Oil shocks and the excise duty tax in a DSGE model setting

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Abstract

This paper sets up a small open economy general equilibrium model operating in a monetary union. Exogenous oil-price shocks affecting the modelled economy are alleviated by introducing a pro-cyclical excise duty tax rule on oil prices. The paper provides a model-based theoretical background for studying a response of fiscal policy that is able to curb the negative effects of volatile global oil prices on inflation. Against this backdrop, we estimate the key parameters of the DSGE model and simulate different responses of the fiscal policy tax rule, based on different values of the responsiveness of the excise duty parameter.

Keywords: Oil shocks, fiscal policy tax rule, DSGE model, inflation.

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1. Introduction

Oil prices have always been a hot topic amongst policy makers as well as entrepreneurs and households. Fluctuations of oil prices can have big effects on the economies and their monetary (and fiscal) policy activity as they can substantially affect the inflation rates and real output. Despite the importance of oil-price shocks declined in the post-1990 period, oil prices have risen in years following the outbreak of the financial crisis in the United States and the European Union. Only recently, as prospects of a possible China cool-down in its economic activity, it forced oil prices to decline drastically and making new ground for further oil-price shocks in the future. In order to tackle this problem, monetary authorities rely on complex dynamic macro models, with which they try to predict different economic outcomes.

Several studies have investigated effects that oil-price shocks have on an economy. The wide fluctuations in oil prices in recent years have spur new research agendas that try to assess the effects of oil-price shocks on the main macroeconomic variables. Despite a relatively small share in the overall consumption basket, these shocks can significantly affect households and firms' decisions *via* rising costs[1], as oil prices usually display larger volatility in comparison to other HICP components. In general, the latest studies have used models to decompose direct effects of oil-price shocks on output and other economic variables, from those generated by the endogenous monetary policy response (Hamilton 1983; Bernanke, Gertler and Watson 1997; Leduc and Sill 2001; Hamilton and Herrera 2004; Herrera and Pesavento 2007; Lippi and Nobili 2009; Anzuini, Pagano and Pisani 2013). However, from studies, that only apply the reduced-form coefficients in VAR-type of models, it is difficult to disentangle the overall contribution

[1] Increased oil prices increase the cost of inputs in the firms' production process. Firms can either lower their profit margin on their output goods, or can raise the price of their output goods. The households, on the other hand, can be affected directly through increased energy (gasoline) prices, and indirectly through increased (non-energy) final good prices.

of the monetary policy, and thus study oil-price shock effects in more detail. This can be done by developing more complex macroeconomic models, a characteristic that DSGE models have. Against this backdrop, a small open economy DSGE model is developed, following the works of Medina and Soto (2005), Hongzhi (2010), and Forni, Gerali, Notarpietro and Pisani (2012), where the difference between oil and non-oil goods are explicitly modelled. Consistently with empirical evidence, the assumption is that crude oil is imported from the rest of the world.

The main contribution of the paper is the following. We follow a Medina and Soto (2005) type of model setting, but we refrain from it in two important aspects. First, we extend the model with a complete government spending block that provides a background for the implementation of the excise duty tax rule.[2] By doing this, the government can offset the negative effects of oil-price shocks on inflation by lowering the excise duty tax rate when oil prices increase, and *vice versa*.

Second, we try to fill the gap by studying the effects of oil-price shocks on a small open economy model integrated in a single monetary union, namely euro area. In our case, Slovenia is a typical example based on the above-mentioned characteristics. It has no oil-producing capacities; therefore all of its oil goods are imported. Consequently, it can be strongly affected by the fluctuations in world prices of oil.

The structure of the model follows a standard New Keynesian framework with frictions such as Calvo pricing (1983) and Calvo wage setting equation introduced by Erceg, Henderson and

[2] Excise duty is a tax on consumption. In Slovenia, the system and obligation of paying the excise duty are regulated by the Excise Duty Act which is harmonized with the EU legislation. It was first introduced on July 1st 1999. The excise duty tax in Slovenia is payable for the following goods released for consumption in the territory of the Republic of Slovenia: alcohol and alcoholic beverages, tobacco products, energy products and electricity (Ministry of Finance, 2016; Ministry of Finance, 2017). The government can act counter-cyclical to the dynamics oil prices and accommodate the rate of the excise duties on oil prices in order to decrease the pressure on the overall inflation.

Levin (2000), and Christiano, Eichenbaum and Evans (2005).[3] For the purpose of simulating a single monetary union the euro area interest rate is modelled in a Taylor type rule setting (Taylor 1993) with the addition of a risk-premium on the home interest rate that allows for deviations of the domestic interest rate from the (riskless) euro area interest rate (Schmitt-Grohé and Uribe 2003). We assume that the domestic economy's size is negligible, so its specific economic fluctuations have no influence on other euro area macroeconomic aggregates.

As commonly done in the DSGE literature, a number of parameters are calibrated from the outset, and are not included in the estimation process. However, some key structural parameters of the modelled economy are estimated following a Bayesian approach as in Smets and Wouters (2003), Adolfson et al. (2005), and Christoffel, Coenen and Warne (2008). With the estimated model we simulate the response of the main macroeconomic variables to an oil-price shock.

The results show that global oil-price shocks can have large effects on the Slovene economy. The fiscal policy authority has the power to offset the pressure that the oil-price shocks have on the overall inflation by counter-cyclically regulating the excise duty tax rate on oil goods. However, this comes at a cost. Decreased excise duty tax income decreases the government spending and increases the budget deficit, if the government chooses not to decrease its spending one to one with the decrease in excise duty tax income.

The rest of the paper is organised as follows. Section 2 presents a concise structure of the DSGE model. Section 3 discusses the calibration of the model, while Section 4 presents the results of

[3] Blanchard and Galí (2007) argue that adding frictions (price and wage rigidities) into a dynamic model provides a more realistic normative implications, and a better interpretation for the dynamic inflation-unemployment relation found in the data.

the estimation. Section 5 provides impulse response functions and historical decomposition. Section 6 concludes.

2. Model

2.1 Households

In the economy there is a continuum of households indexed by $i \epsilon (0,1)$. In time t a household gains utility from consumption, $C_t(i)$, and leisure, $1 - L_t(i)$. The i-th household therefore follows its lifetime utility function:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\ln(C_t(i) - hC_{t-1}(i)) - \frac{\xi_t^l}{1+\varpi} L_t^{1+\varpi}(i) \right] \quad (1)$$

where variables $C_t(i)$ and $L_t(i)$ present consumption and quantity of work effort of a particular household. The parameter $0 < \beta < 1$ is the discount factor of households. We assume that households value the current consumption more than the future one. The parameter $0 < \varpi < \infty$ is the inverse of the elasticity of work effort with respect to the marginal disutility of labour (Frisch elasticity parameter). We allow for habit persistence in preferences by defining $hC_{t-1}(i)$, where the parameter $0 < h < 1$ determines the degree of habit persistence.[4] Variable ξ_t^l is denoted as a labour supply shock.[5]

[4] Introducing habit persistence into the model is intended to better match the data since the response of consumption to expansionary shocks is hump-shaped, and as the peak of the response can occur several quarters after the induced shock. Such a response is harder to replicate in the absence of habit formation (Ravn et al., 2008). Habit persistence and both, price and wage rigidities, are also modelled in the Medina and Soto (2005) paper.

[5] All shocks in the model follow an exogenous $AR(1)$ process given by the following representation $\xi_t = (1 - \rho_\xi)\bar{\eta} + \rho_\xi \xi_{t-1} + \varepsilon_t^\xi$, where $\varepsilon_t^\xi \sim i.i.d., N(0, \sigma_\xi^2)$.

