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Abstract

We estimate deviations of the federal funds rate from the Taylor rule by taking into account the endogeneity of output and inflation to changes in interest rates. We do this by simulating the paths of these variables through a DSGE model using the estimated time series for the exogenous processes except for monetary shocks. We then show that taking the endogeneity of output and inflation into account can make a significant quantitative difference (which can exceed 40 basis points) when calculating the appropriate value of interest rates according to the Taylor rule.

JEL Classification: E32, E37, E50

Keywords: interest rates, New Keynesian models, sticky prices, DSGE, business cycles, Bayesian estimation.

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1 Introduction

In this paper we estimate a medium-scale dynamic stochastic general equilibrium (DSGE) model in which monetary shocks are measured as deviations from the interest rate rule proposed in Taylor (1993). We then use the DSGE model's parameter estimates and the estimated time series for the exogenous processes except for the monetary shock (the deviations in policy from the Taylor rule) to simulate the path that interest rates, inflation and output would have taken in the absence of deviations from the Taylor rule. That is, our calculation of the federal funds rate according to the Taylor rule takes into account that had interest rates been different, then the paths of inflation and output would not have been equal to those which were observed. This is the case because, according to New Keynesian theory, monetary policy shocks have both nominal and real effects (see for example Galí, 2008).

Our results show that the Federal Reserve deviated significantly from what the Taylor rule would have prescribed during the 70s, early 80s and in the early 21st century. We additionally calculated the federal funds rate implied by the Taylor rule assuming that inflation and output would not have been affected had interest rates taken a different value (as is conventionally done). A comparison with the federal funds rate predicted by our model in the absence of monetary shocks suggests that it can make a difference (which can be quantitatively significant and exceed 40 basis points) whether one takes or not into account the endogeneity of inflation and output. We also show that when the endogeneity of output and inflation is taken into account, the values of the Taylor rule become substantially more correlated with the historical (i.e. the observed) values for the federal funds rate.

Our findings are robust to using different modelling assumptions and different sub-sample periods in the estimation.

2 The Linearized DSGE Model

The main focus of our paper is to measure how much the Fed has deviated from the Taylor rule. So we start by describing the central bank's interest rate rule. We consider a general version of the Taylor rule which allows for interest rate smoothing (Clarida et al., 2000). Therefore, in our model, we assume that the central bank sets policy by responding to the interest rate (r_t) in the previous time period, the current inflation rate (π_t) and output (y_t):

$$r_t = \rho r_{t-1} + (1-\rho)[r_\pi \pi_t + r_y y_t] + \varepsilon_t^r, \tag{1}$$

where $\varepsilon_t^r = \eta_t^r$ is an exogenous monetary policy shock (assumed to be IID-Normal), which measures policy deviations from the Taylor rule. All variables are log-linearized around their steady state balanced growth path.

The remaining equations of the DSGE model are identical to Smets and Wouters (2007) and to conserve space we do not include them here (in the online appendix we provide a complete description of the model). Our motivation to use the Smets and Wouters (2007) model is based on its good fit to the main aggregate US time series. As Cúrdia and Reis (2010) point out "central banks around the world have adopted variants of this model" and this too informed our choice to use it as a main reference.

3 Estimation Methodology

The model presented in section 2 is estimated with Bayesian methods (which is currently the preferred approach in DSGE model estimation by macroeconomists, with several advantages over other methodologies, see Fernández-Villaverde, 2009). We start by maximizing the log posterior function, which combines the prior information on the parameters with the likelihood of the data. We then used the Metropolis-Hastings algorithm to get a complete picture of the posterior distribution.[1]

[1] A 250,000 draw sample was created. The value adopted for the scale of the jumping distribution in the Metropolis-Hastings algorithm was chosen in order to have approximately an acceptance rate of 23% (the

The interest rate rule parameters were kept fixed in the estimation procedure. The inflation and output weights were fixed at 1.5 and $0.125 = 0.5/4$ respectively, following Taylor (1993). The value for the coefficient on the lagged interest rate was set at 0.75 which is consistent with the estimates of Clarida et al. (2000). These were also the mean values of the prior distributions chosen by Smets and Wouters (2007). We also fixed the steady state inflation level at a value of 0.5 (consistent with the Federal Open Market Committee aim for 2 percent annual inflation). We maintained the same priors for the remaining parameters as in Smets and Wouters (2007).

We estimated the model using the following 7 seasonally adjusted quarterly US aggregate time series: 100 times the first difference of the natural log of the GDP deflator, real consumption, real investment, real wages, real government expenses and real GDP; 100 times the natural log of average hours worked; and the federal funds rate. These are the same time series as in Smets and Wouters (2007) but we updated the dataset to include observations for more recent years. We will therefore estimate the model for the period 1966Q1 to 2013Q4 (whereas Smets and Wouters, 2007, estimated their model with data from 1966Q1 to 2004Q4).

4 Results

The estimates for most parameters are in line with those obtained by Smets and Wouters (2007). To conserve space parameter estimates are relegated to the online appendix. The steady-state annual real interest rate implied by the parameter estimates is about 2.3% which is not very different from the 2% value used by Taylor (1993).

In Figure 1 we show the historical federal funds rate (FF) and the federal funds rate time series which would have been set according to two different methods to calculate the Taylor rule (FF' and FF''). In the method used to calculate FF' we have taken into account that inflation and output would have taken different values from their actual historical paths

optimal rate indicated in Gelman et al., 1996).

had there not been any deviations from the Taylor rule.[2] This was done by simulating the model in section 2 using the mean parameter estimates and the time series for the exogenous processes except for the monetary shock (the deviations in policy from the Taylor rule). The variable FF'' shows the value the federal funds rate would have taken using the historical values of inflation and output.

For both methods Figure 1 shows large deviations in the federal funds rate from the values implied by the Taylor rule during the late 60s and most of the 70s, the first half of the 80s and between the 2001 recession and the Great Recession. In the 90s the Taylor rule gave a very good fit of Federal Reserve policy. Our findings suggest that central bank policy should have set higher interest rates than it did during a large part of the 70s and in the years prior to the financial crisis of 2007/2008. On the other hand, during the Volcker years in the 80s the Fed deviated from the Taylor rule by setting interest rates too high.

While deviations from the Taylor rule are qualitatively similar according to both methods, Figure 1 also shows that taking into account the endogeneity of inflation and output can at times be quantitatively important. Differences between the methods can exceed 30 basis points (as is the case between 2004Q3 and 2005Q4) and even more than 40 basis points (as is the case between 1984Q3 and 1985Q2). The correlation of the historical federal funds rate for the period 1966Q1 to 2013Q4 with FF' is 0.79 but only 0.64 with FF''. Therefore, not taking into account the endogeneity of output and inflation to interest rate changes exaggerates how much monetary policy has deviated from the Taylor rule. These findings illustrate well the issue raised by Bernanke (2010) that assessing the extent of interest rate deviations from the Taylor rule is not an easy task and requires taking into account the response of inflation and output to monetary policy.

