Shocks and Frictions in US Business Cycle: A Bayesian DSGE Approach

Mansur, Alfan

Fiscal Policy Agency, Ministry of Finance of the Republic of Indonesia, Faculty of Social Sciences, University of Helsinki

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Alfan Mansur
Faculty of Social Sciences, University of Helsinki

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Abstract

This paper aims to replicate and extend Smets and Wouters (2007) who study the shocks and frictions in the US business cycle using a Bayesian DSGE methodology. The novelty of this research is by applying extended Taylor rule for monetary policy in which the monetary policy also targets full employment. The SW model seems able to fit the US macroeconomic data very well. When the output gap in the Monetary policy Taylor rule is replaced with unemployment rate, wage mark up shock becomes more persistent in determining inflation and interest rate. Productivity shock also becomes stronger in driving output. However, some unexpected results also come up, e.g. the negative responses of hours worked to a risk premium shock and inflation to the demand shocks.

Keywords: shocks, frictions, monetary policy

1 Introduction

This paper aims to replicate and extend Smets and Wouters (2007) who study the shocks and frictions in the US business cycle using a Bayesian DSGE methodology. In their paper, Smets and Wouters (2007) depart from a small-scale monetary business cycle model featuring sticky prices and wages (the New Keynesian models), following Smets and Wouters (2003) and Christiano et al. (2005). One main highlight of the model (SW model hereafter) is the feature of seven orthogonal structural shocks, namely, total factor productivity shocks, two shocks affecting intertemporal margin (risk premium and investment-specific technology shocks), two shocks affecting intratemporal margin (wage and price mark-up shocks) and finally two policy shocks (exogenous spending and monetary policy shocks). These seven shocks are represented by seven main macroeconomic indicators of the US economy i.e. real GDP, working hours, consumption, investment, real wages, prices, and short term interest rates, covering the period 1947q3-2004q4 and then reduced to 1966q1-2004q4.

Another highlight of the SW model is the comparison of frictions' importance in explaining the US economy's fluctuation. For instance, which one is more important between price and wage stickiness. Here, the Bayesian estimation approach plays its strength. Finally, the SW model is applied to address the main empirical question, what the main driving forces of the US output fluctuations are. In this aspect, the results are presented in both variance decomposition and historical decomposition extracted from the seven shocks above.

A bit extended from the SW model above, this paper modifies the monetary policy reaction function from equation (14) in Smets and Wouters (2007). In their original model, the monetary policy in SW model follows a generalized Taylor rule in which the policy interest rates respond to inflation and output gap which is defined as the difference between potential and actual output (Taylor, 1993). Here, I modify the equation replacing the output gap with unemployment rate. This is motivated by the fact that the Federal Reserve currently pursues dual mandate of maximum employment and price stability, or the longer run level of interest rates consistent with maximum employment (Yellen, 2015).

2 The Model

2.1 Model Specification and Its Modification

Almost all the specifications in this paper follows the original SW model. There are 14 key equations given in the SW model from aggregate demand side, aggregate supply side, until the monetary policy reaction function. However, since the monetary policy reaction function is modified, then there are only 13 out of 14 key equations of the SW model are used in this paper. Starting from the demand side, the aggregate resource constraint is given by equation (1) in the SW model, then the consumption Euler equation is given by equation (2), the investment Euler equation is given by equation (3), and the arbitrage equation for the value of capital is given by equation (4). For the supply side, the aggregate production function is given by equation (5), the degree of capital utilization and the rate of capital are given by equation (6) and (7), respectively, and the accumulation of installed capital is given by equation (8).

Turning to the monopolistic competitive goods market, the price mark up is given by equation (9) which by price stickiness, prices adjust only slowly to the mark up. Then, equation (10) in the SW model gives the New-Keynesian Phillips curve and equation (11) gives the rental rate of capital which is implied by the firms' cost minimization. Now, for the monopolistic competitive labor market, the wage mark up is given by equation (12) and due to nominal wage stickiness and partial indexation of wages to inflation, real wage adjustment follows equation (13).