Since households are identical *ex ante*, they face the same budget constraint in each period given by the expression:

$$\frac{B_t(i)}{R_t} + \frac{B_t^*(i)}{R_t^* \Theta\left(\frac{B_t^*}{P_t^X X_t}\right)} =$$

$$B_{t-1}(i) + B_{t-1}^*(i) + (1-\tau_L) W_t(i) L_t(i) + \Pi_t(i) + TR_t(i) - (1+\tau_t^C) P_t C_t(i) \tag{2}$$

Variable B_t^* denotes the holdings of one-period foreign (euro area) riskless bonds, while B_t denotes the holdings of one-period domestic bonds that can be issued by the domestic government. The nominal interest rates of bonds prevail at the time when the decision is taken, by R_t^* and R_t, respectively. The assumption of the existence of a full set of contingent bonds ensures that consumption of all households is the same, independently of the labour income they receive each period. The variable Π_t denotes dividend profits of households from domestic firms. The variable W_t is the nominal wage set by a household, while TR_t are the capita lump-sum net transfers from the government. The parameter τ_L is the income tax rate and is assumed to be constant over time. On the opposite side, we assume a time-varying value added tax on consumption, τ_t^C.[6] Each time a domestic household borrows from abroad, it must pay a premium over the international price of external bonds, denoted as $\Theta(B_t^*/P_t^X X_t)$ (Schmitt-Grohé and Uribe, 2003). In comparison to the Medina and Soto (2005), the parametrization of the function Θ depends only of risk premium and not the nominal exchange rate as well. This is due to the fact, that we model a small open economy operating in a monetary union. In the steady state, for Θ holds

[6] Following Almeida (2009) we set $P_t^{num} = (1+\tau_t^C)P_t$ as the *numeraire* for converting nominal variables to real. It is the after tax price of private consumption good.

$$\Theta\left(\frac{B^*}{P^X X}\right) = \overline{\Theta}, \text{ and } \frac{\Theta'\left(\frac{B^*}{P^X X}\right)}{\Theta\left(\frac{B^*}{P^X X}\right)} \frac{B^*}{P^X X} = \varrho \tag{3}$$

The parameter ϱ is the elasticity parameter of the upward sloping supply of international funds, while $P^X X$ is the steady state value of exports and B^* stands for the steady state for net foreign asset position.

We assume that households are the same, so $C_t(i) = C_t$ holds. The consumption bundle of the i-th household is given by the following function

$$C_t = \left[\omega_{OC}^{\frac{1}{\nu_{OC}}} (O_t^C)^{\frac{\nu_{OC}-1}{\nu_{OC}}} + (1-\omega_{OC})(C_t^C)^{\frac{\nu_{OC}-1}{\nu_{OC}}}\right]^{\frac{\nu_{OC}}{\nu_{OC}-1}} \tag{4}$$

where the variable O_t^C represents oil consumption, and the variable C_t^C represents the consumption of every other (non-oil) good. The parameter ν_{OC} is the elasticity of substitution between oil and non-oil consumption, while the parameter ω_{OC} is the share of oil in the overall consumption bundle. Further on, the consumption of every other good, C_t^C, or the so-called core consumption good, again, represents an additional consumption bundle that is made of domestically produced good, and foreign imported goods. The core consumption bundle is then given by

$$C_t^C = \left[\omega_{FH}^{\frac{1}{\nu_{FH}}} (C_t^F)^{\frac{\nu_{FH}-1}{\nu_{FH}}} + (1-\omega_{FH})(C_t^H)^{\frac{\nu_{FH}-1}{\nu_{FH}}}\right]^{\frac{\nu_{FH}}{\nu_{FH}-1}} \tag{5}$$

where the parameter ν_{FH} is the elasticity of substitution between an imported and domestic good. The parameter ω_{FH} is the share of imported goods in the core consumption bundle. Now we have all the ingredients to define demand functions for each type of good. The demands for oil and core consumption good are defined as

$$C_t^C = (1-\omega_{OC})\left(\frac{P_t^C}{P_t}\right)^{-\nu_{OC}} C_t \tag{6}$$

and

$$O_t^C = \omega_{OC}\left(\frac{P_t^O}{P_t}\right)^{-\nu_{OC}} C_t \tag{7}$$

The demands for foreign and home good are defined as

$$C_t^F = \omega_{FH}\left(\frac{P_t^F}{P_t^C}\right)^{-\nu_{FH}} C_t^C \tag{8}$$

and

$$C_t^H = (1-\omega_{FH})\left(\frac{P_t^H}{P_t^C}\right)^{-\nu_{FH}} C_t^C \tag{9}$$

where P_t, P_t^O, P_t^C, P_t^F and P_t^H are prices for the respected consumption goods. Based on the consumption bundles we can define the overall inflation, P_t, as

$$P_t = [\omega_{OC}(P_t^O)^{1-\nu_{OC}} + (1-\omega_{OC})(P_t^C)^{1-\nu_{OC}}]^{\frac{1}{1-\nu_{OC}}} \tag{10}$$

Analogous to the overall inflation, the core inflation, P_t^C, is given by

$$P_t^C = [\omega_{FH}(P_t^F)^{1-\nu_{FH}} + (1-\omega_{FH})(P_t^H)^{1-\nu_{FH}}]^{\frac{1}{1-\nu_{FH}}} \tag{11}$$

Labour is differentiated over households meaning that each household is a monopoly supplier of a distinct variety of labour service, which implies that the households can determine their own wage (Erceg, Henderson and Levin, 2000; Christiano, Eichenbaum and Evans, 2005). In order to apply a wage stickiness *à la* Calvo into the model, households sell their labour service to a firm, which then transforms the labour service into a homogeneous input good L using the Dixit-Stiglitz aggregator

$$L_t = \left[\int_0^1 L_t(i)^{\frac{\nu_L - 1}{\nu_L}}\right]^{\frac{\nu_L}{\nu_L - 1}} \tag{12}$$

The parameter ν_L represents the elasticity of substitution between varieties of labour. Firms take the input price of the i-th differentiated labour service as given, as well as the price of the homogeneous labour. The demand for labour is therefore defined as

$$L_t(i) = \left[\frac{W_t(i)}{W_t}\right]^{-\nu_L} L_t \tag{13}$$

where $W_t(i)$ is the i-th household's wage, and W_t is the aggregate wage that is given by

$$W_t = \left[\int_0^1 W_t(i)^{1-\nu_L}\right]^{\frac{1}{1-\nu_L}} \tag{14}$$

Since households are monopoly suppliers of labour services, then each household has some decision power over the wage it charges, $W_t(i)$. We assume that not all households can set their wages optimally in every period. A household receives a random wage-change signal at a constant probability, $1-\alpha_L$. In this case a household can set a new optimal wage, $W_t^{opt}(i)$. With probability, α_L, other households update their wage by indexation to the current *numeraire* inflation rate target, $\bar{\pi}_t$, and previous period *numeraire* inflation rate, $\pi_t^{num} = P_t^{num}/P_{t-1}^{num}$. The household that cannot re-optimize in period t will passively set its wage according to

$$W_{t+k}(i) = (\pi_t^{num} \dots \pi_{t+k-1}^{num})^{\varphi_L} (\bar{\pi}_{t+1} \dots \bar{\pi}_{t+k})^{1-\varphi_L} W_t(i) \tag{15}$$

where the parameter $0 < \varphi_L < 1$ is the degree of wage indexation to the previous period inflation rate. On the other hand, households, that are able to re-optimize their wage, face the following maximization problem

$$E_t \left\{ \sum_{k=0}^{\infty} \alpha_L{}^k \Lambda_{t,t+k} \left[\frac{W_{t+k}^{opt}(i)(\pi_t^{num} \dots \pi_{t+k-1}^{num})^{\varphi_L}(\bar{\pi}_{t+1} \dots \bar{\pi}_{t+k})^{1-\varphi_L}}{P_{t+k}^{num}} - \right. \right.$$

$$\left. \left. \xi_t (L_{t+k}(i))^{\varpi} (C_{t+k} h C_{t+k-1}) \right] L_{t+k}(i) \right\} \tag{16}$$

where the expression $\Lambda_{t,t+k} = \beta\,(C_t - hC_{t-1})/(C_{t+k} - hC_{t+k-1})$ represents a discount factor of the relative consumption between the period t and period $t+k$.