Estimates for interest rates according to the Taylor rule would be different had we used a different model (e.g. a model including a financial sector) or a different time period in the estimation (e.g. estimating the model only for the period of the "Great Moderation",

[2] According to our estimates, had the Taylor rule been followed, inflation would have been quite similar to its historical path (the correlation between the two series is 0.9997). However, the same does not happen with output (the correlation between the two series is 0.9332).

a period of low inflation and economic volatility, in order to avoid issues concerning potential structural breaks). We therefore in the online appendix have the following robustness exercises: 1) a model with an autoregressive process to measure policy deviations from the Taylor rule ($\varepsilon_t^r = \rho_r \varepsilon_{t-1}^r + \eta_t^r$) rather than an IID-Normal shock; 2) a model with financial frictions; 3) considering only the period from 1966Q1 to 2007Q4 (so as to exclude the zero lower bound period, due to concerns that non-linearities could distort parameter estimates); and 4) considering only the period from 1984Q1 to 2004Q4 (which corresponds to the "Great Moderation"). We find that our results are quite robust. Taking into account the endogeneity of inflation and output always results in differences that can be quantitatively large (in all the robustness cases there are periods where differences exceed 40 basis points). It is also always the case that the Taylor rule which takes into account endogeneity of inflation and output is closer to the historical federal funds rate.

5 Conclusion

We obtained federal funds rate deviations from the policy prescribed by the Taylor rule by estimating a structural business cycle model. This allowed us to incorporate the endogeneity of economic variables to interest rate changes when calculating the recommended value for the interest rate by the Taylor rule. We found that the differences in the prescribed interest rate values from taking endogeneity into account can be quantitatively large. Moreover, not taking into account the endogeneity of inflation and output overstates the extent to which monetary policy has deviated from the Taylor rule.

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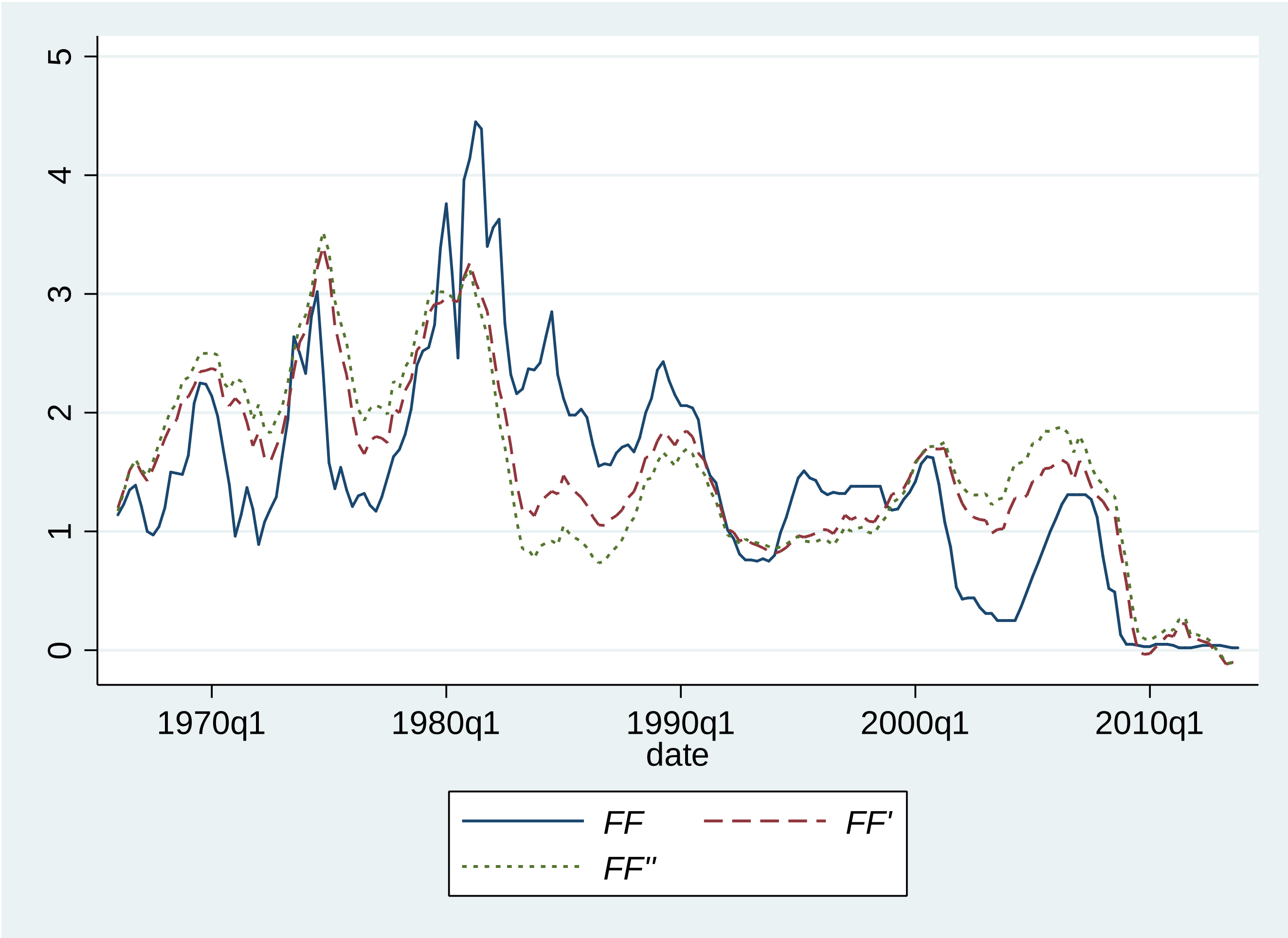
6 Figures

Figure 1 - Federal funds rate (%): historical value (FF), Taylor rule counterfactual taking into account endogeneity (FF') and without taking into account endogeneity (FF'') of inflation and output



7 Web appendix

This appendix shows the equations of the linearized DSGE model used in the paper and reports the estimates for all parameters. The appendix also shows the results of several robustness exercises. The first robustness exercise consists of assuming the monetary policy shock to be an autoregressive process. The second robustness exercise consists of using a DSGE model with financial frictions. The third robustness exercise consists of estimating the model using data only from 1966Q1 until 2007Q4. The fourth robustness exercise consists of estimating the model using data only from 1984Q1 until 2004Q4.