There are slight modifications from the original SW model. First, regarding the consumption Euler equation in equation (2) of the SW model. This Euler equation premultiplies the risk premium process ε_t^b by c_3 which in the modified model in this paper this prefactor is omitted by setting the coefficient to 1. This modification is adopted from Pfeifer (2016). The other modification which is created by me is regarding the monetary policy reaction function. So, instead of using the monetary policy reaction function in equation (14) of the original SW model, this paper uses

$$r_t = \rho r_{t-1} + (1-\rho)\{r_\pi \pi_t + r_u u_t\} + \varepsilon_t^r \tag{1}$$

where the policy rate r_t responds to inflation π_t and unemployment rate u_t. This is consistent with the current dual mandate of the Federal Reserve.

2.2 About the Code

The Dynare and Matlab codes used in this paper use the original code written by Smets and Wouters (2007) which is then modified by Pfeifer (2016). The data used is also retrieved from Smets and Wouters (2007). Due to the modification on the monetary policy reaction function in this paper, I have made some modifications. Firstly, I add an additional variable, i.e. the unemployment rate retrieved from the Fred St. Louis database for the period of

1948q1-2004q4.

Secondly, I add the variable of 'unrate' in the block of endogenous variables in the dynare code. Then, I add a parameter of 'cru' as the parameter for unemployment feedback in the monetary policy reaction function. Next, I set cru=1.10 for the parameter initialisation for unemployment rate. This value refers to Dosi et al. (2015). Afterwards, I create the equation of monetary policy reaction function in the block of model equations. The rest follows Smets and Wouters (2007) and Pfeifer (2016). In addition, as a companion for the dynare code, I also create a simple matlab code to run the mod file.

3 Replication of Smets and Wouters Paper

The priors of the parameters fully follow Smets and Wouters (2007). Pfeifer (2016) then also adds some additional calibrated parameters, i.e. parameters for steady state inflation rate (constepinf = 0.7), time preference rate in percent (constebeta = 0.7420), and net growth rate in percent (ctrend = 0.3982).

Another essential step is when estimating the mode of the posterior distribution. In the first step, Smets and Wouters (2007) maximises the log posterior function combining the prior information on the parameters with the likelihood of the data. In the second step, they use the Metropolis-Hastings (MH) algorithm to obtain the complete posterior distribution and and evaluate the marginal likelihood of the model. They draw a sample of 250,000 draws and drop the first 50,000. Here in this paper, due to time and technical constraints, I draw a number of 20,000 draws when simulating with the MH algorithm and I get an acceptance ratio of 0.51.

Replication of some results of Table 1A and 1B in the original SW paper is presented in Table 1 and 2 below. This replication results do not give exactly the same values with the original SW paper, but most of them are quite close with the parameter values in Table 1A of SW paper. Nevertheless, there is one parameter which deviates far from the original SW paper. This is the $\bar{l}$ in which it is 1.3263 for the mode of the posterior, whereas it is -0.1 in the original SW paper. Even the number is still positive after being deducted with its standard deviation. One possible cause of this is due to the MH algorithm. In their paper, Smets and Wouters (2007) drop the first 50,000 draws out of 250,000 draws, whereas here I only simulate 20,000 draws. One small thing to note, the parameter λ in the Table 1 below is the h parameter in Table 1A of SW paper.

Table 1: Results from posterior maximization (parameters)

	Prior			Posterior	
	Dist.	Mean	Stdev	Mode	Stdev
φ	Normal	4.000	1.5000	6.3144	0.9475
σ_c	Normal	1.500	0.3750	1.2679	0.1135
λ	Beta	0.700	0.1000	0.8056	0.0391
ξ_w	Beta	0.500	0.1000	0.7668	0.0374
σ_l	Normal	2.000	0.7500	2.5201	0.5816
ξ_p	Beta	0.500	0.1000	0.5304	0.0462
ι_w	Beta	0.500	0.1500	0.5345	0.1060
ι_p	Beta	0.500	0.1500	0.1779	0.0784
ψ	Beta	0.500	0.1500	0.3597	0.0991
ϕ_p	Normal	1.250	0.1250	1.6670	0.0728
r_π	Normal	1.500	0.2500	1.8685	0.1640
ρ	Beta	0.750	0.1000	0.8739	0.0167
r_y	Normal	0.125	0.0500	0.1203	0.0257
$r_{\Delta y}$	Normal	0.125	0.0500	0.1282	0.0194
$\bar{\pi}$	Gamma	0.625	0.1000	0.6365	0.0982
$100(\beta^{-1}-1)$	Gamma	0.250	0.1000	0.1126	0.0457
$\bar{l}$	Normal	0.000	2.0000	1.3263	0.8422
$\bar{\gamma}$	Normal	0.400	0.1000	0.5113	0.0135
α	Normal	0.300	0.0500	0.2024	0.0180

