a fixed cost in production (it is equal to one plus the share of fixed costs in production). Total factor productivity follows AR(1) process of the form

$$\varepsilon_t^a = \rho_a \varepsilon_{t-1}^a + \eta_t^a \tag{E4}$$

where η_t^a is a productivity shock.

Current capital services are given by

$$k_t^s = k_{t-1} + z_t \tag{6}$$

where z_t is a capital-utilization rate.

Due to the fact that new capital becomes effective with a one-quarter lag, for current capital services the capital installed in the previous period must be used. Current capital services are also a function of the capital-utilization rate.

The degree of capital utilization is given by

$$z_t = z_1 r_t^k \tag{7}$$

where r_t^k is a rental rate of capital.

The capital-utilization rate is a positive function of the rental rate of capital. Its coefficient is given by $z_1 = \frac{1-\psi}{\psi}$, in which ψ is a positive function of the elasticity of the capital utilization adjustment cost function.[5] ψ is normalized to be between 0 and 1. When $\psi = 1$, it is extremely costly to adjust the utilization of capital and therefore, the capital utilization remains constant. On the contrary, when $\psi = 0$, the marginal cost of changing the capital utilization is constant and in turn the rental rate in equilibrium is constant.

Capital accumulation is given by

$$k_t = k_1 k_{t-1} + (1-k_1) i_t + k_2 \varepsilon_t^i \tag{8}$$

[5] Not to be confused with φ – a steady-state elasticity of the capital adjustment cost function, appearing in investment dynamics equation (3).

Current capital stock depends on capital stock from the previous period, current investment, as well as the efficiency of the investment, which is captured by the disturbance ε_t^i, described by the equation (E3). The coefficients of the equation (8) are given by

$$k_1 = \frac{1-\delta}{\gamma} \text{ and } k_2 = \left(1 - \frac{1-\delta}{\gamma}\right)\left(1 + \beta\gamma^{1-\sigma_c}\right)\gamma^2\varphi$$

where δ is a depreciation rate, γ is a steady-state growth rate, σ_c is an inverse of the elasticity of intertemporal substitution, while φ is a steady-state elasticity of the capital adjustment cost function.

The price markup resulting from the firms' optimization problem is given by

$$\mu_t^p = mpl_t - w_t = \alpha\left(k_t^s - l_t\right) + \varepsilon_t^a - w_t \tag{9}$$

The price markup, i.e. the difference between the average price and the nominal marginal cost, equals the difference between marginal product of labour and the real wage w_t. The marginal product of labour itself is affected by capital services k_t^s, hours worked l_t (negatively) and total factor productivity process ε_t^a, described by the equation (E4).

New-Keynesian Phillips curve (NKPC) of the model is given by

$$\pi_t = \pi_1\pi_{t-1} + \pi_2 E_t\pi_{t+1} - \pi_3\mu_t^p + \varepsilon_t^p \tag{10}$$

where μ_t^p is a price markup, while ε_t^p is a price markup disturbance.

NKPC is derived from the profit maximization problem faced by price setting firms. Current inflation depends not only on expected future inflation, but also on the past inflation rate due to the fact that firms that cannot reoptimize their prices partially index them to the lagged inflation. The coefficients in NKPC are given by

$$\pi_1 = \frac{\iota_p}{1+\beta\gamma^{1-\sigma_c}\iota_p}, \quad \pi_2 = \frac{\beta\gamma^{1-\sigma_c}}{1+\beta\gamma^{1-\sigma_c}\iota_p}, \quad \pi_3 = \frac{1}{1+\beta\gamma^{1-\sigma_c}\iota_p}\frac{\left(1-\xi_p\right)\left(1-\beta\gamma^{1-\sigma_c}\xi_p\right)}{\xi_p\left(\left(\varphi_p - 1\right)\varepsilon_p + 1\right)}$$

where β is a discount factor applied by households, γ is a steady-state growth rate, σ_c is an inverse of the elasticity of intertemporal substitution, while ι_p reflects the degree of indexation to the past inflation, ξ_p represents the degree of price stickiness (probability that a particular firm cannot change its price) and ε_p is a parameter of the Kimball (1995) goods market aggregator.

Inflation is affected positively by its past and expected future rate, as well as by a price markup disturbance, while a current price markup influences it negatively. When there is no indexation to past inflation rates, we have $\iota_p = 0$, as well as $\pi_1 = 0$ and NKPC reduced to its standard purely forward-looking form. When all prices are flexible, we have $\xi_p = 0$ and in the case of no price markup shock, the price markup is constant. The higher the parameter in the Kimball goods market aggregator ε_p, the lower the speed of adjustment to the desired markup, due to the fact that the complementarity with other price setters is higher.

The price markup disturbance follows ARMA(1,1) process with an IID-Normal error term of the form:

$$\varepsilon_t^p = \rho_p \varepsilon_{t-1}^p + \eta_t^p - \mu_p \eta_{t-1}^p \tag{E5}$$

where η_t^p is a price markup shock. The MA part is added to capture the high-frequency fluctuations in inflation.

The rental rate of capital equation is given by

$$r_t^k = -(k_t - l_t) + w_t \tag{11}$$

There is a negative relation between the difference of capital k_t and labour l_t and the rental rate of capital. The rental rate of capital is also positively influenced by the real wage w_t.

The wage markup resulting from the households' optimization problem is given by

$$\mu_t^w = w_t - mrs_t = w_t - \left(\sigma_l l_t + \frac{1}{1-\frac{\lambda}{\gamma}} \left(c_t - \frac{\lambda}{\gamma} c_{t-1} \right) \right) \tag{12}$$

where γ is a steady-state growth rate, λ is a habit formation parameter, while σ_l is the elasticity of labour supply with respect to the real wage.

The wage markup is equal to the difference between the real wage and the marginal rate of substitution between hours worked and consumption. The marginal rate of substitution itself is related to the hours worked, as well as current and lagged consumption.

The real wage dynamics equation is given by

$$w_t = w_1 w_{t-1} + (1 - w_1)(E_t w_{t+1} + E_t \pi_{t+1}) - w_2 \pi_t + w_3 \pi_{t-1} - w_4 \mu_t^w + \varepsilon_t^w \tag{13}$$

where ε_t^w is a wage markup disturbance.

Current real wages depend not only on past w_{t-1} and expected future wages $E_t w_{t+1}$, as well as the current π_t and expected future inflation $E_t \pi_{t+1}$ level, but also on the past inflation rate π_{t-1} due to the partial indexation of not reoptimized wages to lagged inflation. The coefficients are given by

$$w_1 = \frac{1}{1+\beta\gamma^{1-\sigma_c}}, \quad w_2 = \frac{1+\beta\gamma^{1-\sigma_c}\iota_w}{1+\beta\gamma^{1-\sigma_c}}, \quad w_3 = \frac{\iota_w}{1+\beta\gamma^{1-\sigma_c}},$$

$$w_4 = \frac{1}{1+\beta\gamma^{1-\sigma_c}} \frac{(1-\xi_w)(1-\beta\gamma^{1-\sigma_c}\xi_w)}{\xi_w((\varphi_w - 1)\varepsilon_w + 1)}$$

where β is a discount factor applied by households, γ is a steady-state growth rate, σ_c is an inverse of the elasticity of intertemporal substitution, while ι_w reflects the degree of wage indexation to the past inflation, ξ_w represents the degree of wage stickiness (the probability that a particular household cannot change its wage), ($\varphi_w - 1$) is a steady-state labour market markup and ε_w is a parameter of Kimball (1995) labour market aggregator (used in this model instead of typical Dixit and Stiglitz (1977) one).

When there is no wage indexation to past inflation rates, we have $\iota_w = 0$, as well as $w_3 = 0$ and real wages are not affected by lagged inflation. If wages are perfectly flexible, we have $\xi_w = 0$ and the wage markup over the marginal rate of substitution between hours worked and consumption is constant. The higher the parameter in the Kimball labour market aggregator ε_w, the lower the speed of adjustment to the desired wage markup, due to the fact that the complementarity with other wage setters is higher.

The wage markup disturbance follows ARMA(1,1) process with an IID-Normal error term of the form

$$\varepsilon_t^w = \rho_w \varepsilon_{t-1}^w + \eta_t^w - \mu_w \eta_{t-1}^w \tag{E6}$$

where η_t^w is a wage markup shock.

The MA part is added to capture the high-frequency fluctuations in wages (similarly to the case of price markup disturbance).

The monetary policy reaction function is given by

$$r_t = \rho r_{t-1} + (1-\rho)\left(r_\pi \pi_t + r_y\left(y_t - y_t^p\right)\right) + r_{\Delta y}\left[\left(y_t - y_t^p\right) - \left(y_{t-1} - y_{t-1}^p\right)\right] + \varepsilon_t^r \tag{14}$$

where π_t is a current inflation rate, y_t is an actual output, while y_t^p is a potential output, defined as the level of output under flexible-price and flexible-wages economy with no price and wage markup shocks, r_π is a coefficient corresponding to inflation in the monetary policy rule, r_y is a coefficient corresponding to output gap in the monetary policy rule, $r_{\Delta y}$ is a coefficient of feedback from a change in the output gap in the monetary policy rule, while ε_t^r is a monetary policy disturbance.

The monetary policy rule used here is the generalized Taylor (1993) rule. Monetary authorities set a nominal interest rate in response to the evolution of inflation and the output gap. The term ρr_{t-1} is added to capture the interest rate smoothing. A short-run feedback from the change in output gap is also included in the rule.

The monetary policy disturbance follows AR(1) process with an IID-Normal error term, of the form

$$\varepsilon_t^r = \rho_r \varepsilon_{t-1}^r + \eta_t^r \tag{E7}$$

where η_t^r is a monetary policy shock. The monetary policy function closes the model setting.

The model we use has six features believed to be necessary to capture the behaviour of actual economies: sticky nominal prices and wages, habit formation in consumption, investment adjustment costs, variable capital utilization and fixed costs in production. The stochastic dynamics is driven by seven orthogonal structural shocks: a total factor productivity shock η_t^a, two shocks affecting intertemporal choices – a risk premium shock η_t^b and an investment-specific technology shock η_t^i, two shocks affecting intratemporal margin – cost-push shocks – a price markup shock η_t^p and a wage markup shock η_t^w, and two policy shocks – an exogenous spending shock η_t^g and a monetary policy shock η_t^r. In the model we deal with fourteen endogenous variables: output y_t, consumption c_t, investment i_t, hours worked l_t, capital k_t, capital services used in production k_t^s, capital utilization rate z_t, real value of existing capital stock q_t, rental rate of capital r_t^k, wage markup μ_t^w, real wage w_t, price markup μ_t^p, inflation rate π_t, and nominal interest rate r_t.

The model features a significant number of structural parameters. Parameters related to households include: a habit formation parameter λ, the inverse of the elasticity of intertemporal substitution σ_c, the elasticity of labour supply with respect to the real wage σ_l, and the discount factor applied by households β. Parameters connected with the capital utilization and production function are: a depreciation rate of capital δ, a steady-state elasticity of the capital adjustment cost function φ, a positive function of the elasticity of the capital utilization adjustment cost function ψ, a share of capital in production α, a parameter reflecting the fixed cost in production φ_p. Parameters of labour, goods and final output market consist of: a steady-state labour market markup φ_w, a parameter of the Kimball labour market aggregator ε_w, a parameter of the Kimball goods market aggregator ε_p, and a steady-state exogenous spending-output ratio g_y.

We also have parameters connected with price and wage inflation and the indexation to past inflation rates: degree of indexation to the past inflation ι_p, degree of price stickiness ξ_p, degree of wage indexation to the past inflation ι_w, degree of wage stickiness ξ_w. In addition to this, parameters of the monetary policy reaction function are: a reaction coefficient corresponding to inflation in the monetary policy rule r_π, a reaction coefficient corresponding to the output gap in the monetary policy rule r_y, a reaction coefficient of change in the output gap in the monetary policy rule $r_{\Delta y}$, and a degree of interest rate smoothing ρ.

Finally, the model features parameters that are related to the exogenous stochastic processes: seven persistence parameters – one for each of the disturbances (denoted by ρ), seven standard deviation parameters – one for each of the shocks (denoted by σ), as well a moving-average parameter in price markup process μ_p, a moving-average parameter in wage markup process μ_w, and a total factor productivity shock parameter in exogenous spending process ρ_{ga}.