7.1 The Linearized DSGE Model

This section describes the DSGE model that we subsequently estimate using US data. All variables are log-linearized around their steady state balanced growth path.[3] Starred variables denote steady state values. The model includes a variety of frictions such as sticky prices and wages, habits in consumption and investment adjustments costs. The model is otherwise identical to Smets and Wouters (2007), apart from the interest rate rule (which could be viewed as a special case of that adopted by Smets and Wouters, 2007). Our motivation to do so is based on the good fit of the Smets and Wouters (2007) model to the main aggregate US time series (output, consumption, investment, hours worked, real wages, inflation and nominal interest rate) and, in a slightly different version to the Euro-area data as well (Smets and Wouters, 2003). As Cúrdia and Reis (2010) point out "central banks around the world have adopted variants of this model" and this too informed our choice to use it as a main reference.

The main focus of our paper is to measure how much the Fed has deviated from the Taylor rule. So we start by describing the central bank's interest rate rule. We consider a general version of the Taylor rule which allows for interest rate smoothing (as in Clarida, Galí and Gertler, 2000). Therefore, in our model, we assume that the central bank sets policy by responding to the interest rate (r_t) in the previous time period, the current inflation rate (π_t) and output (y_t):

$$r_t = \rho r_{t-1} + (1-\rho)[r_\pi \pi_t + r_y y_t] + \varepsilon_t^r, \tag{1}$$

where ε_t^r is an exogenous monetary policy shock, which measures policy deviations from the Taylor rule.

We now briefly describe the remaining equations of the DSGE model, as mentioned previously, we follow Smets and Wouters (2007) closely, including their notation.

[3] See the Smets and Wouters (2007) appendix for a full derivation of the steady state and the linearized model equations.

The economy's resource constraint is:

$$y_t = c_y c_t + i_y i_t + z_y z_t + \varepsilon_t^g. \tag{2}$$

Total output (y_t) is allocated to private consumption (c_t), investment (i_t), capital-utilization costs (z_t) and exogenous spending (ε_t^g). $c_y = 1 - g_y - i_y$ and $i_y = (\gamma - 1 + \delta)k_y$ are respectively the steady state consumption-output ratio and investment-output ratio. g_y is the exogenous spending-output ratio, γ is the steady state growth rate, δ is the depreciation rate of capital, k_y is the steady state capital-output ratio and finally $z_y = R_*^k k_y$ with R_*^k denoting the steady state rental rate of capital. Like Smets and Wouters (2007) we normalize exogenous spending by dividing it by g_y.

The linearized consumption Euler equation is given by:

$$c_t = c_1 c_{t-1} + (1 - c_1)E_t c_{t+1} + c_2(l_t - E_t l_{t+1}) - c_3(r_t - E_t \pi_{t+1} + \varepsilon_t^b), \tag{3}$$

where $c_1 = \frac{\lambda/\gamma}{1+\lambda/\gamma}$, $c_2 = \frac{(\sigma_c - 1)(W_*^h L_*/C_*)}{(1+\lambda/\gamma)\sigma_c}$ and $c_3 = \frac{1-\lambda/\gamma}{(1+\lambda/\gamma)\sigma_c}$. The parameter σ_c defines the level of the intertemporal elasticity of substitution, W_*^h is the steady state hourly wage, L_* steady state hours worked and C_* steady state consumption . Current consumption depends on a weighted average of past and expected future consumption (due to external habit formation, the extent of which is determined by λ), on expected growth in hours worked (l_t) and on the ex-ante real interest rate and the risk premium disturbance (ε_t^b).

The dynamics of investment (i_t) is given by:

$$i_t = i_1 i_{t-1} + (1 - i_1)E_t i_{t+1} + i_2 q_t + \varepsilon_t^i, \tag{4}$$

where $i_1 = \frac{1}{1+\beta\gamma^{1-\sigma_c}}$, $i_2 = \frac{1}{(1+\beta\gamma^{1-\sigma_c})\gamma^2\varphi}$, φ is the steady state elasticity of the cost of adjusting capital (which is a function of the change in investment, as in Christiano, Eichenbaum and Evans, 2005, in order to better capture the delayed response of investment to exogenous shocks) and ε_t^i represents a shock to the investment-specific technology process. Agents price capital according to:

$$q_t = q_1 E_t q_{t+1} + (1 - q_1) E_t r^k_{t+1} - (r_t - E_t \pi_{t+1} + \varepsilon^b_t), \tag{5}$$

where $q_1 = \beta\gamma^{-\sigma_c}(1-\delta)$ with β being the discount factor of households. The value of the capital stock (q_t) is given by the present value of its expected future price and the expected real rental rate on capital (r^k_{t+1}).

The aggregate production function is given by:

$$y_t = \phi_p(\varepsilon^a_t + \alpha k^s_t + (1-\alpha) l_t), \tag{6}$$

where k^s_t is the capital input, ε^a_t is an exogenous productivity process, α is the capital share and ϕ_p is one plus the share of fixed costs in production. The capital input used in production is a function of capital installed in the previous period (k_t) and the degree of capital utilization (z_t):

$$k^s_t = z_t + k_{t-1}. \tag{7}$$

which the households optimality conditions imply that:

$$z_t = \frac{1-\Psi}{\Psi} r^k_t, \tag{8}$$

where Ψ is a positive function of the elasticity of the capital utilization adjustment cost function and normalized to be between zero and one. The capital accumulation equation is given by:

$$k_t = k_1 k_{t-1} + (1-k_1) i_t + k_2 \varepsilon^i_t, \tag{9}$$

where $k_1 = (1-\delta)/\gamma$ and $k_2 = (1-(1-\delta)/\gamma)(1+\beta\gamma^{1-\sigma_c})\gamma^2\varphi$.

Cost minimization by firms implies that the price mark-up (μ^p_t) is equal to the difference between the marginal product of labour (mpl_t) and the real wage (w_t):

$$\mu_t^p = mpl_t - w_t = \varepsilon_t^a + \alpha(k_t^s - l_t) - w_t, \tag{10}$$

and that the rental rate of capital is given by:

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

Firms are subject to Calvo price stickiness with partial indexation to lagged inflation of non-reoptimized prices, resulting in the following "hybrid" New Keynesian Phillips Curve:

$$\pi_t = \pi_1 \pi_{t-1} + \pi_2 E_t \pi_{t+1} - \pi_3 \mu_t^p + \varepsilon_t^p, \tag{12}$$

where $\pi_1 = \frac{t_p}{1+\beta\gamma^{1-\sigma_c}t_p}$, $\pi_2 = \frac{\beta\gamma^{1-\sigma_c}}{1+\beta\gamma^{1-\sigma_c}t_p}$, $\pi_3 = \frac{1}{1+\beta\gamma^{1-\sigma_c}t_p}\frac{(1-\zeta_p)(1-\beta\gamma^{1-\sigma_c}\zeta_p)}{\zeta_p((\phi_p-1)\varepsilon_p+1)}$, t_p is the degree of indexation to past inflation, ζ_p is the probability that firms will not be able to reoptimize their prices, ε_p is the curvature of the Kimball goods market aggregator and ε_t^p is a price mark-up disturbance.