Note: The posterior distribution is obtained using the Metropolis-Hastings algorithm

Table 2: Results from posterior maximization (standard deviation of structural shocks)

	Prior			Posterior	
	Dist.	Mean	Stdev	Mode	Stdev
σ^a	Invgamma	0.100	2.0000	0.5017	0.0263
σ^b	Invgamma	0.100	2.0000	0.3583	0.0305
σ^g	Invgamma	0.100	2.0000	0.6752	0.0323
σ^i	Invgamma	0.100	2.0000	0.5678	0.0554
σ^m	Invgamma	0.100	2.0000	0.2290	0.0121
σ^p	Invgamma	0.100	2.0000	0.2181	0.0235
σ^w	Invgamma	0.100	2.0000	0.2663	0.0180
ρ_a	Beta	0.500	0.2000	0.9826	0.0044
ρ_b	Beta	0.500	0.2000	0.1391	0.0815
ρ_g	Beta	0.500	0.2000	0.9686	0.0102
ρ_i	Beta	0.500	0.2000	0.6121	0.0549
ρ_r	Beta	0.500	0.2000	0.1999	0.0639
ρ_p	Beta	0.500	0.2000	0.9856	0.0084
ρ_w	Beta	0.500	0.2000	0.9818	0.0092
μ_p	Beta	0.500	0.2000	0.8340	0.0568
μ_w	Beta	0.500	0.2000	0.9337	0.0203
ρ_{ga}	Normal	0.500	0.2500	0.5881	0.0859

Note: The posterior distribution is obtained using the Metropolis-Hastings algorithm

Another estimated parameter in Table 1, for example the trend growth rate ($\bar{\gamma}$), it shows around 0.51 here. It is very close to the average growth rate of output per capita over the sample of 0.50. In the SW original paper, it is estimated to be around 0.43, lower than both previous numbers. Another result, the mode of the discount rate on annual basis is estimated to be 0.65 percent in the SW paper and here is about 0.45 percent.

With $\alpha = 0.19$ in the SW paper or $\alpha = 0.20$ here, it indicates that there is no evidence of dynamic inefficiency for the US economy.

Now from Table 2 which replicates the Table 1B of SW paper, again they don't present exactly the same numbers as in the original SW paper, but they are pretty close both quantitatively and in terms of signs. From the Table 2 which presents the estimated processes of exogenous shocks above, the productivity (ρ_a), government spending (ρ_g), and wage mark up (ρ_w) processes seem to be the most persistent shocks. Their estimated AR(1) coefficients are around 0.98, 0.97, and 0.98, respectively. Another persistent shock which is not yet mentioned in the original SW paper is the price mark up (ρ_p) with estimated AR(1) coefficient of around 0.99. These persistent processes implies that most of forecast error variance of the real variables at long horizons will be explained by these shocks.

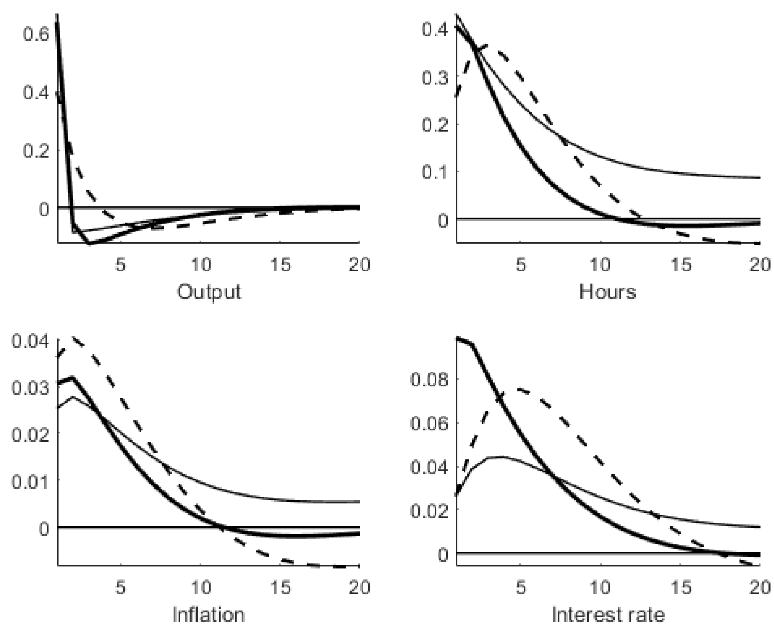

Figure 1: Replication of Figure 2 SW paper: the estimated mean impulse responses to "demand" shocks.