4 Statistical data and estimation methodology

For the purpose of our empirical investigation, which aims to estimate the parameters of the economies of the Eurozone and Poland, we use seven quarterly macroeconomic time series: output, consumption, investment, hours worked, real wage, inflation, and interest rate from the period 2001–2017. Output is the gross domestic product (GDP) expressed in market prices in euros. Consumption is a final consumption expenditure by households in market prices in euros. Investment is a gross capital formation in market prices in euro. Hours worked are computed as an average number of usual weekly hours of work in the main job multiplied by the employment index of 15 years old or over. Real wage is derived from a nominal labour cost index. Inflation is calculated as the difference of the logs of the GDP deflator. The interest rate is a central bank official refinancing operation rate. All these data are taken from the Eurostat.

Output, consumption, investment and nominal wage were divided by a price index (GDP deflator), logarithmized and multiplied by 100. For the obtained values we have calculated the first differences. Hours worked were logarithmized and multiplied by 100 and then for these values we obtained the differences from the average of the period, as it is assumed that hours worked are zero in the steady state. The central bank interest rate was divided by 4 to make it consistent with the interval of the model, which is a quarter. The transformation of the data results in the following measurement equations

$$100\tilde{y}_t = \bar{\gamma} + [y_t - y_{t-1}] \tag{M1}$$

$$100\tilde{c}_t = \bar{\gamma} + [c_t - c_{t-1}] \tag{M2}$$

$$100\tilde{i}_t = \bar{\gamma} + [i_t - i_{t-1}] \tag{M3}$$

$$100\tilde{w}_t = \bar{\gamma} + [w_t - w_{t-1}] \tag{M4}$$

$$100 logL_t = \bar{l} + l_t \tag{M5}$$

$$100\tilde{p}_t = \bar{\pi} + \pi_t \tag{M6}$$

$$R_t = \bar{r} + r_t \tag{M7}$$

where $\tilde{y}_t, \tilde{c}_t, \tilde{i}_t, \tilde{w}_t, \tilde{p}_t$ are observable growth rates (log differences) of GDP, consumption, investment, real wages and prices, L_t are observable hours worked, R_t is observable interest rate, $\bar{\gamma}$ is a quarterly trend growth rate of real GDP, consumption, investment and wages, $\bar{l}$ is a quarterly steady-state hours worked (normalized to zero), $\bar{\pi}$ is a quarterly steady-state inflation rate, $\bar{r}$ is a quarterly steady-state nominal interest rate.

The left-hand sides of the measurement equations consist of the transformed data and that is the way they enter the model specification. The right-hand sides of the measurement equations consist of the variables of the model and steady-state rates that can be estimated. The parameters of the model are estimated with Bayesian techniques using Dynare software. Following Smets and Wouters (2005) in our international comparison between the Eurozone and Poland we estimate two independent closed--economy models. As we use Bayesian techniques, we begin with providing priors of the distributions of the parameters and then we obtain the posterior distribution numerically from the Metropolis-Hastings algorithm. Bayesian estimation allows for combining the tradition of calibration and estimation, since we augment the information from the data by our prior beliefs on the parameters distribution.

The provided prior information is updated by the probability of the data in the next step of the Bayesian estimation. The resulting posterior distribution combines the prior information with the probability of the data. Posterior estimates are obtained in two steps. First, the log posterior function based on the linearized state-space representation of the DSGE model is maximized to obtain the mode of the parameters distribution. Second, the Metropolis-Hastings algorithm is applied to obtain a complete picture of the posterior distribution numerically.

Technically, we replicate the Metropolis Hastings algorithm 100 000 times. We apply five parallel chains of the Metropolis Hastings algorithm which improves the computation of between group variance of the parameter means. We drop one fifth of the initially generated parameter vectors before using posterior simulations, as first draws depend on the initial points and may be far away from the desired distribution. Besides the mode from maximization of the posterior distribution we also obtain the mean value and highest posterior density intervals (so-called credibility sets – which are in principle Bayesian confidence intervals) at the 90% level.

Similarly to Smets and Wouters (2007, p. 592), we treat five parameters as fixed in the estimation procedure. Their values are provided in Table 1.

The depreciation rate is set at 0.025 on a quarterly basis. The steady-state exogenous spending ratio is set at 23% for the Eurozone and 21% for Poland. These values correspond to the average values of this ratio over the analysed period. The steady-state labour market markup is set at 1.5, while the curvature parameters of the Kimball goods and labour market aggregators are both set at 10.

5 Prior and posterior distributions of structural and stochastic processes' parameters

The priors of the structural parameters of the model are presented in the Table 2. As we can see, Smets and Wouters (2007) apply quite standard calibration concerning the utility function of the households. The habit formation parameter reflecting the influence of lagged consumption on current consumption is set at 0.7. The inverse of the intertemporal elasticity of substitution is set at 1.5, while the elasticity of labour supply with respect to the real wage is set at 2. The discount factor applied by households β is set at 0.9975. The prior for the investment adjustment cost parameter is set at 4, while the parameter of capital utilization adjustment costs is set at 0.5. The share of capital in production equals 0.3, while the fixed cost parameter is set at 1.25.

Both price and wage stickiness parameters are set to be equal to 0.5, which corresponds to the average length of the price and wage contracts equal to half a year. The indexation parameter to past inflation rates of prices and wages is also set at 0.5. The priors of the monetary policy reaction function parameters are set according to the standard Taylor (1993) rule. Thus, the coefficient corresponding to inflation is set at 1.5, while the one of the output gap is equal to 0.125. The latter value is also set for/as the reaction coefficient of the change in the output gap. The coefficient of the lagged interest rate in the interest rate rule, reflecting the interest rate smoothing, is equal to 0.75. Finally, we also have priors for the quarterly steady-state growth rate, inflation and hours worked, that are set at 0.4, 0.625 (2.5 on an annual basis) and 0, respectively.

The posterior distributions of structural parameters for the Eurozone and Poland are presented in the Table 3. As we can see, the habit formation parameter is similar in the Eurozone and Poland and a little bit higher than its prior value. Consumption from the previous period is relatively important for households in both economies. The inverse of the elasticity of intertemporal substitution is close to one in both economies, although lower in Poland. Thus, Polish households are more willing to substitute their consumption over the periods after the changes of the real interest rate compared to that of the Eurozone. However, closeness to one of the estimated parameter means suggests that the income and substitution effects of those changes might cancel out one another. The elasticity of labour supply is estimated to be very much below the prior in the Eurozone. It is also lower than the prior in the case of Poland. Households are not very reactive to the changes in the real wage. The subjective discount rate is lower in the Eurozone than in Poland, which may be related to lower market rates in the Eurozone.

When it comes to capital utilization, while capital utilization adjustment is more costly in Poland than in the Eurozone, investment adjustment seems more costly in the Eurozone. However, the differences are not very large. Surprisingly, the share of capital in production is estimated to be slightly lower in the Eurozone than in Poland. One can argue, though, that the equipment in the Eurozone, despite being abundant, is obsolete compared to that of Poland, which results in the lower capital share. It should be emphasized that both estimated values are significantly lower than the prior. The fixed cost is estimated to be almost the same in both economies.

It turns out that prices are more sticky in the Eurozone than in Poland (average duration of price contracts about 5 and 3.3 quarters, respectively). The same is true for wages, which are again more sticky in the Eurozone than in Poland (with average duration of wage contracts about 5 and 3 quarters, respectively). Price indexation to past inflation is comparable between the economies, while in the case of wages we observe a significant indexation to past inflation only in the Eurozone.

If we analyse the monetary policy reaction function, it turns out that in the case of the Eurozone, monetary authorities are more responsive to inflation compared to that of Poland. The reaction coefficient to the output gap is much higher in the Eurozone than in Poland, while the response of the coefficient to the change in the output gap is similar, although lower than the one for the output gap level in the case of the Eurozone, while it is higher in the case of Poland. Finally, we observe a significant degree of interest rate smoothing in both economies. The coefficient is, however, higher in Poland, which means that the Polish monetary authorities dislike jumps in the interest rate they set more than in the Eurozone.

The steady-state quarterly growth rate is estimated to be three times higher in Poland than in the Eurozone, while the steady-state inflation is lower in the Eurozone than in Poland. Finally, the steady-state hours worked are estimated to be above the prior, which is zero. It turns out that the mean of estimated hours worked is four times lower in Poland than in the Eurozone.

We can note that the parameter estimates are quite similar between both economies. Some estimated differences include the lower subjective interest rate in the Eurozone, the higher costs of capital utilization adjustments in Poland, higher price and wage stickiness in the Eurozone, significant indexation of wages to past inflation rates only in the Eurozone and higher responsiveness of the monetary authorities to inflation in the Eurozone. Nevertheless we do not find any reason to reject our hypothesis that the structural parameters of these two economies do not differ significantly.

Prior distributions of the parameters of stochastic processes are presented in Table 4. The parameters reflecting persistence of the shocks are assumed to follow a beta distribution with a mean 0.5 and a standard deviation equal to 0.2. Standard deviations of the shocks are assumed to follow an inverse-gamma distribution with a mean 0.1 and a standard deviation equal to 2. The moving-average parameters in price and wage markup processes and a total factor productivity shock parameter in exogenous spending process are assumed to follow a beta distribution with a mean 0.5 and a standard deviation equal to 0.2.

The posterior distributions of the stochastic processes parameters for the Eurozone and Poland are presented in the Table 5. As we can see, the technology shock is estimated to be more persistent in the Eurozone than in Poland, while the risk premium shock is more persistent in Poland than in the Eurozone. The persistence of the investment-specific technology shock is higher in the Eurozone, while in Poland the persistence is quite small. Both price markup shock and the wage markup shock are estimated to be more persistent in the Eurozone. The persistence of the two policy shocks is similar between the two economies, although the persistence of the exogenous spending shock is much higher than that of the monetary policy.

When it comes to the estimated standard deviations of the shocks, we notice some significant differences between the two economies. It is clear that although less persistent, total factor productivity shock is twice as volatile in Poland than in the Eurozone. The standard deviation of the risk premium shock is estimated to be relatively low in both economies. The investment-specific technology shock is estimated to be twice as volatile in Poland as in the Eurozone. The price markup shock is only slightly volatile in the Eurozone, while it is highly volatile in Poland. The variability of the wage markup shock is also higher in Poland, but the magnitude is significantly lower, compared to that of the price markup shock. The volatility of the exogenous spending shock is higher in Poland than in the Eurozone. Finally, the monetary policy shock is estimated to be almost negligibly volatile.

The moving average parameter in the price markup process that captures high-frequency fluctuations in inflation is higher in the Eurozone than in Poland. The moving average parameter in the wage markup process that captures high-frequency fluctuations in wages is slightly higher in the Eurozone. The coefficient of total factor productivity in the exogenous spending process is estimated to be slightly higher in the Eurozone, which may mean that the Eurozone's net exports are more affected by changes in productivity than net exports in Poland.

Summing up, we can note that in the case of stochastic processes there are significant differences between the Eurozone and Poland. While in both economies the most persistent shock is the exogenous spending shock, the second most persistent shocks are the productivity shock in the Eurozone and the risk premium shock in Poland. An even more striking picture comes from the estimated volatility. The most volatile shock in the Eurozone is the productivity shock, while the most volatile shock in Poland is the price markup shock, the one that is only a little volatile in the Eurozone. The investment-specific technology shock is also significantly more volatile in Poland than in the Eurozone. This might suggest that the economies are hit by the different shocks to a different degree and the common monetary policy might not be advisable to them unless some changes in other policies are introduced to reduce these asymmetries.

6 Sensitivity analysis: subsample estimates

In this section we perform the subsample estimation to verify the influence of the Great Recession on the magnitude of the estimated parameters. In particular, we check how stable our estimates are and how the observations from the crisis period affect the standard deviations of the shocks. Therefore, we estimate the model over two subsamples: 2001 Q1–2008 Q2 and 2008 Q3–2017 Q4. Following Smets and Wouters (2007, p. 603) we focus our attention on the modes of posterior distribution. The results of our sensitivity analysis are presented in Table 6 (structural parameters) and in Table 7 (stochastic processes' parameters).

As we can see, there is an important impact of the crisis on the estimates of both structural parameters and the parameters of stochastic processes. Moreover, its influence shows different patterns for the estimates of the Eurozone and Poland. While the elasticity of intertemporal substitution increases significantly in Poland, it increases only slightly in the Eurozone. The elasticity of labour supply does not change in the case of the Eurozone and increases considerably in Poland.

Although Polish households became more willing to substitute their consumption and labour supply between periods, this was not the case in the Eurozone. Past consumption habit is more important after the crisis both in Poland and in the Eurozone. The estimation shows that the subjective discount rate decreases during the crisis and therefore the households became more patient. As the future income became more uncertain due to the crisis, the households started to care more about the future.