In a manner similar to the goods market, monopolistically competitive households set the wage mark-up as equal to the difference between the real wage and the marginal rate of substitution (mrs_t):

$$\mu_t^w = w_t - mrs_t = w_t - (\sigma_i l_t + \frac{1}{1-\lambda}(c_t - \lambda c_{t-1})), \tag{13}$$

where σ_i is the elasticity of labour supply.

Due to nominal stickiness and partial indexation the wage-setting equation is given by:

$$w_t = w_1 w_{t-1} + (1 - w_1) E_t(w_{t+1} + \pi_{t+1}) - w_2 \pi_t + w_3 \pi_{t-1} - w_4 \mu_t^w + \varepsilon_t^w, \tag{14}$$

with $w_1 = \frac{1}{1+\beta\gamma^{1-\sigma_c}}$, $w_2 = \frac{1+\beta\gamma^{1-\sigma_c}t_w}{1+\beta\gamma^{1-\sigma_c}}$, $w_3 = \frac{t_w}{1+\beta\gamma^{1-\sigma_c}}$, $w_3 = \frac{1}{1+\beta\gamma^{1-\sigma_c}}\frac{(1-\zeta_w)(1-\beta\gamma^{1-\sigma_c}\zeta_w)}{\zeta_w((\phi_w-1)\varepsilon_w+1)}$, t_w is the degree of wage indexation, ζ_w is the probability of not being allowed to optimize one's wage, $(\phi_w - 1)$ is the steady state wage mark-up, ε_w is the curvature of the Kimball labor market aggregator and ε_t^w is a wage mark-up shock.

Finally, the exogenous shocks are assumed to be as follows:

$$\varepsilon_t^r = \eta_t^r, \tag{15}$$

$$\varepsilon_t^b = \rho_b \varepsilon_{t-1}^b + \eta_t^b, \tag{16}$$

$$\varepsilon_t^g = \rho_g \varepsilon_t^g + \eta_t^g + \rho_{ga} \eta_t^a, \tag{17}$$

$$\varepsilon_t^i = \rho_i \varepsilon_{t-1}^i + \eta_t^i, \tag{18}$$

$$\varepsilon_t^a = \rho_a \varepsilon_{t-1}^a + \eta_t^a, \tag{19}$$

$$\varepsilon_t^p = \rho_p \varepsilon_{t-1}^p + \eta_t^p - \mu_p \eta_{t-1}^p, \tag{20}$$

$$\varepsilon_t^w = \rho_w \varepsilon_{t-1}^w + \eta_t^w \ - \mu_w \eta_{t-1}^w, \tag{21}$$

where η_t^r, η_t^b, ε_t^g, η_t^a, η_t^i, η_t^p and η_t^w are assumed to be IID-Normal. The risk premium, exogenous spending and technology shocks follow a first-order autoregressive process whereas the price and wage mark-up shocks follow an autoregressive moving average. The inclusion of the moving average term is designed to capture the high-frequency fluctuations in inflation and wages. Exogenous spending is also affected by the productivity shock so as capture changes to net exports (which can be affected by productivity).

The corresponding measurement equations are:

$$\begin{bmatrix} dlGDP_t \\ dlCONS_t \\ dlINV_t \\ dlWAG_t \\ lHOURS_t \\ dlP_t \\ FEDFUNDS_t \end{bmatrix} = \begin{bmatrix} \overline{\gamma} \\ \overline{\gamma} \\ \overline{\gamma} \\ \overline{\gamma} \\ \bar{l} \\ \overline{\pi} \\ \overline{r} \end{bmatrix} + \begin{bmatrix} y_t - y_{t-1} \\ c_t - c_{t-1} \\ i_t - i_{t-1} \\ w_t - w_{t-1} \\ l_t \\ \pi_t \\ r_t \end{bmatrix}, \tag{22}$$

where l and dl stand respectively for natural log and the first difference of the natural log, $\overline{\gamma} =$

$100(\gamma-1)$ is the common quarterly trend growth rate to real GDP, consumption, investment and wages. $\bar{l}$ is the steady state value of log of hours worked which is normalized to be equal to zero, $\overline{\pi} = 100(\Pi_* - 1)$ is the steady state value of inflation and $\overline{r} = 100\beta^{-1}\gamma^{\sigma_c}(\Pi_* - 1)$ is the steady state value of the interest rate.

7.2 The Linearized DSGE Model with an Autoregressive Monetary Shock

This is the model used in the robustness exercise 1. The model differs only from the baseline case with respect to the monetary policy shock, which is given by the equation below:

$$\varepsilon_t^r = \rho_r \varepsilon_{t-1}^r + \eta_t^r. \tag{23}$$

The remaining equations of the model are given by (1) to (14) and (16) to (22).

7.3 The Linearized DSGE Model with Financial Frictions

This section describes the DSGE model with a financial accelerator. Apart from the interest rate rule, the model is identical to Gilchrist et al. (2009) which is a variant of the Smets and Wouters (2007) model that includes financial frictions and financial shocks.

The economy's resource constraint is:

$$y_t = c_y c_t + c_y^e c_t^e + i_y i_t + z_y z_t + \varepsilon_t^g, \tag{24}$$

where c_y^e is the consumption-output ratio of entrepreneurs. Entrepreneurs who do not survive a given period are assumed to consume their net worth, n_t:

$$c_t^e = n_t. \tag{25}$$

The dynamics of investment (i_t) is given by:

$$i_t = i_1 i_{t-1} + (1 - i_1) E_t i_{t+1} + i_2 q_t, \tag{26}$$

This equation is identical to (4) but without the investment-specific technology shock. Justiniano et al. (2010) argued that the investment-specific technology shock could also be viewed as a disturbance to the financial sector. Gilchrist et al. (2009) "therefore omit the investment-specific technology shock and replace it with the shock to entrepreneurial net worth".

The capital accumulation equation is given by:

$$k_t = k_1 k_{t-1} + (1 - k_1) i_t, \tag{27}$$

This equation is identical to (9) but without the investment-specific technology shock.