Note: Bold solid line: risk premium shock; thin solid line: exogenous spending shock; dashed line: investment shock

Another interesting results of the SW paper to be replicated is the impulse responses of the real variables to exogenous shocks. Figure 1 replicates Figure 2 in SW paper presenting the mean impulse responses of output, working hours, inflation, and interest rates to

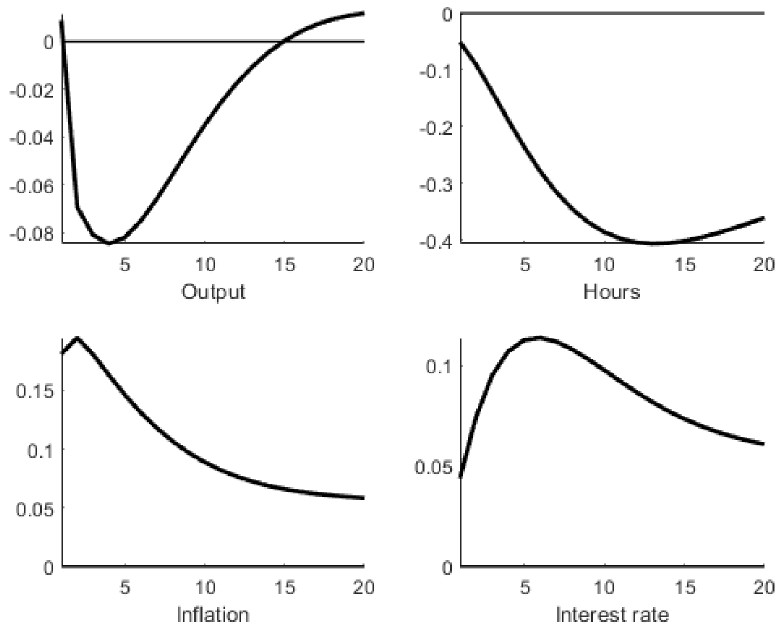

Figure 2: Replication of Figure 3 SW paper: the estimated mean impulse responses to a wage mark-up shock

demand shocks. As in the original SW paper, all three demand shocks i.e. risk premium, exogenous spending, and investments shocks give positive impacts on output, working hours, inflation, and interest rate under the estimated policy rule.

Next, Figure 2 shows the replication of Figure 3 in SW paper. It yields the same results as in the original SW paper in which a wage mark-up shock is followed by negative responses of output and working hours, but positive responses of inflation hence interest rates.

4 Extension: the Impacts of Modified Monetary Policy Rule

In their original paper, Smets and Wouters (2007) follow the generalised Taylor rule for the monetary policy reaction function in which it the monetary policy responds to inflation and output gap. This set up is no longer valid for the current situation because the Federal

Reserve now targets the inflation and employment. This section presents results using this set up, including the estimated parameters as in Table 1 and 2 as well as the impulse responses as well as historical decomposition of shocks in explaining the fluctuations of the real variables.

4.1 Posterior Estimates of Parameters

As before, the posterior distribution is obtained using the Metropolis-Hastings (MH) algorithm. The analysis here will focus on the estimated parameters for the monetary policy reaction functions since all other estimated parameters are similar to those in Table 1 and 2 in previous section.

From Table 3, the estimated inflation feedback for monetary policy (r_π) is around 1.79, lower than before which is 1.87. Both are lower compared with the estimated coefficient in the original SW paper which is 2.0. Then if we look at the estimated coefficient for the degree of interest rate smoothing (ρ), Table 1 and the original SW paper produce a high degree accounted for around 0.87 and 0.81, respectively. Here, with the modified monetary policy rule, the interest rate smoothing degree falls to just around 0.50.

Moreover, in Table 1 the monetary policy react equally to output gap level and output gap changes, but much lower than the reaction to inflation. In the original SW paper, although also low, the reaction to changes in output gap is slightly higher than to output gap level in short run. Now here with the modified monetary policy rule, the policy reaction to unemployment rate (r_{ur}) appears considerably strong with the estimated coefficient of around 1.12, almost sixfold of the policy reaction to changes in output gap in the original SW paper.