2.2 Domestic Firms

We have a continuum of representative domestic good firms indexed by $j\epsilon(0,1)$ which operate in a monopolistic competition environment. They maximize their profits by choosing their optimal Calvo (1983) price of their product variety j. The corresponding demand and the technology is given by

$$Y_t^H(j) = Z_t^H \left[\omega_{OL}^{\frac{1}{v_{OL}}}\left(O_t^H(j)\right)^{\frac{v_{OL}-1}{v_{OL}}} + (1-\omega_{OL})\left(L_t^H(j)\right)^{\frac{v_{OL}-1}{v_{OL}}}\right]^{\frac{v_{OL}}{v_{OL}-1}} \quad (17)$$

where Y_t^H is the quantity of a particular variety of home good, while Z_t^H is a productivity shock in the home goods sector and is the same for all firms with the exogenous innovation ε_t^A. The variables $O_t^H(j)$ and $L_t^H(j)$ are the oil input and labour input in the production process of a particular variety of home produced good. The parameter ω_{OL} represenents the share of oil in the production process, while the parameter v_{OL} is the elasticity of substitution between the oil and labour inputs.

From the first order condition, we can obtain the optimal mix of both production inputs, so that

$$\frac{1-\omega_{OL}}{\omega_{OL}}\frac{O_t^H(j)}{L_t^H(j)} = \left(\frac{W_t}{P_t^O}\right)^{v_{OL}} \quad (18)$$

Based on the minimization problem defined in the equation (17) we get the expression for the nominal marginal costs that depend on the prices of both production inputs and the productivity process[7]

$$MC_t^H = \frac{1}{Z_t^H}\left[\omega_{OL}(P_t^O)^{1-\nu_{OL}} + (1-\omega_{OL})(W_t)^{1-\nu_{OL}}\right]^{\frac{1}{1-\nu_{OL}}} \tag{19}$$

Similarly as in the labour market sector, we assume that a fraction of firms $(1-\alpha_H)$ can reset their prices while the others α_H set their price accordingly to the indexation rule (Calvo, 1983). If a firm receives the price-changing signal then it maximizes the optimal price $P_t^{H,opt}$

$$E_t \sum_{k=0}^{\infty}(\beta\alpha_H)^k \Lambda_{t,t+k}\left[\frac{P_{t+k}^{H,opt}(j)(\pi_t^H \ldots \pi_{t+k-1}^H)^{\varphi_H}(\bar{\pi}_{t+1}\ldots\bar{\pi}_{t+k})^{1-\varphi_H} - MC_{t+k}^H}{P_{t+k}^{num}} Y_{t+k}^H(j)\right] \tag{20}$$

subject to the demand of the variety of j product

$$C_t^H(j) = \left[\frac{P_t^H(i)}{P_t^H}\right]^{-\nu_H}\left(C_t^H + C_t^{H,*}\right) \tag{21}$$

where the parameter ν_H denotes the price elasticity of the demand of a variety of good j. The variable $C_t^{H,*}$ is the foreign demand for home goods. The inflation variable π_t^H is defined by home good prices P_t^H/P_{t-1}^H. The other firms set their price accordingly to the passive indexation rule

[7] The nominal marginal cost depends only on the prices of inputs (oil prices and wages) and the technology level, which is common for all firms. Therefore, the marginal cost is independent from the scale of production of a particular firm (Medina and Soto, 2005). In this case, the (external) supply of oil is not defined, while the oil-prices are modelled as an exogenous $AR(1)$ process.

$$P_{t+k}^{H}(j) = (\pi_t^H \dots \pi_{t+k-1}^H)^{\varphi_H} (\bar{\pi}_{t+1} \dots \bar{\pi}_{t+k})^{1-\varphi_H} P_t^H(i) \tag{22}$$

where $0 < \varphi_H < 1$ is the inflation indexation parameter. In the end we specify the profits that a j-th firm follows

$$\Pi_t(j) = P_t^H(i) Y_t^H(i) - P_t^O O_t^H(j) - W_t L_t^H(j) \tag{23}$$

2.3 Foreign economy

The foreign economy consists of the demand for home produced goods[8]

$$C_t^{H,*} = \omega_{FH,*} \left[\frac{P_t^{H,*}}{P_t^{F,*}} \right]^{-\nu_{H,*}} C_t^* \tag{24}$$

where the parameter $\omega_{FH,*}$ represents the share of the domestic intermediate goods in the consumption basket abroad, while $\nu_{H,*}$ is the price elasticity of demand. The assumption is that domestic firms do not discriminate between prices across markets. Consequently the law of one price holds, so that $P_t^{H,*} = P_t^H$. Since the modelled small open economy operates in a monetary union the real exchange rate is just a relative price between foreign and home price index, so that

$$RER_t \equiv \frac{P_t^{F,*}}{P_t^{num}} \tag{25}$$

[8] For simplicity reasons we leave out the exportable commodity good sector, which is defined in Medina and Soto (2005) alongside the foreign demand for home produced good.

In the real exchange rate equation we assume that the foreign consumption bundle does not include oil consumption, and that the size of $\omega_{FH,*}$ is too small to affect the foreign inflation. Foreign inflation, however, is subject to a $AR(1)$ process with the exogenous innovation $\varepsilon_t^{P_*}$. Based on this we have to define the relative domestic price of oil. The expression is given by

$$\frac{P_t^O}{P_t^{num}} = RER_t \frac{P_t^{O,*}}{P_t^{F,*}}(1+\tau_t^O) \tag{26}$$

The variable τ_t^O corresponds to deviations from the law of one price in the relative oil price, due to excise duty tax on oil prices. Additionally the domestic relative oil price depends on the real exchange rate and the foreign relative oil price. The foreign price of oil $P_t^{O,*}$ is subject to a $AR(1)$ process with $\varepsilon_t^{P_{O,*}}$ being the exogenous innovation.