The marginal product of capital is given by:

$$mpk_t = -(k_t^s - l_t) + w_t, \tag{28}$$

and the capital-utilization rate is:

$$z_t = \frac{1 - \Psi}{\Psi} mpk_t. \tag{29}$$

Entrepreneurs face an external finance premium (s_t) that drives a wedge between the expected return on capital and the expected return demanded by households:

$$s_t = E_t r_{t+1}^k - (r_t - E_t \pi_{t+1}). \tag{30}$$

The presence of financial frictions also implies that the size of the external finance premium is negatively related to the strength of entrepreneurs' balance sheets:

$$s_t = -\chi(n_t - q_t - k_t) + \varepsilon_t^{fd}, \tag{31}$$

where χ is the elasticity of the external finance premium with respect to leverage and ε_t^{fd} is a financial shock to the supply of credit.

Entrepreneurial net worth evolves according to:

$$n_t = \frac{K}{N} r_t^k - (\frac{K}{N} - 1)(s_{t-1} + r_{t-1} - \pi_t) + \theta n_{t-1} + \varepsilon_t^{nw}, \tag{32}$$

where K/N is the steady-state ratio of capital expenditures to entrepreneurial net worth, θ is the survival rate of entrepreneurs, and ε_t^{nw} is a financial shock to entrepreneurial net worth.

The value of installed capital is given by:

$$q_t = q_2 E_t q_{t+1} + (1 - q_2) E_t mpk_{t+1} - E_t r_{t+1}^k, \tag{33}$$

where $q_1 = \beta\gamma^{-\sigma_c}(1-\delta)(K/N)^{-\chi}$.

Finally, the financial shocks follow the stochastic processes:

$$\varepsilon_t^{fd} = \rho_{fd}\varepsilon_{t-1}^{fd} + \eta_t^{fd}, \tag{34}$$

$$\varepsilon_t^{nw} = \rho_{nw}\varepsilon_{t-1}^{nw} + \eta_t^{nw}, \tag{35}$$

where η_t^{fd} and η_t^{nw} are assumed to be IID-Normal.

The remaining equations of the model are given by (1), (3), (6), (7), (10), (12) to (17) and (19) to (22). The parameters K/N, c_y^e and θ were respectively set at 1.7, 0.01 and 0.99 as in Gilchrist et al. (2009). The priors for χ and the financial shocks parameters were also set as in Gilchrist et al. (2009).

7.4 Parameter estimates of baseline case

Table A1: Bayesian Estimation of Structural Parameters

	Prior Distribution			Posterior Distribution	
	Type	Mean	St. Dev	Mean	St. Dev
$\bar{\gamma}$	Normal	0.40	0.10	0.41	0.01
$100(\beta^{-1}-1)$	Gamma	0.25	0.10	0.18	0.06
$\bar{l}$	Normal	0.00	2.00	-1.04	1.05
σ_c	Normal	1.50	0.37	1.00	0.08
λ	Beta	0.70	0.10	0.74	0.04
σ_l	Normal	2.00	0.75	1.22	0.65
Ψ	Beta	0.50	0.15	0.61	0.11
φ	Normal	4.00	1.50	6.39	0.96
α	Normal	0.30	0.05	0.18	0.02
ϕ_p	Normal	1.25	0.12	1.61	0.08
ζ_p	Beta	0.50	0.10	0.88	0.02
ζ_w	Beta	0.50	0.10	0.72	0.05
t_p	Beta	0.50	0.10	0.26	0.09
t_w	Beta	0.50	0.10	0.57	0.14

Table A2: Bayesian Estimation of Exogenous Shock Parameters

	Prior Distribution			Posterior Distribution	
	Type	Mean	St. Dev	Mean	St. Dev
σ_a	Inv. Gamma	0.10	2.00	0.46	0.03
σ_b	Inv. Gamma	0.10	2.00	0.12	0.02
σ_g	Inv. Gamma	0.10	2.00	0.50	0.03
σ_i	Inv. Gamma	0.10	2.00	0.36	0.04
σ_r	Inv. Gamma	0.10	2.00	0.27	0.01
σ_p	Inv. Gamma	0.10	2.00	0.13	0.01
σ_w	Inv. Gamma	0.10	2.00	0.36	0.02
ρ_a	Beta	0.50	0.20	0.97	0.01
ρ_b	Beta	0.50	0.20	0.79	0.05
ρ_g	Beta	0.50	0.20	0.98	0.01
ρ_i	Beta	0.50	0.20	0.71	0.06
ρ_p	Beta	0.50	0.20	0.82	0.06
ρ_w	Beta	0.50	0.20	0.98	0.01
μ_p	Beta	0.50	0.20	0.71	0.09
μ_w	Beta	0.50	0.20	0.94	0.02
ρ_{ga}	Beta	0.50	0.20	0.52	0.08

7.5 Robustness exercise 1

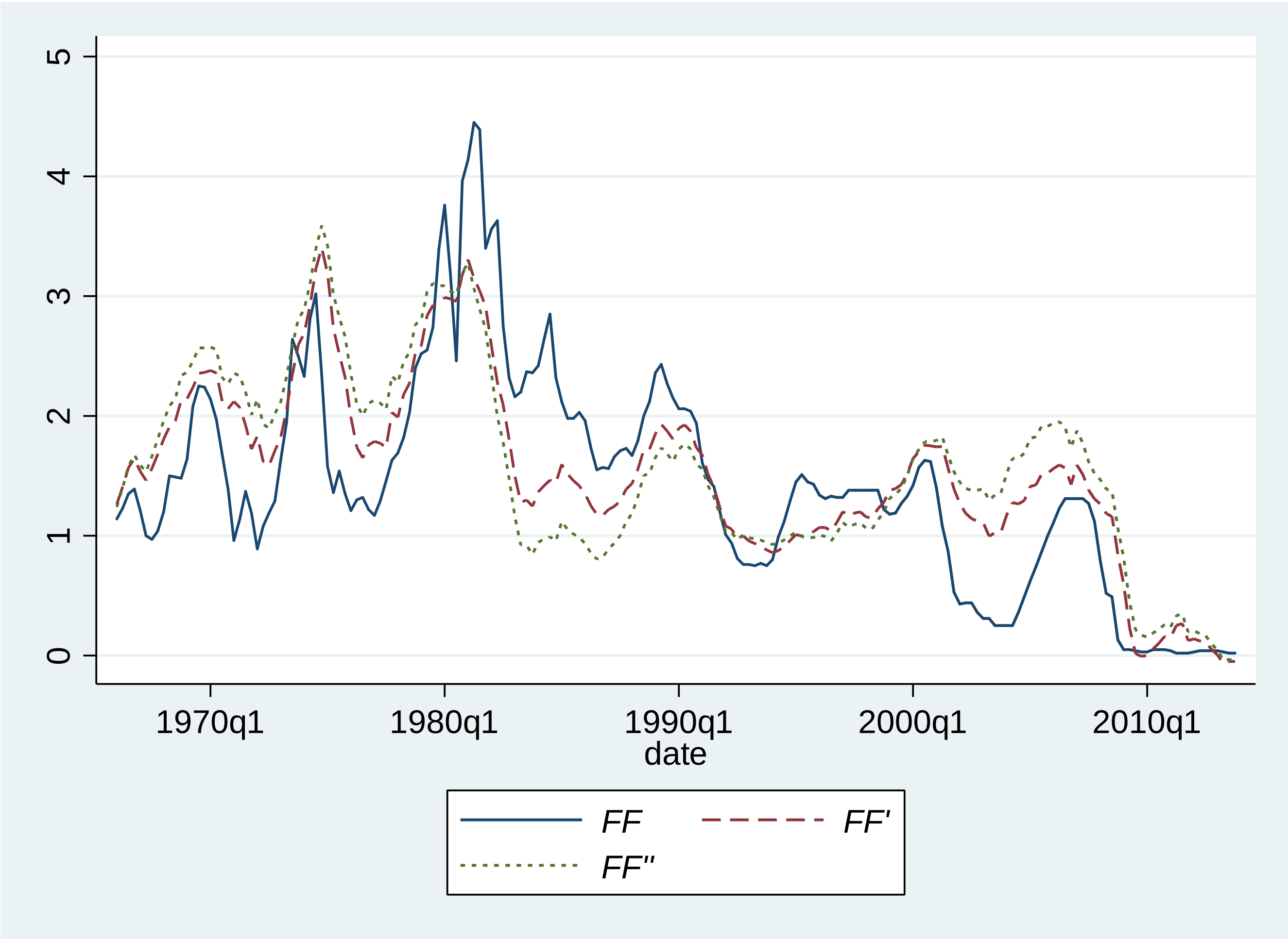
Table A3: Bayesian Estimation of Structural Parameters