As a result of the crisis investment the adjustment costs parameter decreased both in Poland and the Eurozone, while the capital utilization adjustment cost parameter decreased in Poland and the opposite happened in the Eurozone. It turns out that in the Eurozone it was relatively easier to adjust investment and in Poland it was relatively easier to adjust the capital utilization rate. Polish investments might have been somewhat fixed due to European Union funds, thus making the capital utilization adjustment more likely. The share of capital in production declined both in Poland and in the Eurozone as a response to the crisis. We observe an increase in the importance of fixed costs in production in Poland and a decrease in the Eurozone. The latter faced a significant decline in output, which is reflected in the estimated increase in the influence of fixed costs.

We observe an increase in price stickiness in both economies. The average duration of the price contracts increases (at the mode of posterior distribution) to 3 quarters in Poland and 5 quarters in the Eurozone. One can see that the indexation of prices to past inflation increases in Poland and decreases in the Eurozone. Wages became slightly more sticky in Poland, while the stickiness in the Eurozone did not change. Wages indexation to past inflation decreases significantly in Poland and slightly in the Eurozone. Labour market reaction in the direction of more flexibility was not observed in the Eurozone, while in Poland indexation decreased at the expense of more wage stickiness.

Finally, we can notice that monetary policy in Poland became less responsive to inflation and to the output gap. Indeed the policy interest rate in Poland has remained unchanged since March 2015. In the Eurozone the reaction to the output gap also decreases, but the response to inflation increases. This can be explained by some fears of higher inflation due to financial assistance packages given to the members of the Eurozone facing a debt crisis. The estimated steady-state growth rate is reduced in Poland, but not in the Eurozone. Steady-state inflation in Poland is not affected, while in the Eurozone it is estimated to be higher. Steady-state hours worked increase due to the crisis. All in all, though, we observe that the reactions of the structural parameters estimates in the two economies differ after the Great Recession.

When we analyse the impact of the crisis on the estimates of the stochastic processes parameters, the picture is also not uniform. In Poland the government spending shock is the only one of which persistence increases. The investment-specific technology shock features the highest decline in persistence, which is not observed in the Eurozone. There, it is only in the case of the risk premium shock that the persistence does not actually increase. The highest increase in persistence is observed for the price and wage markup shock and government spending. All of these show a decline in persistence in Poland. It might reflect the fact that imperfect competition in the product and labour market prolonged the effects of crisis in the Eurozone, while the Polish economy recovered from the economic slowdown quickly. An increase in the persistence of exogenous spending in Poland and in the Eurozone might be related to the inflow of the EU funds to Poland and some cuts in the Eurozone government spending with long-term effects. Productivity becomes less persistent in Poland and more persistent in the Eurozone. The monetary policy shock shows slightly less persistence in Poland, but its persistence in the Eurozone increases significantly.

When it comes to the standard deviations of the shocks, it turns out that they increase in Poland as a response to the crisis. The only exceptions are the wage markup shock and the monetary policy shock. The increase in the variability of productivity can be explained by the fact that before the crisis, say at the potential level of output, the variability of demand shocks was higher, while later the supply shocks became more volatile. Volatility of productivity also increases in the Eurozone, where we also observe slight increases in the volatility of other shocks with the exception of the government spending shock and price markup shock. In Poland the monetary policy shock became less volatile in the crisis as the changeability of Polish central bank interest rates was significantly reduced during the crisis. Unfortunately, our estimates of the standard deviation of the total factor productivity shock and the price markup shock are not very informative in the case of Poland, as the mode of posterior distribution reached the upper bound that was set as a limit of standard deviations in every sample used. Nevertheless, we observe that these standard deviations are much higher in Poland than in the Eurozone. All in all, it is clear that there are significant differences between the Eurozone and Poland in the reaction of the estimated parameters on the Great Recession.

7 Bayesian impulse response functions

The estimated model includes seven structural shocks: total factor productivity shock, risk premium shock, investment-specific technology shock, price markup shock, wage markup shock, exogenous spending shock, and monetary policy shock. For each of these shocks we perform a simulation of the model that corresponds to the random development of the shocks. Dynare solves a stochastic, rational expectations model and computes a Taylor approximation of the decision and transition functions to compute impulse response functions (IRFs) of the model. The latter are computed as the difference between the trajectory of a variable following a shock of one standard deviation magnitude and its steady-state value.

As we deal with the estimated model, mean values of a posterior distribution of impulse response functions are presented. To construct it, Dynare takes parameters' and shocks' values from the corresponding estimated distributions and generates an IRF for each set of draws. The distribution of impulse response functions is generated thanks to repeating this process a sufficient number of times. In addition, we also provide the highest posterior density intervals (credibility sets – i.e. Bayesian confidence intervals) at the 90% level. We analyse IRFs for 40 periods (quarters), which corresponds to 10 years. The model is in a log-linearized form and thus the deviations depicted on the graphs are percentage deviations from the steady state.

Bayesian impulse response functions to a total factor productivity shock for selected variables of the model are presented on Figure 1. As we can see, output and consumption increase after the shock in both economies. Later on, however, consumption in the Eurozone falls below the steady-state level, a reaction not observed in Poland. While capital and investment expand in Poland several periods after the shock, they both fall in the Eurozone. The hours worked responds negatively to the productivity shock, which indicates that the wealth effect resulting from the higher income dominates over the substitution effect due to an increase in the real wage. This outcome is consistent with the analysis of Galí (1999) and Francis and Ramey (2005). Even though the central bank decreases the interest rate, in Poland it is not enough to offset the decline in marginal costs and to prevent the opening up of the (negative) output gap, thus leading to a fall in inflation. Since inflation in the Eurozone increases, the central bank increases its policy rate in order to combat inflation. When it comes to the international comparison, in addition to different reactions of capital and investment, the magnitude of impulse responses in Poland is significantly higher than that of the Eurozone.

Figure 2 depicts the Bayesian impulse responses to a negative risk premium shock for selected variables. A negative risk premium shock leads to a decrease in the wedge between the interest rate faced by households and set by the central bank. As interest rates are lower, aggregate demand rises and we observe an increase in consumption, investment and output. In the case of Poland, after an initial increase those variables fall below the steady-state level. This might reflect some sort of boom-bust cycle. In the case of the Eurozone, an increase in output and consumption is preceded with a fall in those variables. This might be related to negative wealth effects which precede intertemporal substitution. Hours worked and capital used in production follow the pattern of output. The reaction of the central bank is consistent with the development of inflation and the output gap: a decrease in these two induces a fall in the interest rate, while an increase in inflation in Poland calls for upward adjustment of the policy rate. All in all, in the case of the risk premium shock, the reactions of both economies are quite different and their magnitude is again higher in Poland. It is also the case that the real wage and the rental rate of capital in Poland show some additional fluctuations, not observed in the Eurozone.

Impulse response functions to the investment-specific technology shock for selected variables are shown in Figure 3. It can be seen from the graphs that after the investment-specific technology shock there is an increase in output and a significant increase in investment. Contrary to the productivity shock, hours worked initially increase and then decline below the steady-state level. Capital used in production responds in a hump-shaped manner, while the capital rental rate shows the inverse hump-shaped pattern, as the capital instalment costs are lower after the shock. These reactions are similar for both the Eurozone and Poland. We can notice some differences in the responses of the remaining variables. In particular, in the Eurozone we observe an increase in the nominal interest rate and a fall in consumption, while in Poland after an increase in the nominal interest rate it falls below the steady-state level for several periods, which induces a consumption boom.

Figure 4 summarizes the effects of a price markup shock on selected variables. The price markup shock is a cost-push type of shock. It leads to an increase in inflation, a drop in output and its components – consumption and investment. However, in Poland in the subsequent periods we observe an increase in output and its components, not observed in the Eurozone. An increase in inflation is followed by an increase in the central bank interest rate. The responses of hours worked, capital and their factor rewards follow the pattern of output response. It should be emphasized that the impulse responses are much less pronounced in the Eurozone than in Poland – the Eurozone economy is almost unaffected by the price markup shock, which is also indicated by large credibility sets around zero.

Figure 5 presents the mean impulse responses to a wage markup shock. The wage markup shock leads to an increase in real wages and to a decrease in hours worked in Poland and in the Eurozone. In Poland this initial decline is followed by an increase in hours worked after several periods. In the Eurozone the decline lasts longer and does not transform into an increase in working hours. This indicates that in the Polish labour market the wealth effect is initially stronger than the substitution effect, while in the Eurozone the income effect dominates for the whole horizon of the analysis.

Although at first output falls, after some time we observe a slight increase in output, consumption and investment in Poland, but not in the Eurozone, where the decrease is permanent. Inflation in Poland features some fluctuations around the steady-state level, while in the Eurozone we observe a hump-shaped response. The reaction of the central bank is consistent with inflation and the output gap development but it seems that the Polish monetary authorities are less responsive to wage inflation than that of the Eurozone. Again, we observe large credibility sets around the impulse responses, which indicates that the estimated reactions are small and not significantly different from zero.

Impulse responses to an exogenous spending shock are presented in Figure 6. It can be noted that a rise in exogenous spending leads to an increase in output and hours worked in both economies, while the effects are much stronger for Poland compared to the Eurozone. We observe a crowding-out effect for consumption in both the Eurozone and in Poland. Surprisingly, the economies differ if it comes to the second component of the aggregate demand. Investment (and capital in production) increases in the Eurozone, but declines in Poland. A similar pattern is observed for the real wage. We can also observe an increase in inflation that is suppressed by an increase in the interest rate in Poland and a fall in inflation and the interest rate in the Eurozone.

Impulse responses to a monetary policy shock associated with an increase in the central bank interest rate are shown in Figure 7. The monetary policy shock leads to an initial drop in output, hours worked, consumption, and investment. Similarly, inflation declines below its steady-state level both in Poland and the Eurozone. A decrease in hours worked and a gradual increase in capital in production make labour more productive, which translates into higher real wages that gradually fall to their steady-state level.

We can note that there are some differences between the reactions of the two economies to the structural shocks present in the model. First of all, in general the magnitude of the reaction (i.e. the deviation from the steady state) is higher in Poland than in the Eurozone. Second, an exogenous spending shock leads to a crowding out of consumption in both economies, but it crowds out investment only in Poland. Third, the Eurozone economy is almost unaffected by the price markup shock due to the response of the central bank. Fourth, the wage markup shock leads to a decrease in hours worked in the Eurozone, while in Poland hours worked increase after several periods. Fifth, the monetary authorities are relatively more responsive to both price and wage inflation in the Eurozone than in Poland. The reaction of the central bank in Poland creates some additional fluctuations of the real wage at long time horizons.

8 Forecast error variance decomposition

In this section we present a forecast error variance decomposition for output, consumption and inflation. We show which shocks are responsible for forecast errors of selected variables and how big their influence is. The variance decomposition is calculated through Cholesky decomposition of the covariance matrix of the exogenous variables. The decomposition is computed relative to the sum of the contribution of all the shocks, thus it sums up to 100%. We present the variance decomposition at different time horizons – 1, 2, 4, 10, 40 and 100 quarters based on the mode of the model's posterior distribution.

The forecast error variance decompositions of output in the Eurozone and in Poland are shown in Tables 8 and 9, respectively. It can be noted that the most important shocks explaining the variance of forecast error of output in Poland are the risk premium shock, the monetary policy shock and the price markup shock, while in the Eurozone these are the risk premium shock, the exogenous spending shock, and the investment-specific technology shock. The effects of some demand shocks like the monetary policy shock in both economies and the risk premium shock in Poland are rising instead of falling as we increase the time horizon. In contrast, the effect of the total factor productivity shock in Poland is decreasing instead of increasing, while in the Eurozone, although rising initially, it is still lower compared to the impact of the demand shocks. A productivity change is in fact not persistent in Poland, while it shows certain persistence in the Eurozone. The price markup shock is much less important in the Eurozone, which is not the case in Poland. Finally, the wage markup shock seems to be relatively small in both economies.

The forecast error variance decompositions of consumption in the Eurozone and in Poland are reported in Tables 10 and 11, respectively. As it is clear from the tables, the main drivers of forecast error of consumption in both economies are the risk premium shock and the monetary policy shock. The former is associated with a wedge between the interest rate set by the central bank and perceived by households. Its effect is decreasing in favour of the monetary policy shock in both countries and also the total factor productivity shock in the Eurozone. Another influential shock is the price markup shock in Poland, but not in the Eurozone, where the TFP shock is more important. The rest of the shocks seem to be unimportant in explaining the variability in consumption.