Table 3: Results from posterior maximization (parameters)

	Prior			Posterior	
	Dist.	Mean	Stdev	Mode	Stdev
φ	normal	4.000	1.5000	6.3282	NaN
σ_c	normal	1.500	0.3750	1.1709	NaN
λ	beta	0.700	0.1000	0.6322	NaN
ξ_w	beta	0.500	0.1000	0.8406	NaN
σ_l	normal	2.000	0.7500	2.8211	NaN
ξ_p	beta	0.500	0.1000	0.7087	NaN
ι_w	beta	0.500	0.1500	0.4543	NaN
ι_p	beta	0.500	0.1500	0.2455	NaN
ψ	beta	0.500	0.1500	0.3276	NaN
ϕ_p	normal	1.250	0.1250	1.6880	NaN
r_π	normal	1.500	0.2500	1.7867	NaN
ρ	beta	0.750	0.1000	0.5000	NaN
r_{ur}	normal	1.500	0.2500	1.1156	NaN
$\bar{\pi}$	gamma	0.625	0.1000	0.6249	NaN
$100(\beta^{-1}-1)$	gamma	0.250	0.1000	0.6477	NaN
$\bar{l}$	normal	0.000	2.0000	1.2756	NaN
$\bar{\gamma}$	normal	0.400	0.1000	0.4588	NaN
α	normal	0.300	0.0500	0.1984	NaN

In terms of the estimated parameters for exogenous shocks as presented in Table 4, it indicates the same results as before. The productivity (ρ_a), government spending (ρ_g), wage mark up (ρ_w), and price mark up (ρ_p) processes seem to be the most persistent shocks. Their estimated AR(1) coefficients are around 0.98, 0.95, 0.99, and 0.95, respectively.

Table 4: Results from posterior maximization (standard deviation of structural shocks)

	Prior			Posterior	
	Dist.	Mean	Stdev	Mode	Stdev
σ^a	invgamma	0.100	2.0000	0.5234	NaN
σ^b	invgamma	0.100	2.0000	0.2903	NaN
σ^g	invgamma	0.100	2.0000	0.8152	NaN
σ^i	invgamma	0.100	2.0000	0.6441	NaN
σ^m	invgamma	0.100	2.0000	0.2827	NaN
σ^p	invgamma	0.100	2.0000	0.2315	NaN
σ^w	invgamma	0.100	2.0000	0.2457	NaN
ρ_a	beta	0.500	0.2000	0.9835	NaN
ρ_b	beta	0.500	0.2000	0.3324	NaN
ρ_g	beta	0.500	0.2000	0.9471	NaN
ρ_i	beta	0.500	0.2000	0.5344	NaN
ρ_r	beta	0.500	0.2000	0.8691	NaN
ρ_p	beta	0.500	0.2000	0.9527	NaN
ρ_w	beta	0.500	0.2000	0.9896	NaN
μ_p	beta	0.500	0.2000	0.8898	NaN
μ_w	beta	0.500	0.2000	0.9629	NaN
ρ_{ga}	normal	0.500	0.2500	0.2184	NaN

4.2 Impulse Responses to Shocks

In this subsection, similar to Figure 1, the estimated mean impulse responses to three "demand shocks" under the modified monetary policy rule are presented in Figure 3, while

Figure 4 presents the mean impulse responses of respected variables to a wage mark up shock.

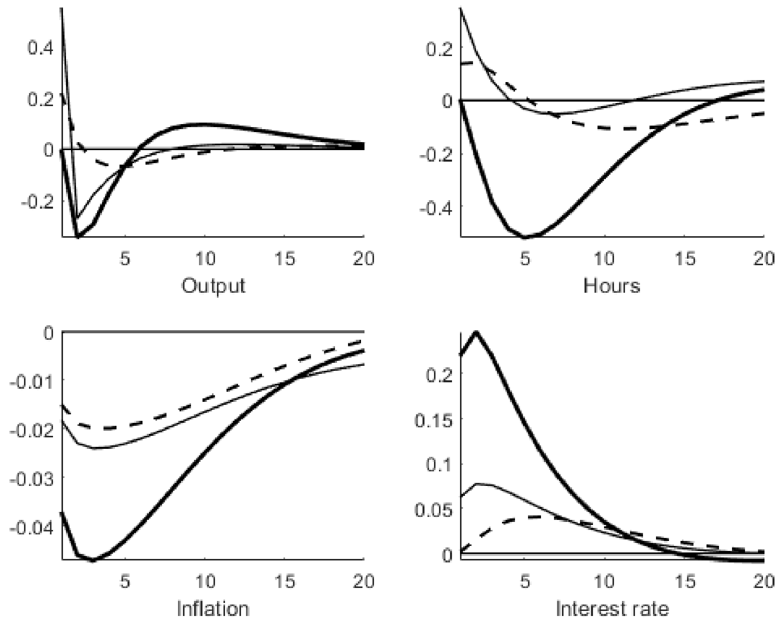

Figure 3: The estimated mean impulse responses to "demand" shocks.