2.4 Government

The fiscal block follows the Almeida (2009) and Almeida et al. (2011) papers, but we add the extension of an excise duty tax rule. The government's activity is based on the acquisition of the government's consumption good, G_t, payment of debt, $(R_{t-1}-1)B_t$, and household transfers, TR_t. On the other side, the government finances itself by collecting value added tax, excise duty tax on oil consumption and income tax, $\tau_t^C P_t C_t + \tau_t^O P_t^O O_t + \tau_L \int_0^1 W_t(i) L_t(i)\mathrm{di}$, and debt issuance, B_t. The variables G_t and τ_t^C are modelled as $AR(1)$ processes with ε_t^G and $\varepsilon_t^{\tau_C}$ being the respected exogenous innovations. Government spending G_t also depends on τ_t^O, so that

$$G_t = \rho_G G_{t-1} + (1-\rho_G)\gamma_G \tau_t^O + \varepsilon_t^G \tag{27}$$

The intuition behind the equation (27) is to introduce the trade-off the government makes when it tries to put less pressure on the inflation as the oil-price shock occurs with respect to a decrease in its spending. Continuing, we get the government's primary deficit

$$def_t^{prim} = P_t G_t + TR_t - \tau_t^C P_t C_t - \tau_t^O P_t^O O_t - \tau_L \int_0^1 W_t(i) L_t(i) \mathrm{di} \tag{28}$$

We allow for the excise duty tax on oil consumption τ_t^O to vary over time so that

$$\tau_t^O = \rho_\tau \tau_{t-1}^O - (1-\rho_\tau)\gamma_O \bar{\pi}_t^{O,*} + \varepsilon_t^{\tau o} \tag{29}$$

This feature helps the fiscal part of the economy to curb the effects of the dynamics of global oil prices, $\bar{\pi}_t^{O,*} = P_t^{O,*}/P_t^{num}$, on the domestic economy via excise duty tax rule. Jakab, Baksa and Benk (2010) implemented a similar tax rule; however, they introduce a general tax rule based on the GDP gap. The idea behind the excise duty tax rule is that when global oil prices rise the government decreases the excise duty tax on oil consumption by $(1-\rho_\tau)\gamma_O$ amount. The parameter ρ_τ is an autoregressive parameter with respect to the past values of excise duty tax on oil consumption τ_{t-1}^O. The parameter γ_O is the response parameter that changes the excise duty tax when global oil prices change. This way the government decreases the oil-price increase pressure on the firms and households. On the other hand, the lower excise duty tax income decreases the government spending and thus decreases the aggregate output. Adding interest outlays, we get the government's total deficit

$$def_t^{tot} = def_t^{prim} + (R_{t-1} - 1)B_t \tag{30}$$

The government's budget constraint is defined by equalling government's resources and expenditures, such that

$$B_{t+1} + \tau_t^C P_t C_t + \tau_t^O P_t^{O,*} O_t + \tau_L \int_0^1 W_t(i) L_t(i) \mathrm{di} = P_t G_t + R_{t-1} B_t + TR_t \tag{31}$$

and such that

$$B_{t+1} = B_t + def_t^{tot} \tag{32}$$

In order to prevent explosiveness of the debt path a fiscal rule has to be imposed by restricting def_t^{prim} with endogenously adjusting TR_t and ensuring that the debt-to-GDP ratio converges to a stable long-term value. The rule is given by

$$\frac{def_t^{prim}}{\widehat{gdp}} = -\nu_g \left(\frac{B_{t+1}}{\widehat{gdp}} - \left(\overline{\frac{B}{\widehat{gdp}}} \right) \right) \tag{33}$$

where $\overline{B/\widehat{gdp}}$ stands for the target value of the stationary debt-to-GDP ratio. The parameter ν_g is the government's response parameter to the compliance of the debt-to-GDP ratio. The idea behind the fiscal rule is that whenever the debt-to-GDP ratio rises above the target value, the transfers to households, TR_t, automatically decrease, in order to reduce the government's expenditures and later on its deficit.

2.5 Monetary policy

Monetary policy interest rate is modelled as a Taylor rule (Taylor, 1993) and determines the interest rate for both economies operating in the monetary union

$$R_t^* = \rho_R R_{t-1}^* + (1-\rho_R)\left(\gamma_\pi \pi_t^* + \gamma_y C_t^*\right) + \varepsilon_t^{MP} \tag{34}$$

Variable ε_t^{MP} represents an exogenous monetary policy shock. For the output gap, we assume that foreign demand C_t^* is large enough in comparison to the Slovene economy, so that the Slovene aggregate production would not significantly affect both economies together. Foreign demand C_t^* and inflation, π_t^*, are assumed to be exogenous $AR(1)$ processes with innovations $\varepsilon_t^{Y_F}$ and $\varepsilon_t^{P_*}$, respectively.

2.6 Market clearing

In the composite good market, supply of domestically produced good must satisfy the all types of demand

$$Y_t^H = C_t^H + C_t^{H,*} + G_t \tag{35}$$

The labour market implies that demand equals supply of labour

$$L_t = L_t^H \tag{36}$$

From the aggregate budget constraint of households, we obtain an expression for the aggregate accumulation of international bonds

$$\frac{B_t^*}{R_t^*\Theta\left(\frac{B_t^*}{P_t^X X_t}\right)P_t^{num}} = \frac{B_{t-1}^*}{P_t^{num}} + \frac{P_t^X}{P_t^{num}} X_t - \frac{P_t^M}{P_t^{num}} M_t \tag{37}$$

The total value of exports depends on the foreign demand for domestically produced goods

$$\frac{P_t^X}{P_t^{num}} X_t = \frac{P_t^H}{P_t^{num}} C_t^{H,*} \tag{38}$$

On the other hand the value of imports depends on the real exchange rate and the domestic demand for foreign goods and demand for oil and is given by

$$\frac{P_t^M}{P_t^{num}} M_t = RER_t C_t^F + \frac{P_t^{O,*}}{P_t^{num}} O_t \tag{39}$$

where $O_t = O_t^C + O_t^H$ represents the total oil imports, comprised by household oil consumption and oil inputs in the home economy production process. We are left with the definition of the GDP, which is given then by

$$\frac{P_t^Y}{P_t^{num}} Y_t = \frac{P_t}{P_t^{num}} C_t + \frac{P_t^X}{P_t^{num}} X_t - \frac{P_t^M}{P_t^{num}} M_t + \frac{P_t}{P_t^{num}} G_t \tag{40}$$

3. Calibration of the model

The key calibrated parameters are set with the intention of suiting the model as close as possible to the economy characteristics of interest - Slovenia, and at the same time are not of interest of the estimation process. The calibrated parameters are set according to already known empirical facts and national statistics data. The inverse of the elasticity of work effort (Frisch elasticity), ϖ, is set to 1. The remaining parameters are: the discount factor, β, is set to 0.995, while the degree of habit persistence is $h = 0.85$. The target debt-to-GDP ratio, $\overline{\hat{b}/\widehat{gdp}}$, is set to 0.6, which is in-line with the Maastricht criteria. The other macro-related parameters relate to long-term averages and are set accordingly to the data from the Statistical Office of Republic of Slovenia (SORS). Government spending relative to the GDP is set to 17%, while net exports are set to 0.5%. The import share of goods in the consumption basket, ω_{FH}, takes the value of 0.5, while the share of oil in the total consumption basket, ω_{OC}, and the share of oil in the production process, ω_{OL}, take the value of 0.06. The Calvo wage parameter α_H is set to 0.875, while the wage indexation parameter φ_H is set to 0.5. The elasticities of substitution between the same varieties of goods, ν_H, and labour, ν_L, are set to 11. Since Slovenia is a small open economy operating in a monetary union (i.e. without a significant effect on the monetary policy decision), we set the inflation and output interest rate response parameters to $\gamma_\pi = 1.5$ and $\gamma_y = 0.1$ (Taylor rule parameters), close to Fourçans and Vranceanu (2004) estimated parameters for the euro area.