The forecast error variance decompositions of inflation in the Eurozone and in Poland are shown in Tables 12 and 13, respectively. When it comes to forecast error variance decomposition of inflation, it is clear that the most important shocks in the Eurozone are the TFP shock, the price markup shock and the risk premium shock. At the same time, in Poland the most important shocks are the risk premium shock, the monetary policy shock and the price markup shock. The influence of the shock related to monetary policy is increasing with a time horizon applied both in Poland and in the Eurozone. Surprisingly, the wage markup shock has only a little influence on inflation variability in Poland and only some in the Eurozone. A certain importance at longer time horizons could be attached to the risk premium shock in Poland and the total factor productivity shock in the Eurozone.

Our analysis of the forecast error variance decomposition shows some similarities between the two economies. Variability of output is driven mainly by the demand shocks and the productivity shock seems to be not so important, while the wage markup shock seems to be relatively negligible. Consumption volatility in both economies is explained by the risk premium shock. Inflation variations are mainly driven by the price markup shock, the risk premium shock and the monetary policy shock and not by the wage markup shock. Despite these similarities, one can indicate certain differences. In particular, the price markup shock is not significant for the volatility of output and consumption in the Eurozone, while it shows some significance in Poland.

9 Historical decomposition of time series

In this section we discuss a historical decomposition of the actual time series of output, consumption and inflation. It is the decomposition of the series of log differences of the main macroeconomic variables on the shocks embedded in the model setting. It decomposes the historical deviations of given variables from their steady-state values into the contribution coming from the shocks. Positive and negative contributions sum up to the observed realizations of the time series. The decomposition is displayed on the graph that shows the contribution of each shock to the development of a specific variable – the most likely realizations that lead to the observed values of the data. It also contains some initial conditions from the data that cannot be eliminated in computing the decomposition. Those initial conditions are related to the distance from the steady state the system was at first, before the shocks arrived. As we do not know how far from the steady state the system starts, the initial values must be preserved to reflect the residual uncertainty about the initial conditions.

Figures 8 and 9 show the historical decomposition of output growth in the Eurozone and in Poland, respectively. In the Eurozone we observe a significant importance of the risk premium shock and the total factor productivity shock. At the same time, it can be noticed that the output growth in Poland is affected by the risk premium shock and the monetary policy shock. There is also an important influence of the price markup shock. The relative impact of the productivity shock is almost negligible. The price markup shock, which is important in Poland, does not play any role in output fluctuations in the Eurozone. These results suggest that the influence of the structural shocks differs among the two economies. In addition to the risk premium shock, in the Eurozone the total factor productivity shock plays a significant role, while in Poland the monetary policy shock and the price markup shock are the ones that affect output fluctuations.

Figures 10 and 11 show the historical decomposition of consumption growth in the Eurozone and in Poland, respectively. It is clear from the graphs that consumption growth in the Eurozone is influenced by the risk premium shock and the total factor productivity shock, while in Poland consumption growth is influenced by the risk premium shock and the monetary policy shock. The latter is much more influential in Poland than in the Eurozone. It should be emphasized that in Poland consumption growth is also influenced by the price markup shock, which is a phenomenon we do not observe in the Eurozone. Thus, the price markup shock development has an asymmetric impact on the consumption in the two economies.

Figures 12 and 13 show the historical decomposition of inflation in the Eurozone and in Poland, respectively. When it comes to inflation developments in the Eurozone, they are mainly influenced by two shocks – the risk premium shock and the TFP shock. At the same time inflation in Poland is mainly influenced by two shocks – the risk premium shock and the monetary policy shock. Inflation is more volatile in Poland than in the Eurozone. We also observe that the relative impact of the price markup shock on inflation is much higher in Poland than in the Eurozone. From the second half of the sample one can infer that the monetary policy shocks are more persistent in the Eurozone, as the monetary authorities are more responsive to inflation development.

10 Concluding remarks

In this paper we studied the business cycle properties in the Eurozone and in Poland using the DSGE approach to determine how similar their economies are. We estimated the model developed by Smets and Wouters (2007) using Bayesian techniques on the quarterly data on output, consumption, investment, hours worked, real wages, inflation and interest rates. Then, we used impulse response functions to seven shocks of the model, as well as forecast error variance decomposition and historical decomposition of the actual time series.

Our main research hypothesis was that the business cycles in the Eurozone and in Poland are similar. However, this hypothesis was only partly confirmed by our empirical study, as we did not find a complete similarity of the business fluctuations in these two economies. We validated the hypothesis that the structural parameters of the economies of the Eurozone and Poland do not differ significantly. However, it was found that the parameters describing the stochastic processes driving the dynamics of the economies display some important differences. While the most persistent shock in both economies is the exogenous spending shock, the second most persistent shocks are the total factor productivity shock in the Eurozone and the risk premium shock in Poland. The most volatile shock in Poland is the price markup shock, which shows only slight volatility in the Eurozone. In the Eurozone the total factor productivity shock is the most volatile. It should be also emphasized that the reaction of the estimates on the usage of the observations from the Great Recession differs among the two economies.

We provided empirical evidence that output fluctuations in both economies were driven by similar demand shocks. However, we observed a significant importance of the price markup shock in Poland, which was not observed in the Eurozone, and larger effects of the exogenous spending and total factor productivity shock on the output development in the Eurozone than in Poland. In general, impulse responses of macroeconomic variables were found to be largely comparable between the Eurozone and Poland, but Poland's economy features a higher magnitude of shock responses. Moreover, we found some differences with respect to the responses to the price markup shock, crowding-out effects of investment and labour market responses. There results again indicated the existence of important dissimilarities between these economies.

Despite only a partial verification of the main hypothesis, there are many possible policies that can help in making the economies of the Eurozone and Poland more similar. The particular policy recommendations arising from our study would be related to increased government spending in Poland, better accommodation of investment-specific shocks as well as labour market reforms. In particular, the importance of the price markup shock in Poland could be reduced by implementing the relevant antitrust policy that would cut the monopoly power of Polish producers. Implementation of these policies should decrease the level of asymmetry between the Eurozone and Poland. In this case taking into account all the benefits of the euro adoption in Poland, it would be advisable to join the Eurozone, as the costs of this event would be significantly reduced. The fundamental message from our research is that the dissimilarities between the Eurozone and Poland identified in our study might be successfully overcome due to implementation of relevant macroeconomic and labour market policies and therefore despite the existing differences the euro adoption could still be justified.

References

Bielecki M., Brzoza-Brzezina M., Makarski K., Kolasa M. (2019), Could the boom-bust in the Eurozone periphery have been prevented?, *Journal of Common Market Studies*, 57(2), 336–352.

Brzoza-Brzezina M., Jacquinot P., Kolasa M. (2014), Can we prevent boom-bust cycles during euro area accession?, *Open Economies Review*, 25(1), 35–69.

Brzoza-Brzezina M., Makarski K., Wesołowski G. (2014), Would it have paid to be in the Eurozone?, *Economic Modelling*, 41, 66–79.

Calvo G.A. (1983), Staggered prices in a utility-maximizing framework, *Journal of Monetary Economics*, 12(3), 383–398.

Christiano L.J., Eichenbaum M., Evans C.L. (2005), Nominal rigidities and the dynamic effects of a shock to monetary policy, *Journal of Political Economy*, 113(1), 1–45.

Dixit A.K., Stiglitz J.E. (1977), Monopolistic competition and optimum product diversity, *American Economic Review*, 67(3), 297–308.

Erceg C.J., Henderson D.W, Levin A.T. (2000), Optimal monetary policy with staggered wage and price contracts, *Journal of Monetary Economics*, 46(2), 281–313.

Galí J. (2008), *Monetary Policy, Inflation, and the Business Cycle. An Introduction to the New Keynesian Framework*, Princeton University Press.

Gradzewicz M., Makarski K. (2013), The business cycle implications of the euro adoption in Poland, *Applied Economics*, 45(17), 2443–2455.

Kimball M.S. (1995), The quantitative analytics of the basic neomonetarist model, *Journal of Money, Credit, and Banking*, 27(4), 1241–1277.

Kolasa M. (2009), Structural heterogeneity or asymmetric shocks? Poland and the euro area through the lens of a two-country DSGE model, *Economic Modelling*, 26(6), 1245–1269.

Kolasa M. (2013), Business cycles in EU new member states: How and why are they different?, *Journal of Macroeconomics*, 38, Part B, 487–496.

Romer D. (2012), *Advanced Macroeconomics*, McGraw-Hill.

Sin H.L., Gaglianone W.P. (2006), *Stochastic simulation of a DSGE model for Brazil*, MPRA Paper, 20853.

Smets F., Wouters R. (2003), An estimated dynamic stochastic general equilibrium model of the euro area, *Journal of the European Economic Association*, 1(5), 1123–1175.

Smets F., Wouters R. (2005), Comparing shocks and frictions in US and euro area business cycles: a Bayesian DSGE approach, *Journal of Applied Econometrics*, 20(2), 161–183.

Smets F., Wouters R. (2007), Shocks and frictions in US business cycles: a Bayesian DSGE approach, *American Economic Review*, 97(3), 586–606.

Taylor J.B. (1993), Discretion versus policy rules in practice, *Carnegie-Rochester Conference Series on Public Policy*, 39, 195–214.

Appendix

Table 1
Fixed parameters

Parameter	Description	Fixed value
δ	Depreciation rate of capital on quarterly basis	0.025
g_y	Steady-state exogenous spending-output ratio	0.21 (Poland) 0.23 (Eurozone)
φ_w	Steady-state labour market markup	1.5
ε_p	Parameter of Kimball goods market aggregator	10
ε_w	Parameter of Kimball labour market aggregator	10

Source: own description, based on Smets, Wouters (2007, p. 592).

Table 2
Prior distributions of structural parameters

Parameter	Description	Distribution	Mean	Standard deviation
λ	Habit formation parameter	beta	0.700	0.100
σ_c	Inverse of the elasticity of intertemporal substitution	normal	1.500	0.375
σ_l	Elasticity of labour supply with respect to the real wage	normal	2.000	0.750
$100(\beta^{-1}-1)$	Discount factor applied by households	gamma	0.250	0.100
φ	Steady-state elasticity of the capital adjustment cost function	normal	4.000	1.500
ψ	Positive function of the elasticity of the capital utilization adjustment cost function	beta	0.500	0.150
α	Share of capital in production	normal	0.300	0.050
φ_p	Parameter reflecting the fixed cost in production	normal	1.250	0.125

Table 2, cont'd

Parameter	Description	Distribution	Mean	Standard deviation
ξ_p	Degree of price stickiness	beta	0.500	0.100
ι_p	Degree of indexation to the past inflation	beta	0.500	0.150
ξ_w	Degree of wage stickiness	beta	0.500	0.100
ι_w	Degree of wage indexation to the past inflation	beta	0.500	0.150
r_π	Reaction coefficient corresponding to inflation in monetary policy rule	normal	1.500	0.250
r_y	Reaction coefficient corresponding to output gap in monetary policy rule	normal	0.125	0.050
$r_{\Delta y}$	Reaction coefficient of change in output gap in monetary policy rule	normal	0.125	0.050
ρ	Degree of interest rate smoothing	beta	0.750	0.100
$\bar{\gamma}$	Quarterly trend growth rate	normal	0.400	0.100
$\bar{\pi}$	Quarterly steady-state inflation rate	gamma	0.625	0.100
$\bar{l}$	Steady-state hours worked	normal	0.000	2.000

Source: Smets, Wouters (2007, p. 593).