Note: Bold solid line: risk premium shock; thin solid line: exogenous spending shock; dashed line: investment shock

In terms of the responses to the wage mark up shock, there is no difference between the two different monetary policy set up. As before, in short run, output and working hours respond negatively to the wage mark up shock, whereas inflation as well interest rate respond positively.

However, the responses to the three "demand" shocks indicate a slight different results. Output responses are positive, but lower than before under this new policy rule, even it yields immediate zero responses to risk premium shock. For hours worked, it stills responds positively to both exogenous and investment shocks, but surprisingly negative responses to risk premium shock. Interest rate shows positive responses to all demand shocks as expected. However, inflation responds negatively to the demand shocks. This result is undesirable. One possible way to fix this, maybe the monetary policy function should also include the growth of unemployment rate instead of its level solely.

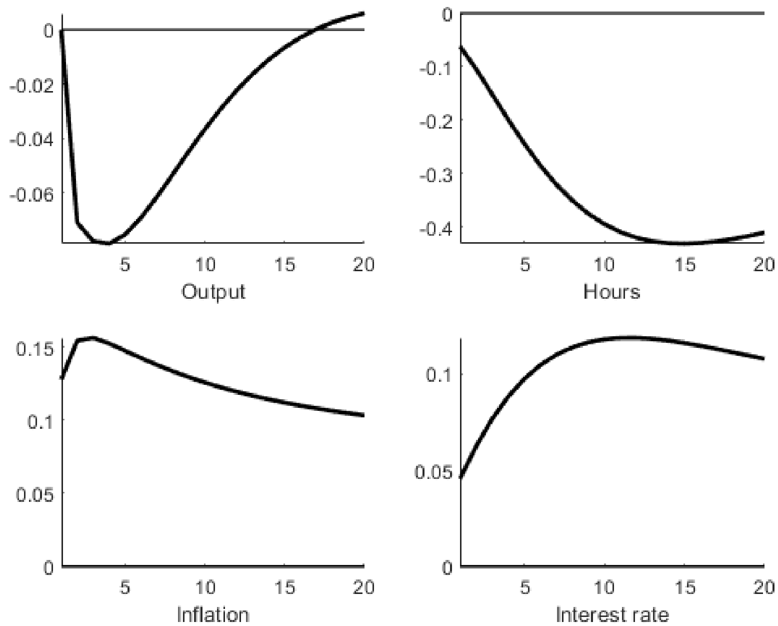

Figure 4: The estimated mean impulse responses to a wage mark-up shock

4.3 Variance Decomposition

In this subsection, forecast error variance decomposition of shocks is presented by comparing the contribution of shocks under two different regimes of monetary policy. The first regime is when monetary policy targets inflation and output gap. The second is when monetary policy targets inflation and unemployment rate.

For output, under the first monetary policy regime, the main determinants of output are exogenous spending shock (30.83 per cent), risk premium shock (29.65 per cent), and investment shock (14.23 per cent). Meanwhile, under the new monetary policy rule, they are monetary policy shock (52.18 per cent), productivity shock (18.54 per cent), and exogenous spending shock (14.55 per cent).

Next for inflation, under the first monetary policy regime, the main determinants of inflation are wage mark up shock (47.90 per cent) and price mark up shock (40.17 per cent). Meanwhile under the new monetary policy rule, they are wage mark up shock (56.91 per cent), price mark up shock (23.28 per cent), and monetary policy shock (17.47 per cent).