4. Estimation and results

In this subsection Bayesian estimation results of the model are presented. The parameters of our interest are estimated with Bayesian methods. Bayesian inference starts from setting out prior distributions of the model's parameters, which are not calibrated. In more detail, the prior distributions describe the available information priors. Then we observe the available statistical data in order to update the information prior with Bayes theorem, and obtain posterior distributions of the model's parameters. The dataset spanning from 2002Q1 to 2017Q3 in this process is comprised of Slovene quarterly data: real GDP, real government spending, employment, excise duty tax rate, core inflation and HICP inflation. [9] We also add quarterly time series for the euro area real GDP. The original statistical series are not stationary; therefore, the stationarity of the data has to be imposed first by log differentiating and demeaning of the data. The data enters the model as percent deviation from the steady state. The Metropolis-Hastings MCMC algorithm is used with 1.000.000 steps and two sequential chains with the acceptance rate per chain at a rate of 33.7%.

The results of the prior and posterior distribution of the estimated parameters and shocks are shown in Table 1. Looking at the estimation results, all the shocks are relatively persistent. The persistence parameters of shocks are denoted by parameters ρ. Their values are mostly estimated to be between 0.65 and 0.8. While none of the shocks is excessively persistent, but are in-line with the existing literature (for example Forni et al., 2015; Smets and Wouters, 2003). The elasticities of substitution between oil and non-oil products, ν_{OC}, and factors, ν_{OL}, as expected exhibit low values, suggesting that oil is very inelastic. Inelasticity of oil is widely empirically documented (Miyazawa, 2009; Caldara, Cavallo and Iacoviello, 2016). What is more interesting is the estimate of the response parameter of excise duty tax rule, γ_O. It takes the value of 0.0966. If we consider the persistence parameter of the excise duty tax rule, ρ_{τ_O}, than by simple algebra we can conclude that the government's reaction to a 1 p.p. increase in global oil price, the excise duty tax rate decreases by 0.025 p.p.. More on the effects of oil shocks are presented in the next section where we analyse impulse response functions.

[9] Sources: Eurostat, SORS and ECB.

Table 1. Prior and posterior distribution of the estimated parameters and shocks

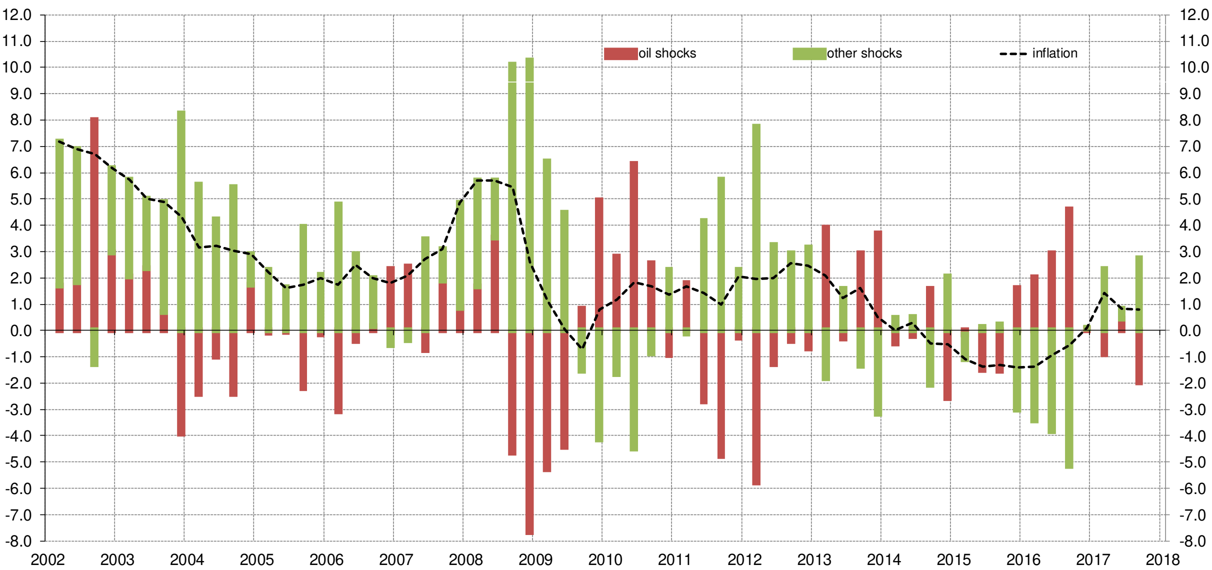
Parameter	Prior mode	Posterior mode	90% HPD interval		Type of prior	Prior distribution
γ_O	0.1000	0.0966	0.0498	0.1420	beta	0.0300
γ_G	0.1000	0.0929	0.0462	0.1371	beta	0.0300
ν_{FH}	1.0000	0.8497	0.7037	0.9899	gamma	0.1000
ν_{OC}	0.1000	0.0807	0.0421	0.1189	gamma	0.0300
ν_{OL}	0.1000	0.0956	0.0495	0.1407	gamma	0.0300
$\nu_{FH,*}$	1.0000	0.6925	0.5618	0.8165	gamma	0.1000
φ_H	0.7500	0.1658	0.0950	0.2328	beta	0.1000
α_H	0.7500	0.7263	0.6536	0.8021	beta	0.1000
ρ_{P_*}	0.7500	0.7794	0.7219	0.8405	beta	0.0700
ρ_A	0.7500	0.7165	0.5626	0.8747	beta	0.1000
$\rho_{P_{O,*}}$	0.7500	0.6548	0.4964	0.8154	beta	0.1000
ρ_{Y_F}	0.7500	0.7322	0.5731	0.8952	beta	0.1000
ρ_{τ_O}	0.7500	0.7473	0.603	0.8995	beta	0.1000
ρ_G	0.7500	0.7639	0.6177	0.9124	beta	0.1000
ρ_{τ_C}	0.7500	0.7928	0.6539	0.9383	beta	0.1000
ϱ_R	0.7500	0.6998	0.6947	0.7049	beta	0.1000
ε_{MP}	0.4000	0.4020	0.3225	0.4796	inv. gamma	0.1000
ε_{P_*}	0.5000	0.1341	0.1148	0.1530	inv. gamma	0.2000
ε_A	0.7000	0.2148	0.1857	0.2435	inv. gamma	0.2000
$\varepsilon_{P_{O,*}}$	0.5000	0.3265	0.2204	0.4269	inv. gamma	0.2000
ε_{Y_F}	0.7000	0.2150	0.1862	0.2438	inv. gamma	0.2000
ε_{τ_O}	0.5000	0.1192	0.1027	0.1355	inv. gamma	0.2000
ε_G	1.0000	0.4092	0.3549	0.4614	inv. gamma	0.2000
ε_{τ_C}	1.0000	0.4185	0.3631	0.4724	inv. gamma	0.2000

Source: author's calculations

5. Impulse response functions and the historical shock decomposition

Figure 1 shows the contributions of the exogenous shocks onto the overall inflation through time. It is evident, that the inflation in Slovenia was influenced by global oil price dynamics. During the 2006-2008 boom period in Slovenia the global oil prices positively contributed to the Slovene inflation as the global economy was in a large upswing. The Slovene inflation drastically decreased as the global financial crisis hit at the second half of the 2008. As the global economy rebounded from the first wave of the global financial crisis, so did the global oil prices as they again positively contributed to the Slovene inflation in 2010 and the beginning of 2011. The 2011 and 2012 were characterised by the European sovereign crisis which affected the global demand for crude oil. This is shown by the negative contribution of oil-price shocks on the Slovene inflation. The negative contribution of oil-price shocks continued in the next years as the global oil prices continued to fall in 2014 and 2015. Only with the start of 2016 the pattern of positive oil-price shocks on the Slovene inflation emerged again, which is in line with the global oil-price dynamics as the emerging economies increased the global demand.