Table 3

Posterior distributions of the structural parameters

Parameter	**Prior mean**	**Prior st. dev.**	**Post. mode Poland**	**Post. mode Eurozone**	**Post. mean Poland**	**Post. mean Eurozone**	**Credibility set Poland**		**Credibility set Eurozone**	
λ	0.700	0.1000	0.8193	0.7436	0.8010	0.7942	0.7531	0.8511	0.7277	0.8963
σ_c	1.500	0.3750	0.9032	0.9390	0.8724	0.9631	0.7771	0.9641	0.9034	1.0197
σ_l	2.000	0.7500	1.1872	0.2500	1.3342	0.2725	0.6484	2.0280	0.1057	0.3843
$100(\beta^{-1}-1)$	0.250	0.1000	0.2940	0.2756	0.3358	0.2605	0.1872	0.4626	0.1758	0.3600
φ	4.000	1.5000	6.5743	7.7842	7.0719	7.1447	5.4078	8.4567	5.5246	8.1721
ψ	0.500	0.1500	0.6594	0.5776	0.6809	0.6000	0.5794	0.7903	0.4876	0.7201
α	0.300	0.0500	0.1495	0.1417	0.1472	0.1463	0.1183	0.1743	0.1299	0.1676
φ_p	1.250	0.1250	1.3611	1.3620	1.3876	1.3279	1.2690	1.4962	1.2346	1.4050
ξ_p	0.500	0.1000	0.7082	0.7817	0.6995	0.8031	0.6382	0.7674	0.7648	0.8498
ι_p	0.500	0.1500	0.3803	0.4514	0.4078	0.3790	0.2749	0.5705	0.2729	0.4426
ξ_w	0.500	0.1000	0.6858	0.8158	0.6773	0.8044	0.6046	0.7399	0.7644	0.8393
ι_w	0.500	0.1500	0.1477	0.2810	0.1602	0.2938	0.0801	0.2517	0.1744	0.4268
r_π	1.500	0.2500	1.1777	1.6112	1.2035	1.6483	1.0447	1.3816	1.5331	1.8358
r_y	0.125	0.0500	0.0010	0.1565	0.0125	0.1626	0.0010	0.0240	0.1035	0.2150
$r_{\Delta y}$	0.125	0.0500	0.0657	0.0780	0.0716	0.0613	0.0407	0.0968	0.0237	0.0851
ρ	0.750	0.1000	0.9744	0.8245	0.9700	0.8344	0.9650	0.9750	0.8019	0.8691
$\bar{\gamma}$	0.400	0.1000	0.5913	0.2056	0.6043	0.2068	0.5417	0.6658	0.1917	0.2209
$\bar{\pi}$	0.625	0.1000	0.5618	0.4117	0.5721	0.4309	0.4467	0.7042	0.3596	0.5300
$\bar{l}$	0.000	2.0000	-0.2387	0.5102	0.2994	1.1650	-1.1769	1.8679	0.4494	2.4492

Source: own calculations in Dynare.

Table 4
Prior distributions of the stochastic processes' parameters

Parameter	Description	Distribution	Mean	Standard deviation
ρ_a	Total factor productivity process persistence	beta	0.50	0.20
ρ_b	Risk premium process persistence	beta	0.50	0.20
ρ_i	Investment-specific technology process persistence	beta	0.50	0.20
ρ_p	Price mark-up process persistence	beta	0.50	0.20
ρ_w	Wage mark-up process persistence	beta	0.50	0.20
ρ_g	Exogenous spending process persistence	beta	0.50	0.20
ρ_r	Monetary policy process persistence	beta	0.50	0.20
σ_a	Standard deviation of total factor productivity shock	inverse-gamma	0.10	2.00
σ_b	Standard deviation of risk premium shock	inverse-gamma	0.10	2.00
σ_i	Standard deviation of investment-specific technology shock	inverse-gamma	0.10	2.00
σ_p	Standard deviation of price mark-up shock	inverse-gamma	0.10	2.00
σ_w	Standard deviation of wage markup shock	inverse-gamma	0.10	2.00
σ_g	Standard deviation of exogenous spending shock	inverse-gamma	0.10	2.00
σ_r	Standard deviation of monetary policy shock	inverse-gamma	0.10	2.00
μ_p	MA parameter in price markup process	beta	0.50	0.20
μ_w	MA parameter in wage markup process	beta	0.50	0.20
ρ_{ga}	Total factor productivity shock parameter in exogenous spending process	beta	0.50	0.20

Source: Smets, Wouters (2007, p. 594).

Table 5
Posterior distributions of the stochastic processes' parameters

Parameter	Prior mean	Prior st.dev	Post. Mode Poland	Post. Mode Eurozone	Post. Mean Poland	Post. Mean Eurozone	Credibility set Poland		Credibility set Eurozone	
ρ_a	0.500	0.2000	0.2918	0.5081	0.3573	0.4894	0.2155	0.4977	0.3774	0.5746
ρ_b	0.500	0.2000	0.9617	0.7539	0.9534	0.7187	0.931	0.9766	0.6040	0.8074
ρ_i	0.500	0.2000	0.2636	0.5467	0.2405	0.4961	0.0951	0.3728	0.3126	0.6517
ρ_p	0.500	0.2000	0.5270	0.6475	0.5669	0.6224	0.414	0.7087	0.4509	0.8426
ρ_w	0.500	0.2000	0.7649	0.8967	0.7574	0.8867	0.6193	0.873	0.8293	0.9547
ρ_g	0.500	0.2000	0.9664	0.9848	0.9588	0.9747	0.9305	0.9917	0.9595	0.9890
ρ_r	0.500	0.2000	0.2678	0.3662	0.2325	0.3678	0.1141	0.372	0.2160	0.5122
σ_a	0.100	2.0000	2.498	1.3884	2.597	1.4242	2.3145	2.9049	1.2083	1.6005
σ_b	0.100	2.0000	0.3974	0.5703	0.4273	0.8332	0.1994	0.6430	0.3856	1.3246
σ_i	0.100	2.0000	2.4508	0.5742	2.4382	0.6402	2.0800	2.7932	0.4929	0.8503
σ_p	0.100	2.0000	3.0000	0.1479	2.8844	0.1514	2.7376	3.0000	0.1247	0.1817
σ_w	0.100	2.0000	0.9418	0.1017	0.9701	0.1059	0.7183	1.1575	0.0885	0.1210
σ_g	0.100	2.0000	0.8552	0.2546	0.8851	0.2611	0.7485	1.0168	0.2260	0.2985
σ_r	0.100	2.0000	0.1447	0.0941	0.1656	0.0930	0.1307	0.2013	0.0766	0.1064
μ_p	0.500	0.2000	0.5680	0.7500	0.5966	0.7327	0.4751	0.7498	0.6202	0.8467
μ_w	0.500	0.2000	0.8739	0.9280	0.8463	0.9189	0.6600	0.9678	0.876	0.9746
ρ_{ga}	0.500	0.2000	0.0990	0.1211	0.1039	0.1200	0.0336	0.1672	0.0845	0.1570

Source: own calculations in Dynare.

Table 6
Subsample estimates – structural parameters

Parameter	Mode Poland full sample	Mode Poland pre-crisis	Mode Poland post-crisis	Mode Eurozone full sample	Mode Eurozone pre-crisis	Mode Eurozone post-crisis
λ	0.8193	0.7568	0.8422	0.7436	0.6989	0.8532
σ_c	0.9032	0.6254	0.9101	0.9390	0.9782	0.9825
σ_l	1.1872	1.2372	2.3872	0.2500	0.2500	0.2500
$100(\beta^{-1}-1)$	0.2940	0.2395	0.1551	0.2756	0.2263	0.1539
φ	6.5743	6.6057	5.4199	7.7842	5.7899	4.8522
ψ	0.6594	0.6905	0.3925	0.5776	0.6282	0.6787
α	0.1495	0.1921	0.1719	0.1417	0.2220	0.1505
φ_p	1.3611	1.3436	1.3949	1.3620	1.4104	1.3212
ξ_p	0.7082	0.5574	0.6753	0.7817	0.7118	0.7884
ι_p	0.3803	0.3820	0.5626	0.4514	0.7425	0.6929
ξ_w	0.6858	0.6016	0.6863	0.8158	0.8010	0.8023
ι_w	0.1477	0.3247	0.1032	0.2810	0.2609	0.2346
r_π	1.1777	1.1828	1.0011	1.6112	1.4155	1.5727
r_y	0.0010	0.1143	0.0506	0.1565	0.1480	0.1246
$r_{\Delta y}$	0.0657	0.1941	0.0221	0.0780	0.0497	0.0872
ρ	0.9744	0.9402	0.9750	0.8245	0.8825	0.8430
$\bar{\gamma}$	0.5913	0.6051	0.5155	0.2056	0.1997	0.2146
$\bar{\pi}$	0.5618	0.6368	0.6342	0.4117	0.6176	0.6574
$\bar{l}$	-0.2387	-2.4077	3.0558	0.5102	0.4946	1.8676

Source: own calculations in Dynare.

Table 7
Subsample estimates – stochastic processes' parameters

Parameter	Mode Poland full sample	Mode Poland pre-crisis	Mode Poland post-crisis	Mode Eurozone full sample	Mode Eurozone pre-crisis	Mode Eurozone post-crisis
ρ_a	0.2918	0.4858	0.3586	0.5081	0.1818	0.3205
ρ_b	0.9617	0.9735	0.9119	0.7539	0.8180	0.8111
ρ_i	0.2636	0.8194	0.1714	0.5467	0.1515	0.2172
ρ_p	0.5270	0.6923	0.5635	0.6475	0.1383	0.3229
ρ_w	0.7649	0.5212	0.3395	0.8967	0.3463	0.8639
ρ_g	0.9664	0.7727	0.8507	0.9848	0.7376	0.9612
ρ_r	0.2678	0.1969	0.1856	0.3662	0.1978	0.3367
σ_a	2.498	1.8164	3.0000	1.3884	0.9239	1.5254
σ_b	0.3974	0.0648	0.5891	0.5703	0.3538	0.6940
σ_i	2.4508	0.8808	2.0871	0.5742	0.7756	0.8067
σ_p	3.0000	2.7687	3.0000	0.1479	0.1748	0.1303
σ_w	0.9418	1.1966	0.7042	0.1017	0.0916	0.1164
σ_g	0.8552	0.6819	0.9319	0.2546	0.3027	0.2175
σ_r	0.1447	0.2362	0.0863	0.0941	0.0716	0.0768
μ_p	0.5680	0.3039	0.7668	0.7500	0.5556	0.6132
μ_w	0.8739	0.5015	0.6445	0.9280	0.6379	0.9108
ρ_{ga}	0.0990	0.1429	0.1630	0.1211	0.2370	0.0939

Source: own calculations in Dynare.

Table 8

Forecast error variance decomposition of output in the Eurozone

Time horizon	Total factor productivity shock	Risk premium shock	Investment--specific technology shock	Price markup shock	Wage markup shock	Exogeno-us spending shock	Monetary policy shock
1	7.09	41.09	24.65	0.56	0.06	23.32	3.23
2	7.45	45.55	25.09	0.69	0.08	17.08	4.07
4	7.3	47.01	24.75	0.98	0.21	14.81	4.93
10	6.82	40.28	22.39	2.44	1.7	21.67	4.70
40	5.74	30.72	20.79	3.70	6.58	24.48	7.98
100	5.71	29.29	20.00	3.73	7.19	25.83	8.25

Source*:* own calculations in Dynare.

Table 9

Forecast error variance decomposition of output in Poland

Time horizon	Total factor productivity shock	Risk premium shock	Investment--specific technology shock	Price markup shock	Wage markup shock	Exogenous spending shock	Monetary policy shock
1	4.17	24.52	13.82	23.08	0.30	20.07	14.03
2	3.77	22.91	10.69	35.11	0.73	13.77	13.03
4	2.90	16.10	7.21	52.33	2.89	9.44	9.15
10	0.67	44.03	1.32	18.01	5.73	2.04	28.20
40	0.32	51.27	0.41	10.36	4.04	0.89	32.70
100	0.33	51.27	0.40	10.34	4.00	0.98	32.68

Source*:* own calculations in Dynare.

Table 10

Forecast error variance decomposition of consumption in the Eurozone

Time horizon	Total factor productivity shock	Risk premium shock	Investment--specific technology shock	Price markup shock	Wage markup shock	Exogenous spending shock	Monetary policy shock
1	4.18	88.94	0.07	0.69	0.03	0.07	6.01
2	3.33	88.62	0.15	0.88	0.07	0.09	6.87
4	2.28	87.68	0.42	1.23	0.24	0.13	8.02
10	4.83	79.71	2.17	2.86	2.13	0.31	7.99
40	21.76	50.69	3.40	5.03	8.68	0.45	9.99
100	23.67	45.1	4.15	5.23	10.42	0.47	10.96

Source: own calculations in Dynare.

Table 11

Forecast error variance decomposition of consumption in Poland

Time horizon	Total factor productivity shock	Risk premium shock	Investment--specific technology shock	Price markup shock	Wage markup shock	Exogenous spending shock	Monetary policy shock
1	3.05	52.82	0.16	13.22	0.03	0.30	30.43ą
2	1.85	49.28	0.20	19.66	0.06	0.39	28.56
4	1.00	41.35	0.27	32.28	0.39	0.69	24.01
10	0.48	39.19	0.24	30.65	3.75	1.72	23.98
40	0.24	48.88	0.61	13.6	3.68	1.84	31.16
100	0.26	48.85	0.61	13.34	3.67	2.06	31.22

Source: own calculations in Dynare.