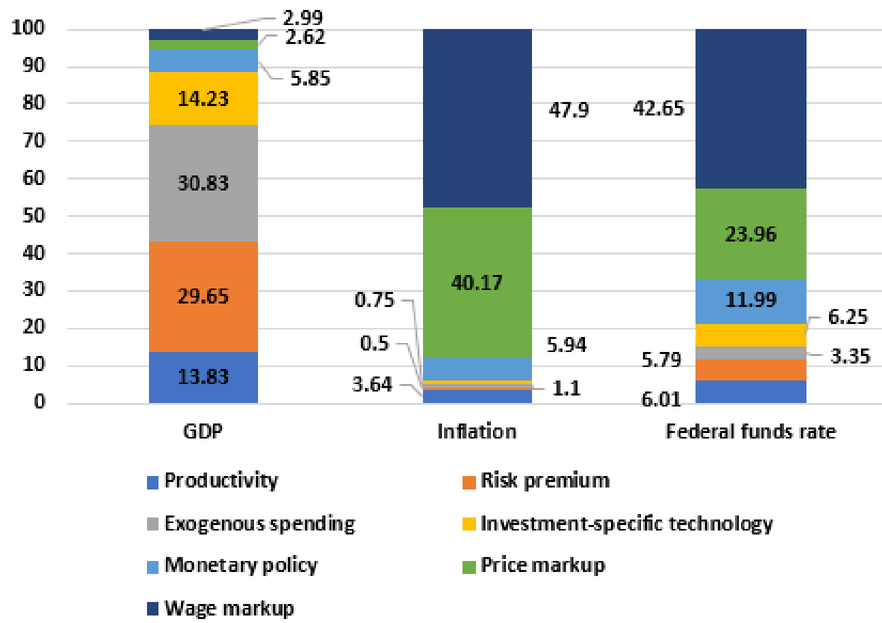

Figure 5: Variance decomposition (unconditional) using Taylor rule used in Smets and Wouters (2007)

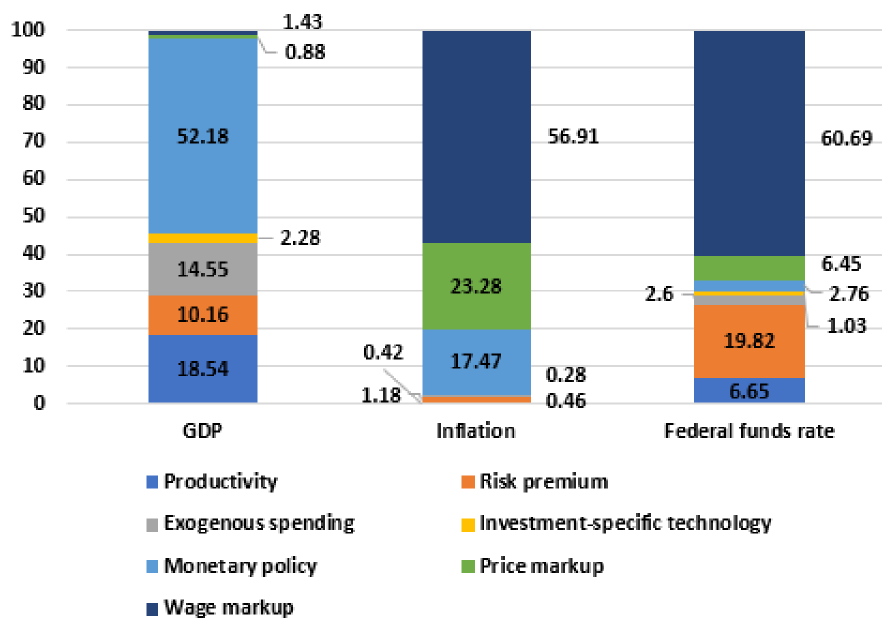

Figure 6: Variance decomposition (unconditional) using modified Taylor rule targeting inflation and unemployment rate

Finally for the Fed funds rate, under the first monetary policy rule, the main determinants are wage mark up shock (42.65 per cent), price mark up shock (23.96 per cent), and monetary policy shock (11.99 per cent). Meanwhile under the new monetary policy rule, they are wage mark up shock (60.69 per cent), risk premium shock (19.82 per cent), productivity shock (6.65 per cent), and price mark up shock (6.45 per cent).

5 Conclusion

The SW model seems able to fit the US macroeconomic data very well. When the output gap in the Monetary policy Taylor rule is replaced with unemployment rate, wage mark up shock becomes more persistent in determining inflation and interest rate. On the other hand, productivity shock shows a stronger force in driving output. However, some unexpected results also come up, e.g. the negative responses of hours worked to a risk premium shock and negative responses of inflation to the demand shocks.

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