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The Impact of Monetary Policy Shock on Macroeconomic Variables

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Abstract

Researchers have used macroeconomic models to assess the monetary transmission process. Employing a Dynamic Stochastic General Equilibrium model, the study shows that a monetary policy shock in the form of an unanticipated rise in the interest rate causes real output and inflation to fall. The results are consistent with those obtained from other two New Keynesian models used to check the robustness of the findings. As regards the degree of inflation and output persistence, the benchmark model shows low level of inflation persistence but no output persistence under all monetary rules. The other two models show some degree of output and inflation persistence for all the three monetary rules. Finally, it looks as if the choice of monetary policy rule determines the degree of output and inflation persistence.

Keywords: monetary policy shock; dynamic stochastic general equilibrium; New Keynesian models; inflation and output persistence.

1. Introduction

Over the years researchers have attempted to evaluate the monetary transmission process through the use of macroeconomic models. The number of monetary models has increased rapidly over time as researchers have intensified their efforts to improve on existing ones or build new ones. A monetary policy shock in the form of an unexpected change in the interest rate is likely to have an effect on an inflation forecast targeting regime. Having a good understanding of the monetary policy regime in place will enable the monetary authorities to adopt a stance of policy that will ensure that inflation is kept on target. The purpose of this paper is therefore to evaluate the impact of a monetary policy shock on macroeconomic variables such as inflation and Gross Domestic Product (GDP). A Dynamic Stochastic General Equilibrium (DSGE) model is used as the benchmark model to assess the impact.

The usual approach to a monetary policy strategy is to use a macroeconomic model to give recommendations concerning the optimal policy response to deviations in inflation and output from their desired levels. Dieppe, Küster, and McAdam (2005) examine the conduct of optimal monetary policy for the new euro area. They assume that adjustment in the aggregate euro economy is very slow and the economy has a private sector with backward-looking expectations. They find that interest rate adjustment should be relatively mild and that the central bank should consider new information quickly in policy formulation. They also find considerable benefit to be derived from implementing and communicating quite forward-looking policies. Finally, they find that optimal policy should be based on a broad information set, even if the resulting policy framework is difficult to communicate to the outside world. Coenen (2007) analyses the behaviour of optimised interest-rate rules when the degree of inflation persistence is uncertain. He concentrates on the euro area and employs two variants of an estimated small-scale macroeconomic model with different types of staggered contracts specifications which induce quite different degrees of inflation persistence. The paper demonstrates that a careful monetary policy-maker must design and implement interest-rate policies under the assumption that inflation persistence is high when there is much uncertainty about the extent of inflation persistence. Such policies are characterised by a relatively aggressive reaction to inflation developments and show a considerable degree of inertia.

Given the uncertainty about the structure of an economy, it is not sufficient to analyse the impact of monetary policy under a single macroeconomic model. It is essential to consider a variety of models. Of late, researchers have adopted a comparative approach in order to strengthen the robustness of policy recommendations. For instance, Wieland and Wolters (2011) conduct an investigation into the accuracy and heterogeneity of output growth and inflation forecasts during the current and the four preceding NBER-dated US recessions. They generate forecasts from six different models of the US economy and compare them to professional forecasts from the Federal Reserve's Greenbook and the Survey of Professional Forecasters (SPF). The model parameters and model forecasts are derived from historical data vintages in order to be comparable to historical forecasts by professionals. The mean model forecast comes surprisingly close to the mean SPF and Greenbook forecasts in terms of accuracy although the models only make use of a small number of data series. The degree of forecast heterogeneity is similar for model and professional forecasts but varies considerably over time. Hence, forecast heterogeneity is a potential important source of economic fluctuations. Even though the specific reasons for differences in professional forecasts are not observable, the diversity in model forecasts can be attributable to different modeling assumptions, information sets and parameter estimates.

To facilitate these model comparison and robustness objectives a new “monetary model database” has been developed which provides an interactive collection of models that can be simulated, optimized, and compared. The monetary model database can be used for model comparison projects and policy robustness exercises. Taylor and Wieland (2012) explore the comparative properties of empirically estimated monetary models of the U.S. economy by means of this new database of models designed for such investigations. They focus on three representative models by Christiano, Eichenbaum, and Evans (2005), Smets and Wouters (2007), and Taylor (1993a). While these models differ in terms of structure, estimation method, sample period, and data vintage, they find astonishingly similar economic effects of unexpected changes in the federal funds rate. However, optimized monetary policy rules differ across models and lack robustness. Model averaging provides an effective approach for improving the robustness of policy rules. Also, Wieland and Schmidt (2013) offer a suitable approach for comparing new models to available benchmarks and for investigating whether particular policy recommendations are robust to model uncertainty. Such robustness analysis is shown by evaluating the performance of simple monetary policy rules across a range of recently estimated models, including some with financial market imperfections, and by reviewing recent comparative findings regarding the magnitude of government spending multipliers.

To help establish the robustness of my results, I consider different types of models. First I derive and use a baseline small stylized model derived from microeconomic foundations with calibrated parameter values. I assume the economy consists of a representative household, two types of firms: monopolistic competitive, intermediate-good-producing firms and perfectly competitive, final-good-producing firms. There is also a monetary authority. The representative household maximizes an expected utility subject to a budget constraint. Final goods firms take the continuum of intermediate goods and bundle it up for final consumption. Intermediate firms minimize costs and choose prices to maximize profits. The monetary authority sets the interest rate according to a monetary policy rule.