Figure 1. Historical decomposition of oil and other shocks on inflation (y-o-y growth rate in percent)



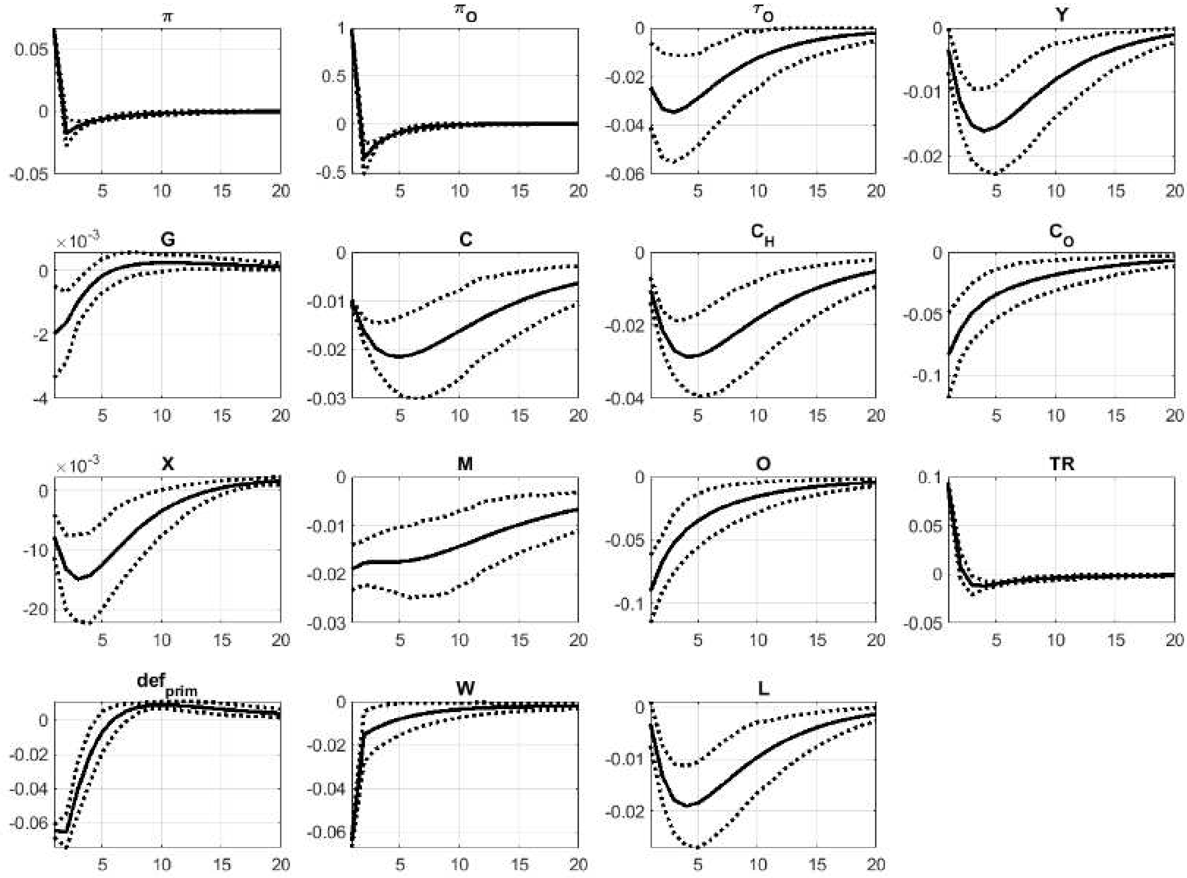
**Note: The contribution of other shocks are the sum of the initial values and shocks ε_{MP}, ε_{P_*}, ε_A, , ε_{τ_O}, ε_{Y_F}, ε_G, and ε_{τ_C}.*

Source: author's calculations.

Going deeper into the analysis, the impulse response functions are depicted and assess how the key macroeconomic variables react to shocks induced to the modelled economy. In applied work namely, it is often of our interest to study the response of one variable to an exogenous impulse in another variable. Impulse response describes the evolution of the variable of interest along a specified time horizon after a shock in a given moment. The impulse responses of the exogenous shocks in the following figure depict a 30-period horizon. It is not, however, our objective to thoroughly analyse the simulated economy's impulse responses to all defined shocks, thus we limit the analysis to the response of macroeconomic variables only to the oil-price shock and the shock to the tax rate of the excise duty tax on energy products.

According to our model, it seems that foreign oil-price shocks can play a significant role in driving the macroeconomic dynamics in Slovenia. To show the effect of changing global oil-price dynamics, we analyse a 1 percentage point (p.p.) ex-ante increase in global oil prices. The effects of this shock are displayed in Figure 2, representing the impulse responses of the main macroeconomic variables to the global oil-price shock. The rise in global oil prices causes oil imports to decline for 0.1 p.p. from the steady state. On the other side the price of oil goods increases for 1 p.p., making the whole economy worse off as the real aggregate output, consumption of all type of goods, overall imports, exports, labour and wages decrease. At the same time the inflation increases marginally as it mostly depends on the weight of oil goods in the inflation basket. When an oil-price shock occurs the primary deficit decreases as well. There are two reasons for it. First, the overall cooldown of the economic activity indirectly decreases the government's income side *via* lower overall tax revenues. Second, the excise duty tax rule responds to an increase in oil prices and thus directly decreases the excise duty tax rate. Comparing the impulse responses of the oil-price shock to the existing literature, it closely matches the responses to a negative oil-price shock done by Forni et al. (2015) as they estimated the effect of the oil-price shock to the euro area economy. The excise duty tax rate on oil products immediately decreases as the government acts counter-cyclically to the dynamics of global oil prices.

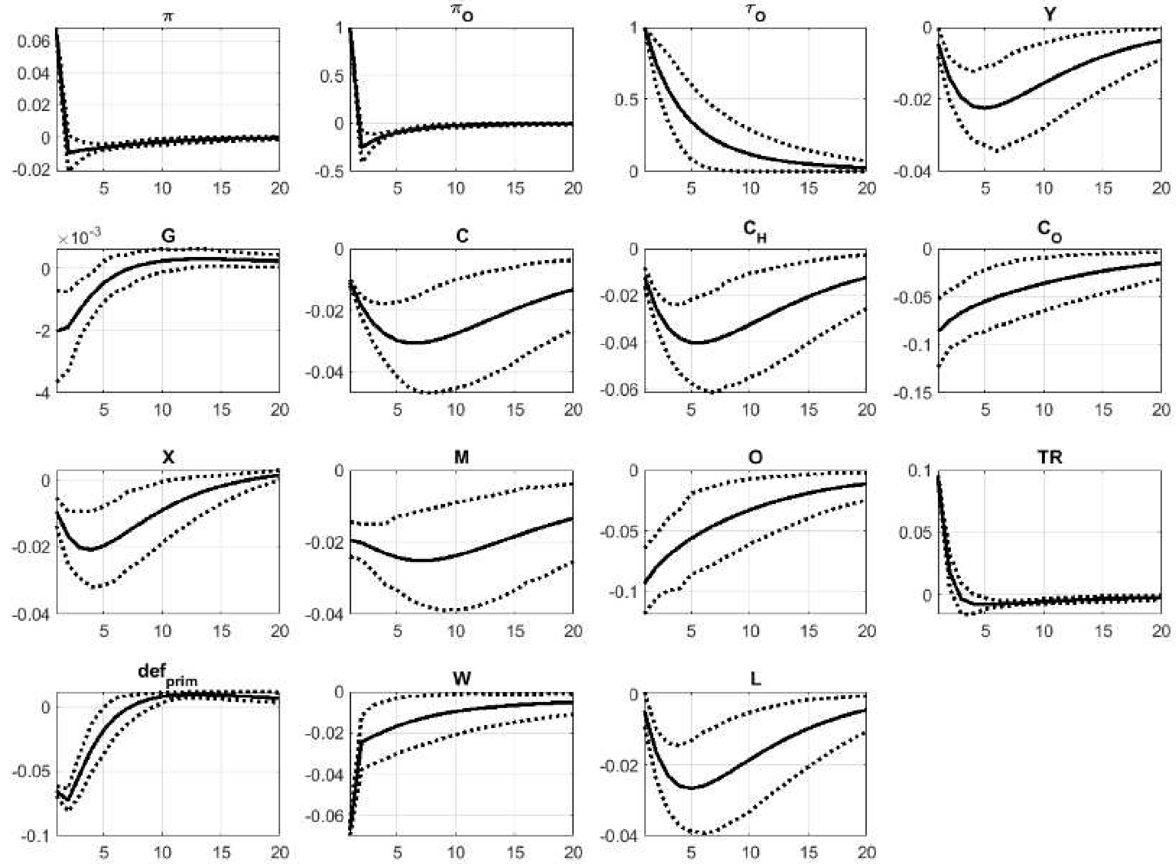
Figure 2. Impulse responses of the macroeconomic variables to a 1 p.p. foreign oil price shock (deviations from steady state)