	Prior Distribution			Posterior Distribution	
	Type	Mean	St. Dev	Mean	St. Dev
$\bar{\gamma}$	Normal	0.40	0.10	0.41	0.01
$100(\beta^{-1}-1)$	Gamma	0.25	0.10	0.17	0.06
$\bar{l}$	Normal	0.00	2.00	-0.56	1.16
σ_c	Normal	1.50	0.37	1.19	0.11
λ	Beta	0.70	0.10	0.82	0.03
σ_l	Normal	2.00	0.75	1.17	0.64
Ψ	Beta	0.50	0.15	0.61	0.10
φ	Normal	4.00	1.50	7.38	0.97
α	Normal	0.30	0.05	0.19	0.02
ϕ_p	Normal	1.25	0.12	1.63	0.08
ζ_p	Beta	0.50	0.10	0.87	0.02
ζ_w	Beta	0.50	0.10	0.72	0.06
t_p	Beta	0.50	0.10	0.26	0.09
t_w	Beta	0.50	0.10	0.57	0.14

Table A4: Bayesian Estimation of Exogenous Shock Parameters

	Prior Distribution			Posterior Distribution	
	Type	Mean	St. Dev	Mean	St. Dev
σ_a	Inv. Gamma	0.10	2.00	0.46	0.02
σ_b	Inv. Gamma	0.10	2.00	0.20	0.03
σ_g	Inv. Gamma	0.10	2.00	0.50	0.03
σ_i	Inv. Gamma	0.10	2.00	0.36	0.03
σ_r	Inv. Gamma	0.10	2.00	0.24	0.01
σ_p	Inv. Gamma	0.10	2.00	0.13	0.01
σ_w	Inv. Gamma	0.10	2.00	0.36	0.02
ρ_a	Beta	0.50	0.20	0.97	0.01
ρ_b	Beta	0.50	0.20	0.49	0.10
ρ_g	Beta	0.50	0.20	0.98	0.01
ρ_i	Beta	0.50	0.20	0.74	0.04
ρ_r	Beta	0.50	0.20	0.37	0.05
ρ_p	Beta	0.50	0.20	0.84	0.05
ρ_w	Beta	0.50	0.20	0.98	0.01
μ_p	Beta	0.50	0.20	0.73	0.08
μ_w	Beta	0.50	0.20	0.94	0.02
ρ_{ga}	Beta	0.50	0.20	0.52	0.08

Figure A1 - Federal funds rate (%): historical value (FF), Taylor rule counterfactual taking into account endogeneity (FF') and without taking into account endogeneity (FF'') of inflation and output



7.6 Robustness exercise 2

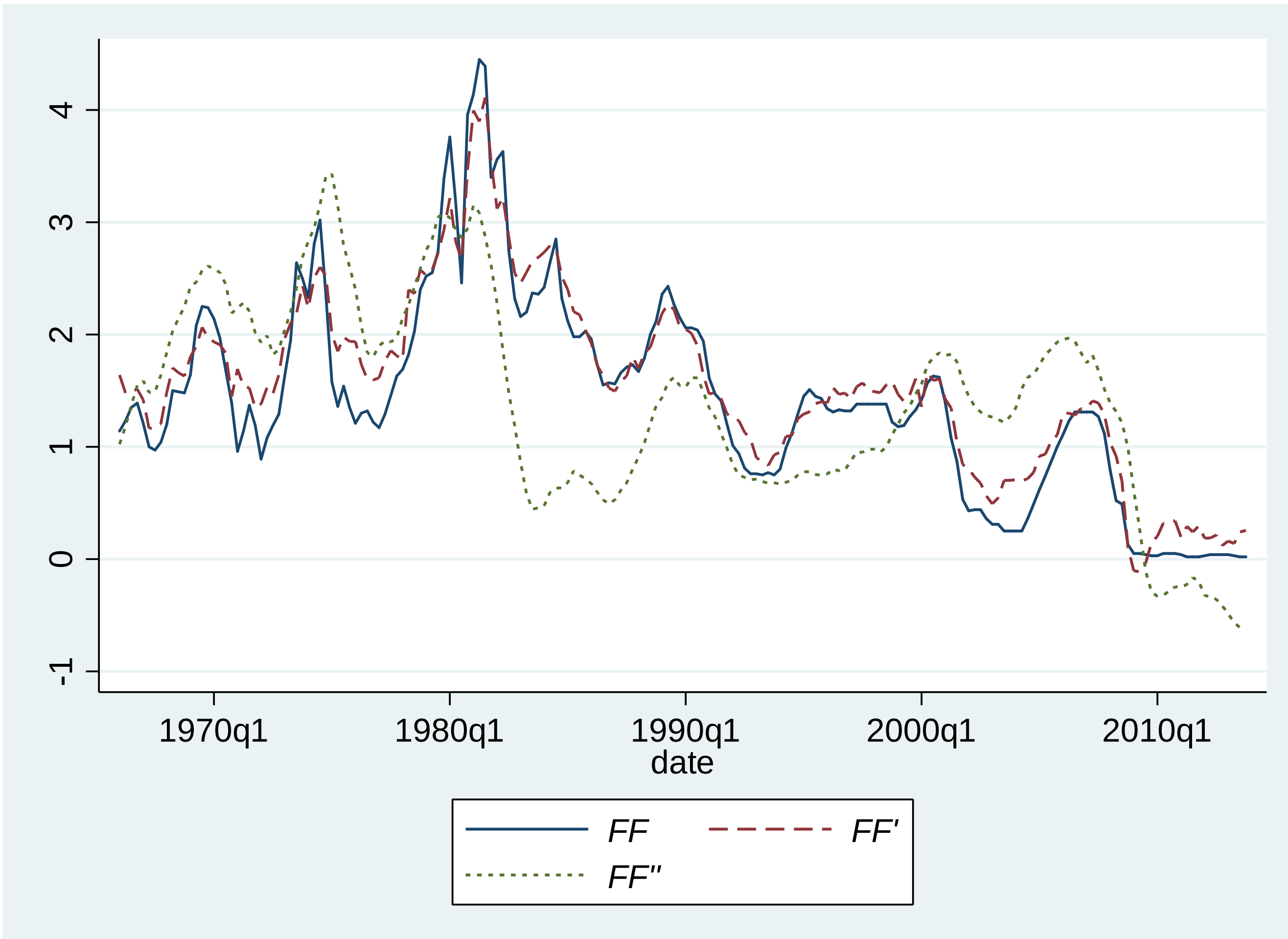
Table A5: Bayesian Estimation of Structural Parameters