Table 12
Forecast error variance decomposition of inflation in the Eurozone

Time horizon	Total factor productivity shock	Risk premium shock	Investment-specific technology shock	Price markup shock	Wage markup shock	Exogenous spending shock	Monetary policy shock
1	15.22	3.86	1.86	75.16	1.26	0.2	2.44
2	23.51	7.47	3.56	57.91	2.48	0.4	4.68
4	27.9	12.39	5.93	41.43	3.96	0.64	7.75
10	28.16	18.57	9.55	25.11	6.1	0.89	11.62
40	26.67	21.75	11.70	15.63	9.48	0.91	13.88
100	26.46	22.01	11.43	14.93	10.23	0.89	14.04

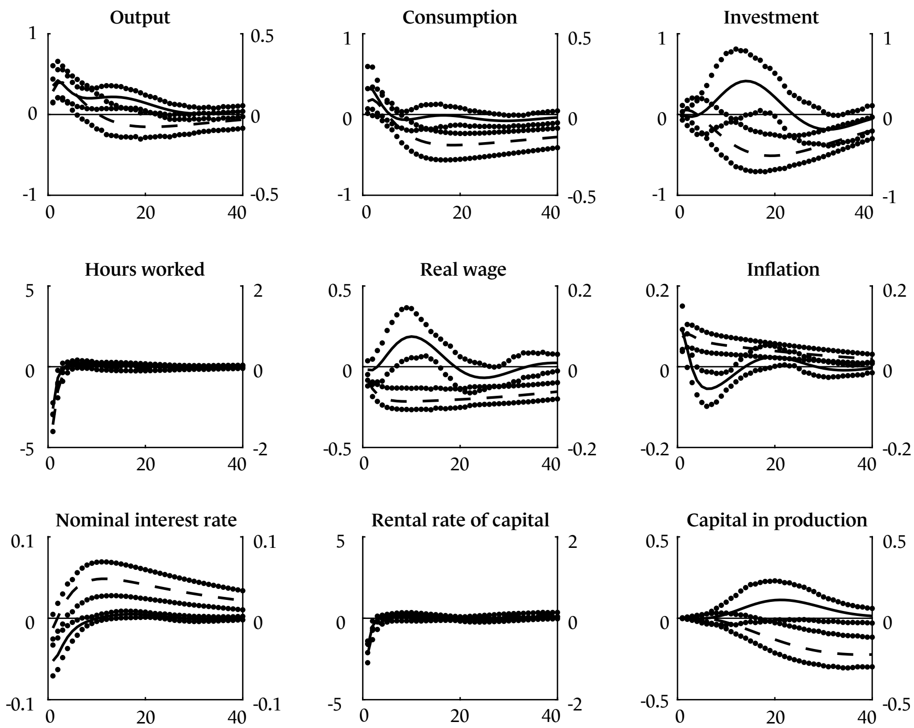
Source: own calculation in Dynare.

Table 13
Forecast error variance decomposition of inflation in Poland

Time horizon	Total factor productivity shock	Risk premium shock	Investment-specific technology shock	Price markup shock	Wage markup shock	Exogenous spending shock	Monetary policy shock
1	0.05	13.47	0.00	77.31	0.24	0.01	8.910
2	0.05	25.54	0.00	56.93	0.49	0.02	16.98
4	0.03	37.41	0.00	36.67	0.77	0.04	25.07
10	0.05	40.43	0.01	31.04	0.83	0.04	27.59
40	0.05	44.59	0.03	25.06	1.45	0.04	28.78
100	0.05	44.78	0.03	24.74	1.47	0.04	28.88

Source: own calculation in Dynare.

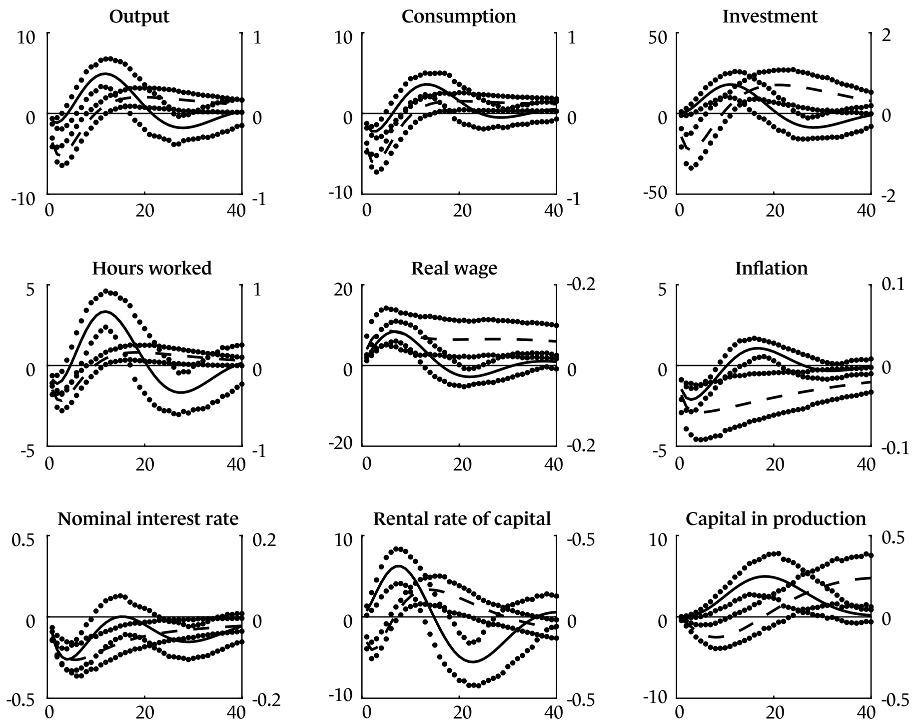
Figure 1
The estimated mean impulse response functions to a total factor productivity shock in the Eurozone and in Poland



Note: vertical axis: percentage deviation from the steady state, horizontal axis: quarters, solid lines: mean impulse response functions for Poland (left-hand side scale), dashed lines: mean impulse response functions for the Eurozone (right-hand side scale), dotted lines: credibility sets (confidence intervals at 90% level).

Source: own calculations in Dynare.

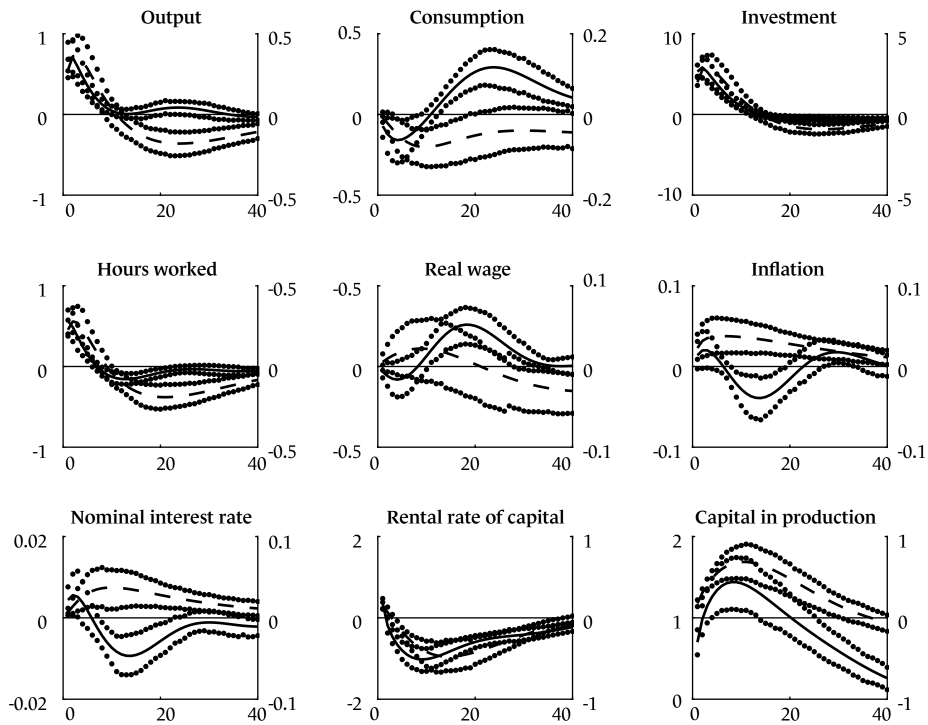
Figure 2
The estimated mean impulse response functions to a negative risk premium shock in the Eurozone and in Poland



Note: vertical axis: percentage deviation from the steady state, horizontal axis: quarters, solid lines: mean impulse response functions for Poland (left-hand side scale), dashed lines: mean impulse response functions for the Eurozone (right-hand side scale), dotted lines: credibility sets (confidence intervals at 90% level).

Source: own calculations in Dynare.

Figure 3
The estimated mean impulse response functions to an investment-specific technology shock in the Eurozone and in Poland

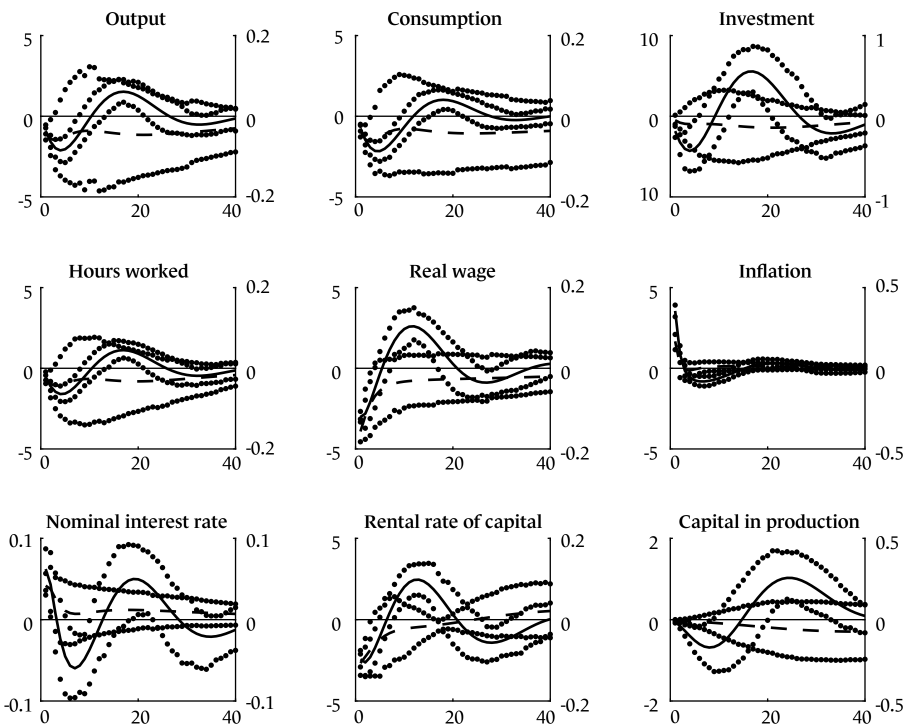


Note: vertical axis: percentage deviation from the steady state, horizontal axis: quarters, solid lines: mean impulse response functions for Poland (left-hand side scale), dashed lines: mean impulse response functions for the Eurozone (right-hand side scale), dotted lines: credibility sets (confidence intervals at 90% level).

Source: own calculations in Dynare.

Figure 4

The estimated mean impulse response functions to a price markup shock in the Eurozone and in Poland

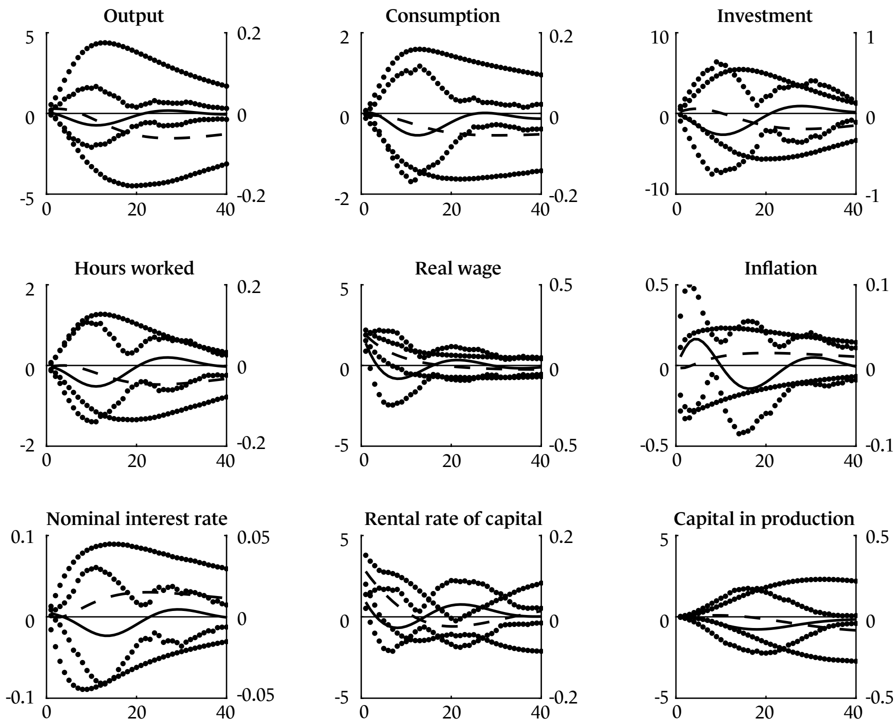


Note: vertical axis: percentage deviation from the steady state, horizontal axis: quarters, solid lines: mean impulse response functions for Poland (left-hand side scale), dashed lines: mean impulse response functions for the Eurozone (right-hand side scale), dotted lines: credibility sets (confidence intervals at 90% level).