Source: author's calculations

Figure 3 represents the impulse responses of the macroeconomic variables to a 1 p.p. increase of the excise duty tax rate on oil prices. By doing this we show the effects of the government's decision of raising the excise duty tax rate on the economy. As expected the increase in the excise duty tax rate on oil products has similar effects as the global oil-price shocks – the costpush type shocks.[10] The inflation increases, as well as the domestic oil prices. On the other side the aggregate output, consumption, exports, imports, wages and labour decrease.

Figure 3. Impulse responses of the macroeconomic variables to a 1 p.p. excise duty tax on oil prices shock (deviations from steady state)



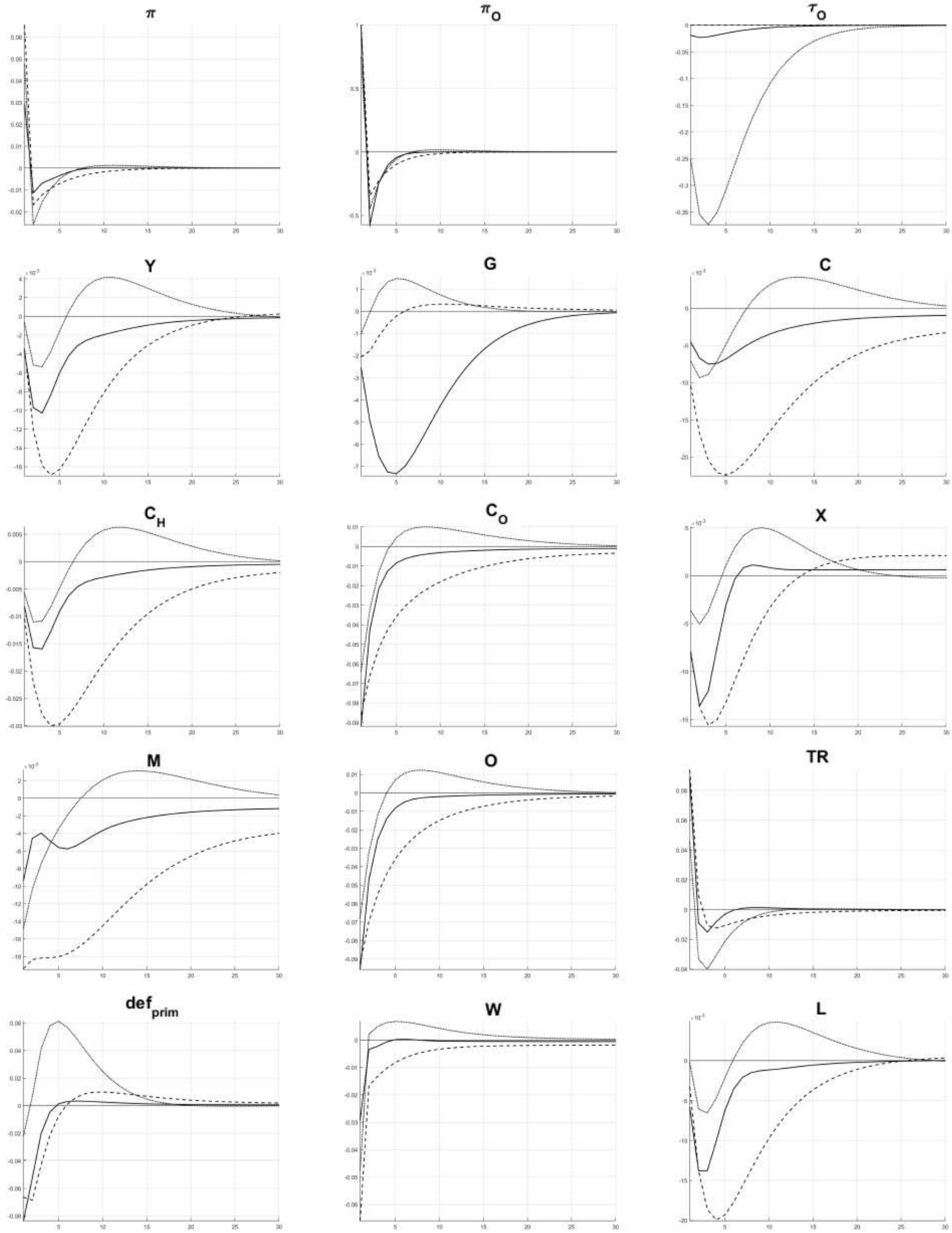
Source: author's calculations

Against this backdrop we provide three different scenarios by changing the value of the excise duty tax parameter. Having obtained the estimated values of the model parameters we continue with a comparison of the impulse responses of the main macroeconomic variables by fixing all

[10] Implementation of an excise duty tax rate shock was intended to show the similarities between the oil-price and the excise duty tax rate shock that both have on the economy. In this manner, a government should be cautious in adjusting the excise duty tax rate, especially if the government decides to increase the tax rate. Nonetheless, the main contribution of the paper is to introduce the excise duty tax rule that offsets hikes in oil-price fluctuations and volatility.

the parameters to an estimated value and changing the value of the excise duty tax response parameter γ_O. The solid line in Figure 4 represents the responses of the variables when γ_O is set to the estimated value of 0.0966. The dashed line represents the responses of the variables when γ_O is calibrated to 0 and the dotted line represents the responses of the variables when γ_O is calibrated to 1. This way we provide two additional calibrated values of the excise duty tax rate response parameter γ_O. The distinction of implementing the excise duty tax rule is evident in our case. If the government does not respond to an oil-price shock by increasing the excise duty tax rate (when $\gamma_O = 0$), the domestic economy faces a stagflation, as the overall inflation increases while output, consumption, real wages, exports and imports (oil and non-oil goods) decrerase. On the other hand, if the government accommodates the excise duty tax rate by considering the excise duty tax rule (when $\gamma_O > 0$), the government's fiscal policy is able to steer the increase of global oil prices away from the overall inflation. The harder the government tries to offset the oil-price shock, the better it is for the economy, especially inflation-wise. Oil-price shocks have lower negative effects on real wages and employment of households, since the inflation increases less than in the absence of the counter-cyclical excise duty tax rule. Consequently, real consumption of every type decreases less in the case of more aggressive fiscal accommodation of the excise duty tax parameter ($\gamma_O = 1$). The same applies for real output, exports and imports. On the other hand, if the government is highly aggressive (i.e. $\gamma_O = 1$), it has to increase its budget deficit in order to offset the negative oil-price shocks, which is not the case in the other two scenarios.