	Prior Distribution			Posterior Distribution	
	Type	Mean	St. Dev	Mean	St. Dev
$\bar{\gamma}$	Normal	0.40	0.10	0.40	0.01
$100(\beta^{-1}-1)$	Gamma	0.25	0.10	0.12	0.04
$\bar{l}$	Normal	0.00	2.00	-0.96	1.34
σ_c	Normal	1.50	0.37	1.86	0.23
λ	Beta	0.70	0.10	0.55	0.07
σ_l	Normal	2.00	0.75	1.06	0.79
Ψ	Beta	0.50	0.15	0.59	0.10
χ	Beta	0.07	0.02	0.05	0.01
φ	Normal	4.00	1.50	3.59	0.72
α	Normal	0.30	0.05	0.25	0.02
ϕ_p	Normal	1.25	0.12	1.71	0.08
ζ_p	Beta	0.50	0.10	0.82	0.03
ζ_w	Beta	0.50	0.10	0.81	0.06
t_p	Beta	0.50	0.10	0.26	0.09
t_w	Beta	0.50	0.10	0.60	0.13

Table A6: Bayesian Estimation of Exogenous Shock Parameters

	Prior Distribution			Posterior Distribution	
	Type	Mean	St. Dev	Mean	St. Dev
σ_a	Inv. Gamma	0.10	2.00	0.44	0.03
σ_b	Inv. Gamma	0.10	2.00	0.15	0.03
σ_g	Inv. Gamma	0.10	2.00	0.50	0.03
σ_{nw}	Inv. Gamma	0.10	2.00	0.08	0.02
σ_{fd}	Inv. Gamma	0.10	2.00	1.66	0.43
σ_r	Inv. Gamma	0.10	2.00	0.25	0.01
σ_p	Inv. Gamma	0.10	2.00	0.12	0.01
σ_w	Inv. Gamma	0.10	2.00	0.35	0.02
ρ_a	Beta	0.50	0.20	0.97	0.01
ρ_b	Beta	0.50	0.20	0.59	0.09
ρ_g	Beta	0.50	0.20	0.98	0.005
ρ_{nw}	Beta	0.50	0.20	0.51	0.32
ρ_{fd}	Beta	0.50	0.20	0.72	0.07
ρ_p	Beta	0.50	0.20	0.91	0.03
ρ_w	Beta	0.50	0.20	0.95	0.02
μ_p	Beta	0.50	0.20	0.81	0.06
μ_w	Beta	0.50	0.20	0.93	0.02
ρ_{ga}	Beta	0.50	0.20	0.53	0.08

Figure A2 - Federal funds rate (%): historical value (FF), Taylor rule counterfactual taking into account endogeneity (FF') and without taking into account endogeneity (FF'') of inflation and output



7.7 Robustness exercise 3

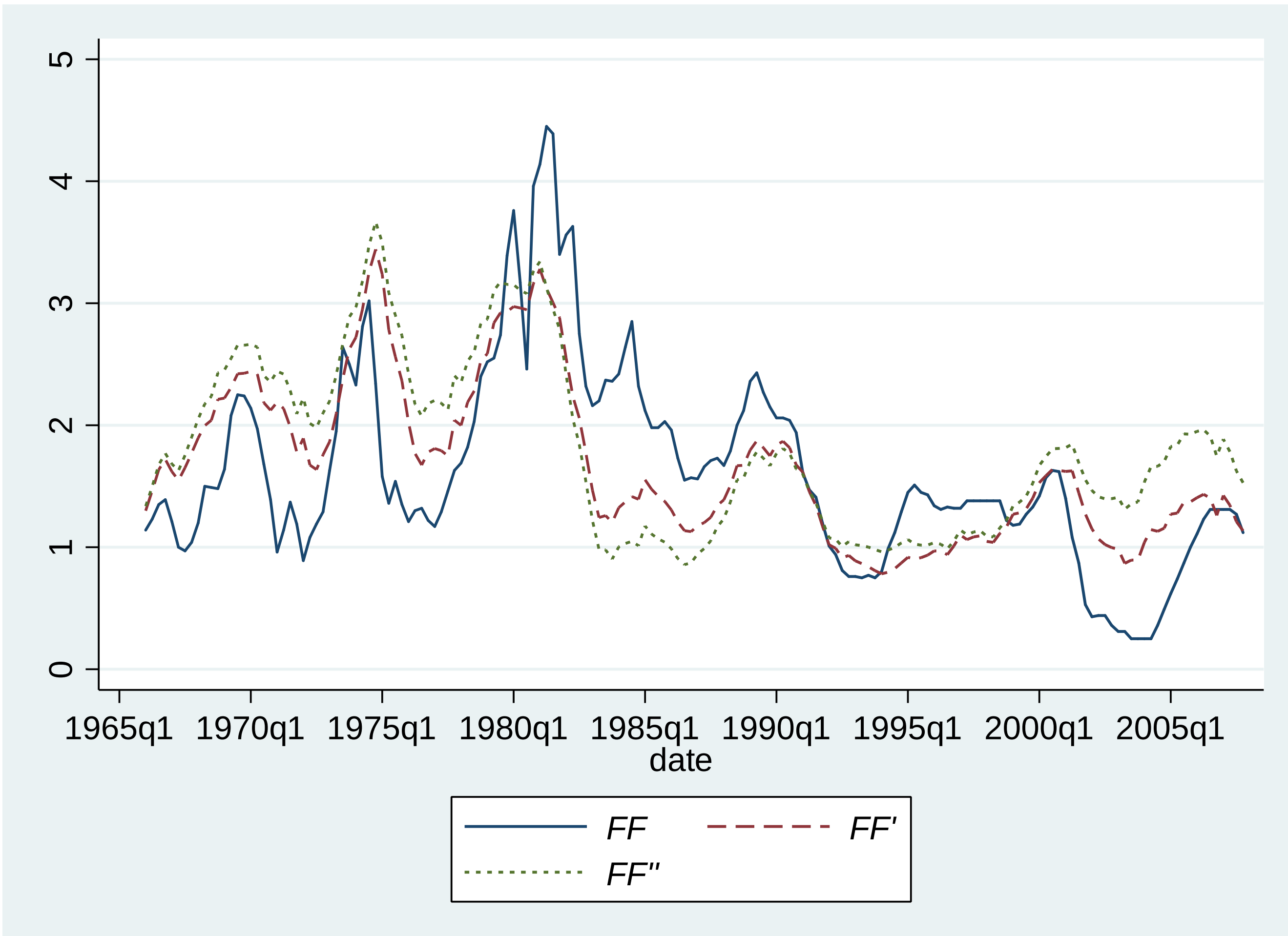
Table A7: Bayesian Estimation of Structural Parameters