Source: own calculations in Dynare.

Figure 5

The estimated mean impulse response functions to a wage markup shock in the Eurozone and in Poland

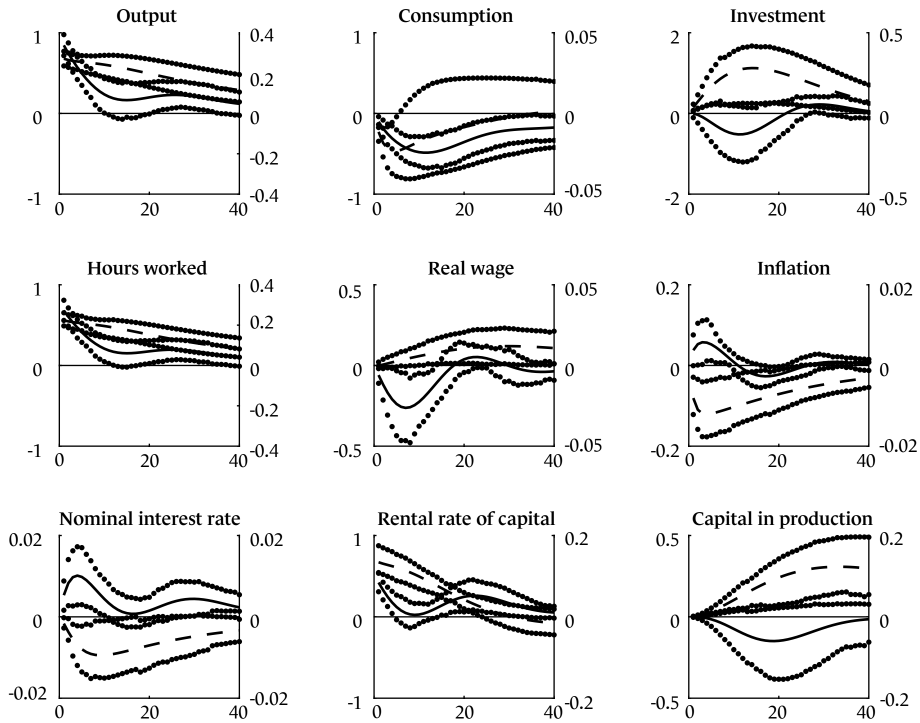


Note: vertical axis: percentage deviation from the steady state, horizontal axis: quarters, solid lines: mean impulse response functions for Poland (left-hand side scale), dashed lines: mean impulse response functions for the Eurozone (right-hand side scale), dotted lines: credibility sets (confidence intervals at 90% level).

Source: own calculations in Dynare.

Figure 6

The estimated mean impulse response functions to an exogenous spending shock in the Eurozone and in Poland

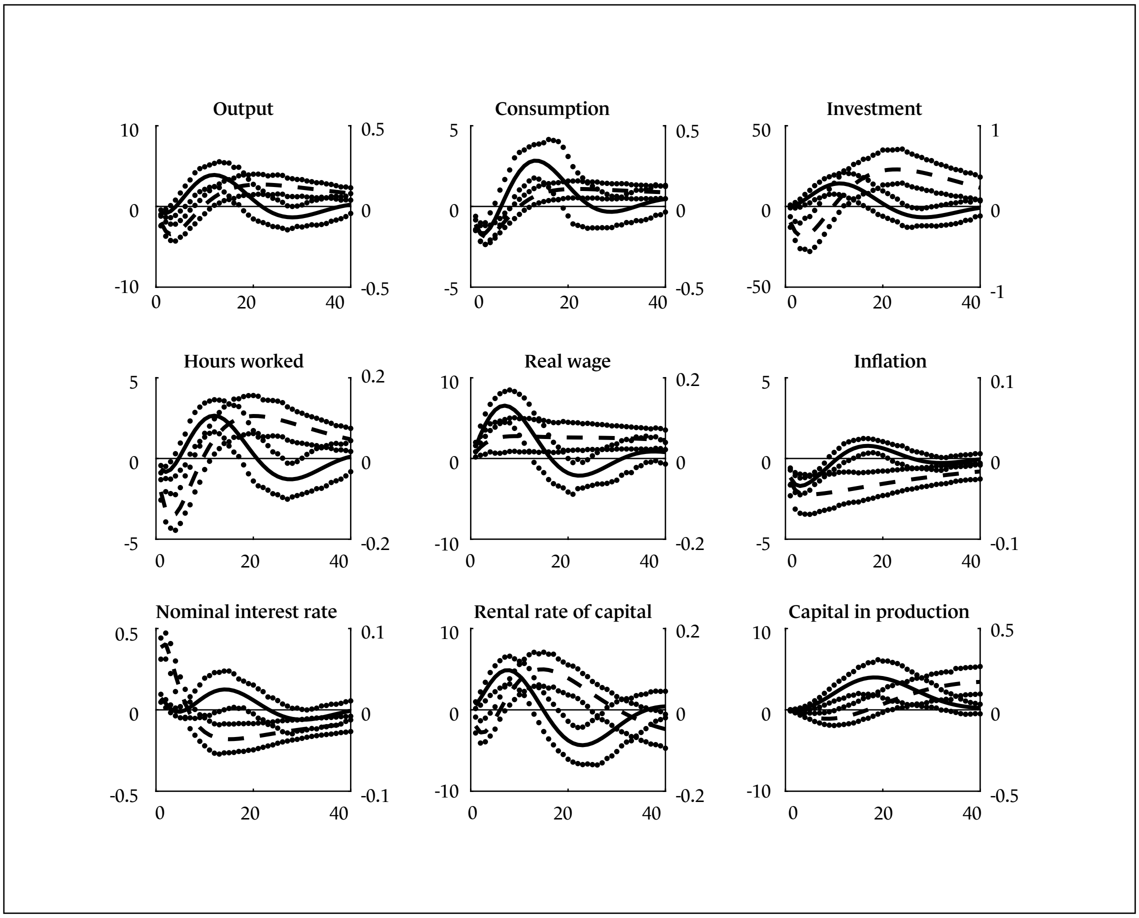


Note: vertical axis: percentage deviation from the steady state, horizontal axis: quarters, solid lines: mean impulse response functions for Poland (left-hand side scale), dashed lines: mean impulse response functions for the Eurozone (right-hand side scale), dotted lines: credibility sets (confidence intervals at 90% level).

Source: own calculations in Dynare.

Figure 7

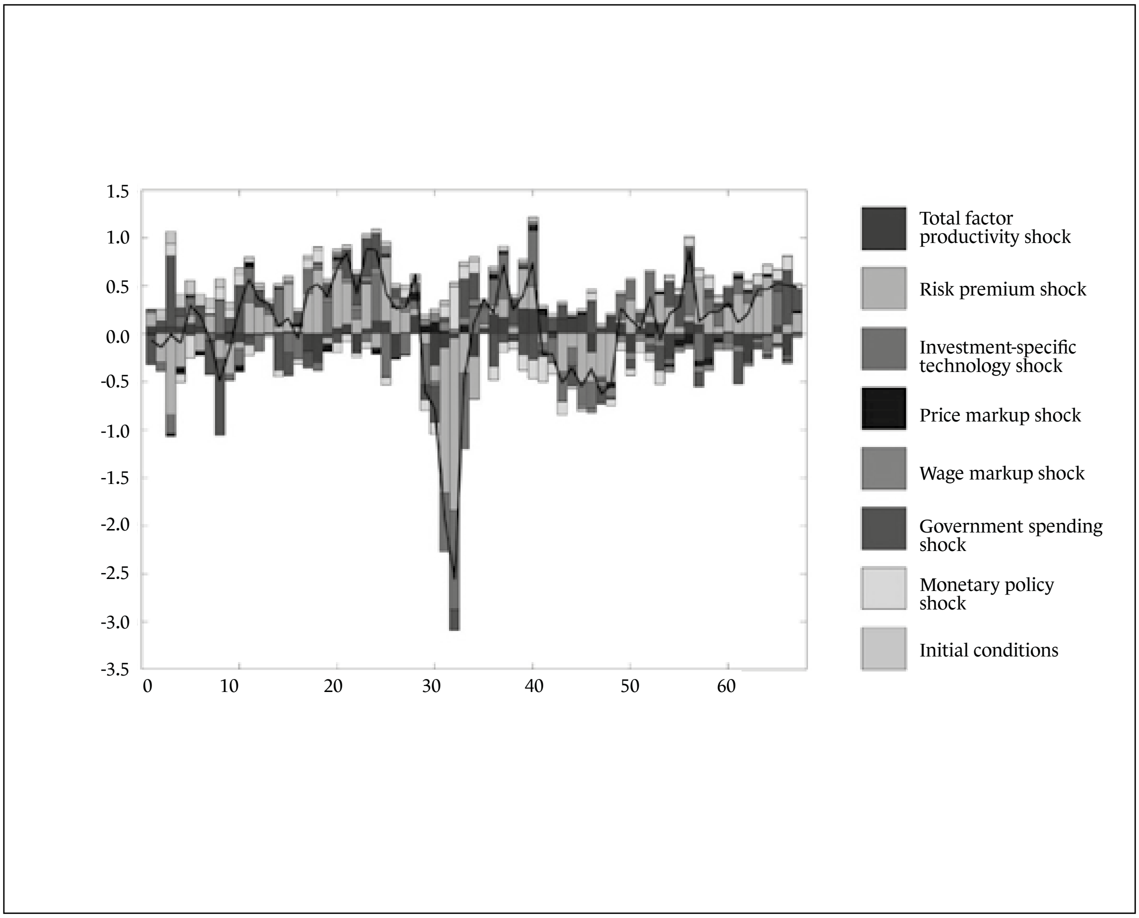
The estimated mean impulse response functions to a monetary policy shock in the Eurozone and in Poland



Note: vertical axis: percentage deviation from the steady state, horizontal axis: quarters, solid lines: mean impulse response functions for Poland (left-hand side scale), dashed lines: mean impulse response functions for the Eurozone (right-hand side scale), dotted lines: credibility sets (confidence intervals at 90% level).

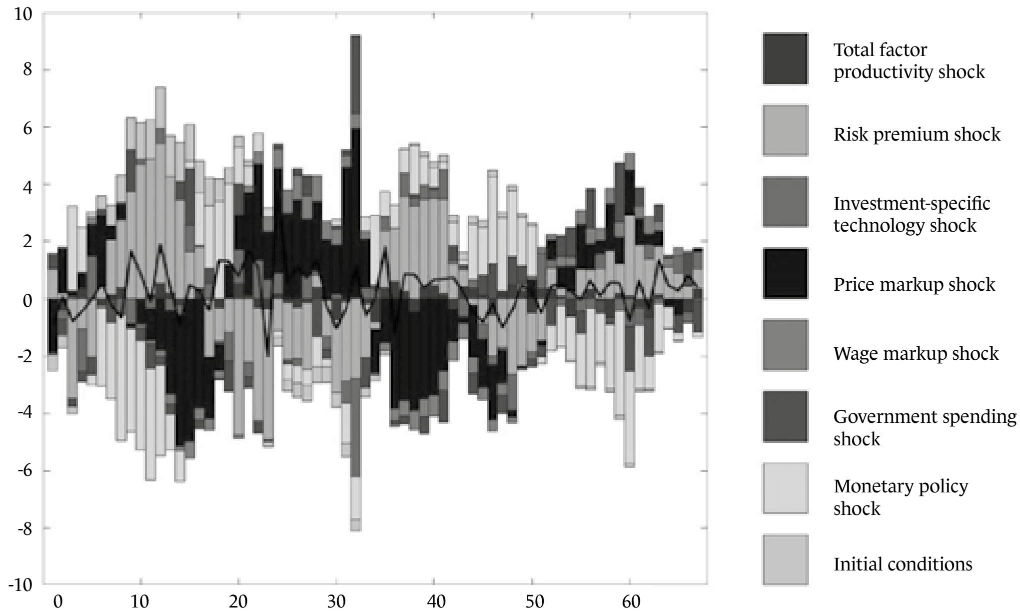
Source: own calculations in Dynare.