Figure 4. Impulse responses of the inflation variables to a 1 p.p. foreign oil-price shock with changing government excise duty parameter (deviations from steady state)



Source: author's calculations

6. Conclusion

In this paper a DSGE model is estimated on Slovene economy data. The main contribution of the paper aims to fill the gap by studying the effects of oil-price shocks in a small open economy model setting integrated in a single monetary union, namely the euro area, and introducing a concise government sector with excise duty tax rule for oil related products. The structure of the model is set in a typical small open economy fashion, where firms and households are assumed to adjust prices and wages *à la* Calvo, respectively. The different composition of the goods bundle allows for the changing demands of different types of goods that are affected by different price setting. By using Bayesian inference methodology the key parameters of interest are estimated.

The results show that global oil-price shocks can still have large effects on the Slovene economy. The fiscal policy authority has the power to offset the pressure that the oil-price shocks have onto the overall inflation by counter-cyclically regulate the excise duty tax rate on oil products. However, this comes at a cost. Decreased tax income decreases government spending and increases the budget deficit, if the government chooses not to decrease its spending one to one with the decrease in tax income.

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Appendices

Appendix A: Prior and posterior distribution

Figure A1. Prior (dashed line) and posterior distribution (solid line) of the estimated shocks

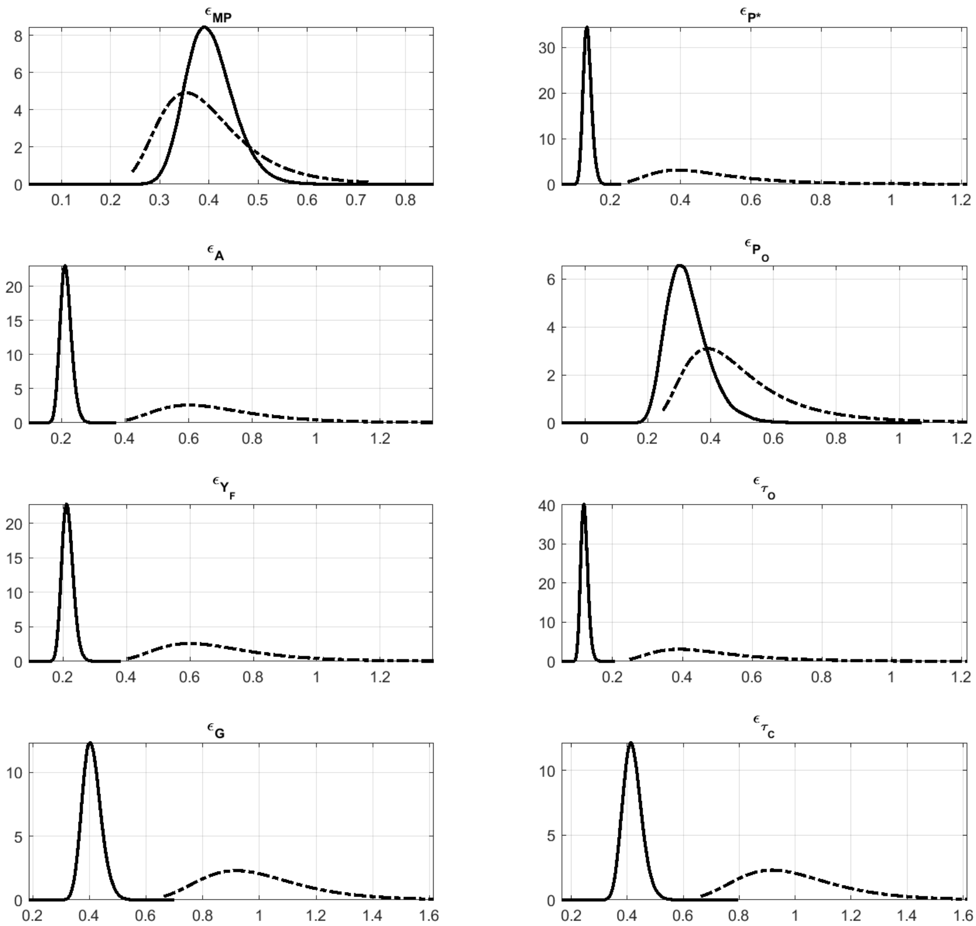
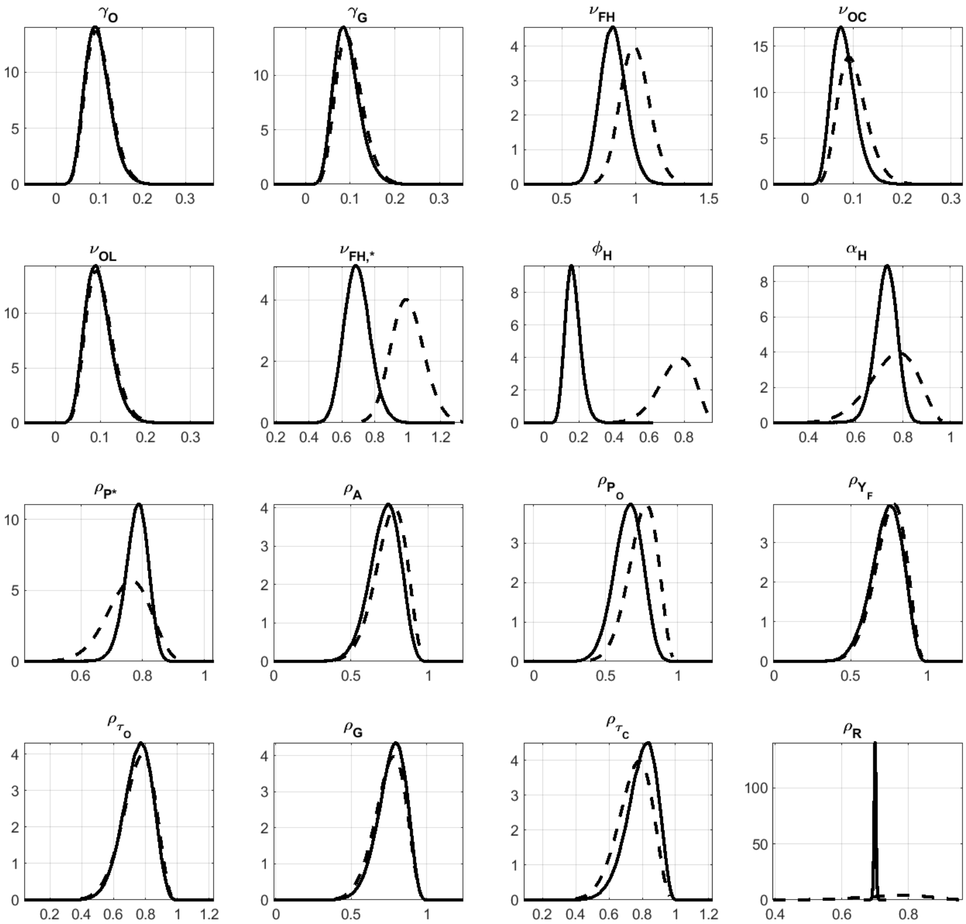


Figure A2. Prior (dashed line) and posterior distribution (solid line) of the estimated parameters



Appendix B: Exogenous shocks

Figure B1. Exogenous shocks