	Prior Distribution			Posterior Distribution	
	Type	Mean	St. Dev	Mean	St. Dev
$\bar{\gamma}$	Normal	0.40	0.10	0.42	0.01
$100(\beta^{-1}-1)$	Gamma	0.25	0.10	0.19	0.06
$\bar{l}$	Normal	0.00	2.00	0.83	1.23
σ_c	Normal	1.50	0.37	1.30	0.12
λ	Beta	0.70	0.10	0.83	0.03
σ_l	Normal	2.00	0.75	0.82	0.52
Ψ	Beta	0.50	0.15	0.44	0.11
φ	Normal	4.00	1.50	7.10	0.92
α	Normal	0.30	0.05	0.20	0.02
ϕ_p	Normal	1.25	0.12	1.67	0.08
ζ_p	Beta	0.50	0.10	0.82	0.03
ζ_w	Beta	0.50	0.10	0.67	0.06
t_p	Beta	0.50	0.10	0.31	0.10
t_w	Beta	0.50	0.10	0.52	0.14

Table A8: Bayesian Estimation of Exogenous Shock Parameters

	Prior Distribution			Posterior Distribution	
	Type	Mean	St. Dev	Mean	St. Dev
σ_a	Inv. Gamma	0.10	2.00	0.44	0.03
σ_b	Inv. Gamma	0.10	2.00	0.25	0.03
σ_g	Inv. Gamma	0.10	2.00	0.51	0.03
σ_i	Inv. Gamma	0.10	2.00	0.43	0.05
σ_r	Inv. Gamma	0.10	2.00	0.29	0.02
σ_p	Inv. Gamma	0.10	2.00	0.13	0.01
σ_w	Inv. Gamma	0.10	2.00	0.28	0.02
ρ_a	Beta	0.50	0.20	0.97	0.01
ρ_b	Beta	0.50	0.20	0.26	0.09
ρ_g	Beta	0.50	0.20	0.98	0.01
ρ_i	Beta	0.50	0.20	0.64	0.06
ρ_p	Beta	0.50	0.20	0.83	0.05
ρ_w	Beta	0.50	0.20	0.97	0.01
μ_p	Beta	0.50	0.20	0.71	0.09
μ_w	Beta	0.50	0.20	0.88	0.04
ρ_{ga}	Beta	0.50	0.20	0.54	0.09

Figure A3 - Federal funds rate (%): historical value (FF), Taylor rule counterfactual taking into account endogeneity (FF') and without taking into account endogeneity (FF'') of inflation and output



7.8 Robustness exercise 4

Table A9: Bayesian Estimation of Structural Parameters

	Prior Distribution			Posterior Distribution	
	Type	Mean	St. Dev	Mean	St. Dev
$\bar{\gamma}$	Normal	0.40	0.10	0.56	0.01
$100(\beta^{-1}-1)$	Gamma	0.25	0.10	0.18	0.05
$\bar{l}$	Normal	0.00	2.00	1.50	0.65
σ_c	Normal	1.50	0.37	0.96	0.12
λ	Beta	0.70	0.10	0.59	0.05
σ_l	Normal	2.00	0.75	1.33	0.64
Ψ	Beta	0.50	0.15	0.57	0.13
φ	Normal	4.00	1.50	5.79	1.08
α	Normal	0.30	0.05	0.22	0.02
ϕ_p	Normal	1.25	0.12	1.51	0.09
ζ_p	Beta	0.50	0.10	0.85	0.03
ζ_w	Beta	0.50	0.10	0.61	0.08
t_p	Beta	0.50	0.10	0.38	0.14
t_w	Beta	0.50	0.10	0.50	0.17

Table A10: Bayesian Estimation of Exogenous Shock Parameters

	Prior Distribution			Posterior Distribution	
	Type	Mean	St. Dev	Mean	St. Dev
σ_a	Inv. Gamma	0.10	2.00	0.37	0.03
σ_b	Inv. Gamma	0.10	2.00	0.09	0.03
σ_g	Inv. Gamma	0.10	2.00	0.41	0.03
σ_i	Inv. Gamma	0.10	2.00	0.34	0.05
σ_r	Inv. Gamma	0.10	2.00	0.14	0.01
σ_p	Inv. Gamma	0.10	2.00	0.09	0.01
σ_w	Inv. Gamma	0.10	2.00	0.28	0.04
ρ_a	Beta	0.50	0.20	0.90	0.04
ρ_b	Beta	0.50	0.20	0.83	0.10
ρ_g	Beta	0.50	0.20	0.96	0.01
ρ_i	Beta	0.50	0.20	0.64	0.07
ρ_p	Beta	0.50	0.20	0.58	0.11
ρ_w	Beta	0.50	0.20	0.85	0.04
μ_p	Beta	0.50	0.20	0.47	0.16
μ_w	Beta	0.50	0.20	0.60	0.11
ρ_{ga}	Beta	0.50	0.20	0.52	0.12

Figure A4 - Federal funds rate (%): historical value (FF), Taylor rule counterfactual taking into account endogeneity (FF') and without taking into account endogeneity (FF'') of inflation and output