Figure 8
Historical decomposition of output growth in the Eurozone



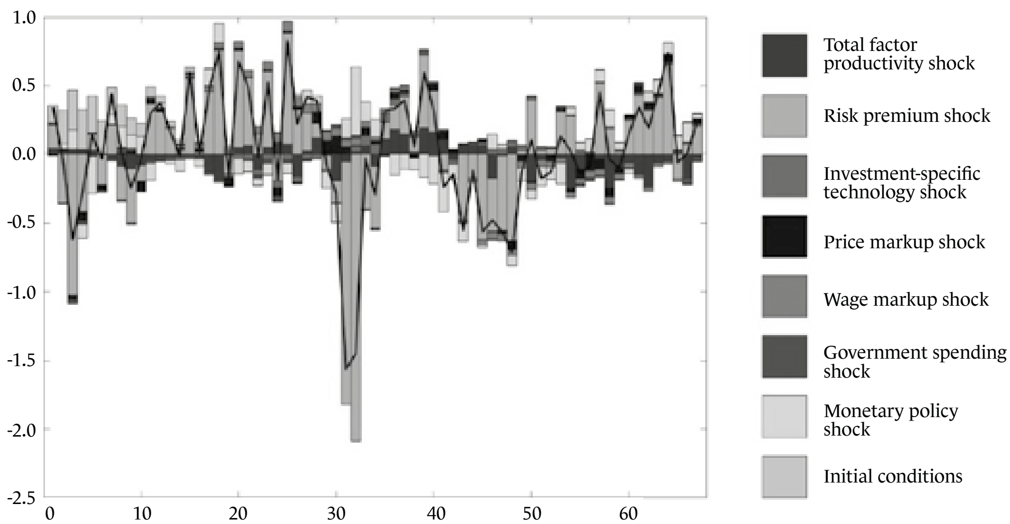
Source: own calculations in Dynare.

Figure 9
Historical decomposition of output growth in Poland



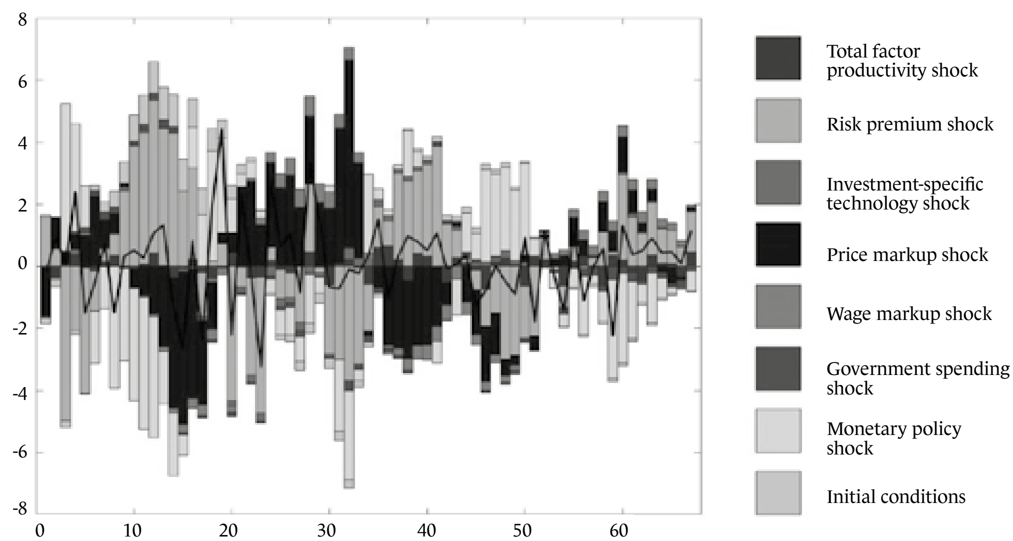
Source: own calculations in Dynare.

Figure 10
Historical decomposition of consumption growth in the Eurozone



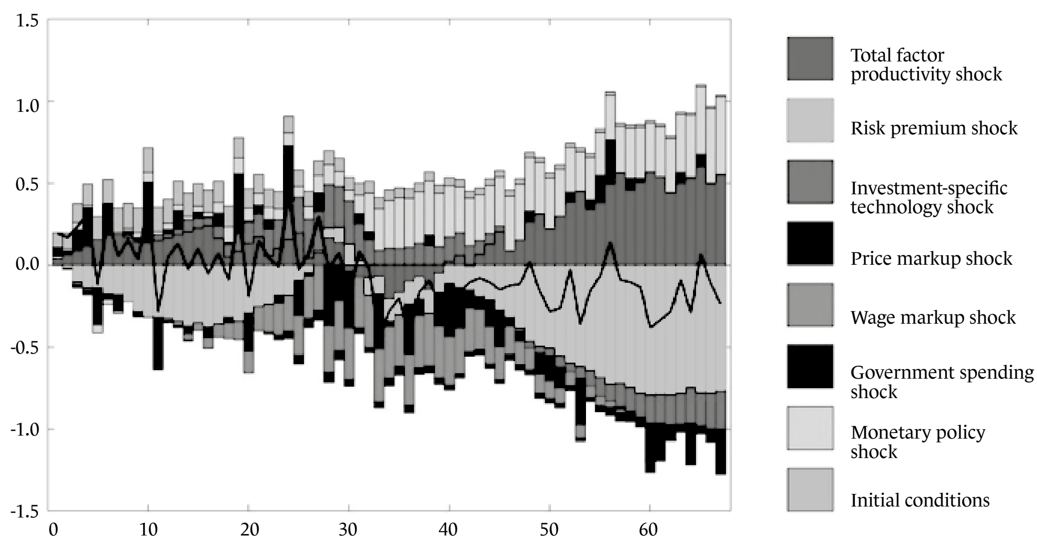
Source: own calculations in Dynare.

Figure 11
Historical decomposition of consumption growth in Poland



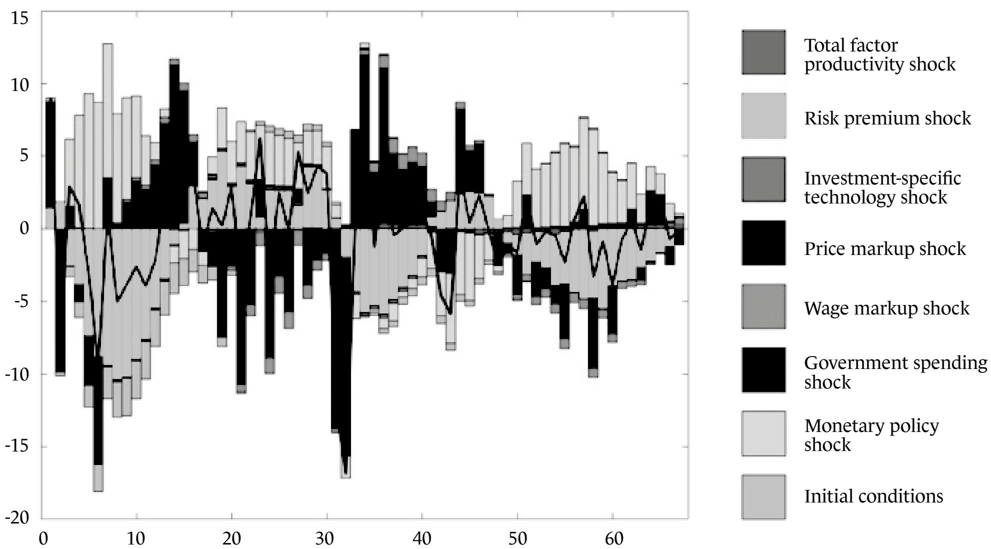
Source: own calculations in Dynare.

Figure 12
Historical decomposition of inflation in the Eurozone



Source: own calculations in Dynare.

Figure 13
Historical decomposition of inflation in Poland



Source: own calculations in Dynare.

Porównanie cykli koniunkturalnych w strefie euro i Polsce: podejście bayesowskie DSGE

Streszczenie

W artykule dokonano porównania cykli koniunkturalnych w strefie euro i w Polsce oraz zbadano cechy strukturalne ich gospodarek. Gospodarka strefy euro jest największą gospodarką europejską i stanowi rdzeń Unii Europejskiej, podczas gdy Polska jest gospodarką wschodzącą, która po udanej transformacji gospodarczej stara się dogonić kraje Europy Zachodniej pod względem poziomu dochodu na mieszkańca i jest zobowiązana do przyjęcia euro w bliżej nieokreślonej przyszłości. Główny powód przeprowadzenia analizy cykli koniunkturalnych w strefie euro i w Polsce wynika z faktu, że ich gospodarki są od siebie zależne, w związku z czym badane jest, jak silne są te relacje. W szczególności strefa euro jest głównym partnerem dla Polski pod względem handlu zagranicznego oraz inwestycji bezpośrednich. Z tego względu ważne jest zbadanie, w jakim stopniu polska gospodarka i jej cykl koniunkturalny są podobne do tego w strefie euro. Kwestia ta ma wiele ważnych implikacji dla prowadzenia polityki gospodarczej, nie tylko w odniesieniu do kwestii możliwego przyjęcia euro w Polsce, ale także sposobu, w jaki odpowiednie narzędzia polityki gospodarczej powinny być stosowane w celu neutralizacji różnego rodzaju wstrząsów wpływających na kluczowe zmienne makroekonomiczne. Artykuł ma kilka celów. Po pierwsze, porównano w nim właściwości cyklu koniunkturalnego w strefie euro i w Polsce, by dowiedzieć się, które wstrząsy są odpowiedzialne za wahania koniunktury w ich gospodarkach i jak duża jest trwałość tych wstrząsów. Ponadto przeprowadzono symulacje modelu w celu sprawdzenia, czy obydwie gospodarki reagują w ten sam sposób na wstrząsy egzogeniczne. Kolejnym celem jest oszacowanie parametrów strukturalnych dla gospodarek strefy euro i Polski w celu porównania ich ze sobą. Ostatnim celem jest sprawdzenie, w jaki sposób wykorzystanie obserwacji z okresu Wielkiej Recesji wpływa na oszacowania parametrów modelu. Główna hipoteza postawiona w badaniu mówi, że cykle koniunkturalne w strefie euro i w Polsce są podobne. Szczegółowe hipotezy badawcze, które zostały poddane empirycznej weryfikacji, są następujące: i) parametry strukturalne ich gospodarek nie różnią się znacząco, ii) trwałość wstrząsów oraz ich odchylenia standardowe są podobne w strefie euro i w Polsce, iii) kryzys zwiększa odchylenia standardowe wstrząsów, iv) fluktuacje produkcji w obu gospodarkach są w podobnym stopniu napędzane przez te same wstrząsy, v) odpowiedzi impulsowe zmiennych makroekonomicznych są porównywalne w strefie euro i w Polsce. Te hipotezy zostały zweryfikowane empirycznie przy użyciu makroekonomicznych szeregów czasowych. W badaniu empirycznym wykorzystano dynamiczny stochastyczny model równowagi ogólnej (DSGE) oparty na podejściu zaproponowanym przez Smetsa i Woutersa (2007). Model ten został oszacowany na podstawie danych kwartalnych z okresu 2001–2018, dotyczących siedmiu makroekonomicznych szeregów czasowych: produkcji, konsumpcji, inwestycji, godzin pracy, płacy realnej, stopy inflacji oraz stóp procentowych dla strefy euro i dla Polski, z zastosowaniem technik bayesowskich. Następnie dokonano symulacji modelu, aby uzyskać funkcje odpowiedzi impulsowej, dekompozycję wariancji błędu prognozy oraz historyczną dekompozycję szeregów czasowych pokazującą wpływ wstrząsów egzogenicznych. Wszystkie obliczenia, szacunki i symulacje zostały wykonane przy użyciu oprogramowania Dynare. Chociaż przeprowadzone badanie nie pokazuje istotnych różnic w szacunkach parametrów strukturalnych, okazuje się, że trwałość i zmienność wstrząsów różnią się między dwiema gospodarkami. Funkcje odpowiedzi impulsowej są porównywalne, a fluktuacje produkcji wynikają z podobnych wstrząsów popytowych. Można jednak zauważyć istotny wpływ egzogenicznego wstrząsu wydatkowego w strefie euro i szoku cenowego w Polsce. Przeprowadzona analiza pokazuje również, że przyjęcie euro w Polsce nie jest w chwili obecnej zalecane, chyba że zostaną wprowadzone odpowiednie zmiany w polityce makroekonomicznej i polityce rynku pracy.

Słowa kluczowe: estymacja Bayesowska, cykl koniunkturalny, model DSGE, strefa euro, Polska