Second, I consider a small New Keynesian model by Ireland (2004) where real money balances enter forward looking IS and Phillips curves specifications. This model was used to study the role of money in the U.S. business cycle. As in a typical New Keynesian model, the representative intermediate goods-producing firm has monopolistic power in the market and therefore sets prices. However, price setting is subject to Rotemberg quadratic adjustment costs.

Finally, a model of a small open economy developed by Gali and Monacelli (2005) is also considered. This model helps to take into account issues relating to the foreign sector of an economy. As in the case of a closed economy, firms face price stickiness a la Cavo.

The aim of this study is to adopt the comparative approach to assess the monetary transmission mechanism and hence contribute to the literature by establishing the robustness of the findings. To attain the objective of the study two specific questions are addressed: What is the effect of monetary policy shock on output and inflation? What is the degree of output and inflation persistence in an economy? The rest of the study is organized as follows. Section 2 presents the baseline DSGE model. Section 3 compares the consequences of monetary policy shocks on inflation and output across the different models. Then, the models' predictions regarding the persistence of output and inflation under different monetary rules are evaluated. Section 4 concludes the study with closing remarks.

2. The DSGE Model

The model assumes the economy consists of a representative household, a representative finished goods-producing firm, a continuum of intermediate goods-producing firms indexed by $i \in [0,1]$, and a monetary authority. Households consume the final goods. Firms own their capital stock and hire labour supplied by the households. Each of the intermediate goods firms is a monopolist and is able to set the price. The final goods firms package the intermediate goods and sell them in a competitive market to the households. The monetary authority sets the nominal interest rate.

Households

The representative household seeks to maximize the expected discounted lifetime utility

$$E_{t_0} \sum_{s=0}^{\infty} \left\{ \beta^s \left[b_{t_0+s} \left(\log(C_{t_0+s}) - \int_0^1 v(H_{t_0+s}(i)) di \right) \right] \right\} \quad (1)$$

subject to the budget constraint

$$\frac{B_t}{R_t} = B_{t-1} - P_t C_t + Y_t \quad (2)$$

The households work a certain amount of hours H_t and earn income of Y_t . They hold their financial wealth in the form of bonds B_t . Bonds are one-period securities whose gross rate of return between t and $t+1$ is R_t . Current income and financial wealth can be spent on consumption goods (C_t) at a price P_t or invested in one-period discount government bonds B_t . The household discounts utility in period $t+1$ by a time-varying factor $\beta b_{t+1}/b_t$ where b_{t+1}/b_t acts as a demand shock.

If λ_t represents the Lagrange multiplier, the households first order conditions with respect to B_{t+1} and C_t are

$$\lambda_t = \beta E_t[\lambda_{t+1}]R_t \tag{3}$$

$$\frac{\lambda_t}{b_t} P_t = \frac{1}{C_t} \tag{4}$$

Equations (3) and (4) can be combined to obtain the following Euler equation:

$$\frac{1}{C_t} = E_t \left[\frac{\beta b_{t+1}}{b_t} \frac{1}{C_{t+1}} \frac{R_t}{P_{t+1}/P_t} \right]. \tag{5}$$

The Euler equation (5) is log-linearised and manipulated to give

$$y_t = E_t y_{t+1} - (i_t - E_t \pi_{t+1}) - \delta_t, \tag{6}$$

where $\pi_t \equiv \log P_t / P_{t-1}$ is the quarterly inflation rate, $i_t \equiv \log R_t$ is the continuously compounded nominal interest rate, $\delta_t \equiv E_t \log(\beta b_{t+1}/b_t)$ is a transformation of the demand shock, and $y_t \equiv \log Y_t^r$ is the logarithm of total output. In this expression, we can substitute consumption of the final good C_t with its output Y_t^r because in our model consumption is the only source of demand for the final good. Therefore, market clearing implies $Y_t^r = C_t$.

Equation (6) is a forward-looking IS curve which shows a relationship between current output and future expected real interest rate.

If we let y_t and y_t^* be the stochastic components of output and the natural level of output, respectively, both in logs, the output gap x_t can be stated as:

$$x_t = y_t - y_t^*$$

Hence, it is possible to express the output gap as a function of future expected real interest rate as follows:

$$x_t = E_t x_{t+1} - (i_t - E_t \pi_{t+1}) + g_t, \tag{7}$$

where $g_t = E_t \Delta y_{t+1}^* - \delta_t$.
 g_t represents the demand shock.

Firms

The intermediate goods firms hire $H_t(i)$ units of labour of type i on a competitive market to produce $Y_t^f(i)$ units of intermediate good i with the technology

$$Y_t^f(i) = A_t H_t(i), \tag{8}$$

where A_t represents the productivity shock.

The market for intermediate goods is monopolistically competitive and firms set prices subject to the requirement that they satisfy the demand for their good. This demand comes from the final goods firms and takes the form

$$Y_t^r(i) = Y_t^f \left(\frac{P_t(i)}{P_t} \right)^{-\varepsilon_t}, \tag{9}$$

where $P_t(i)$ is the price of good i and ε_t is the elasticity of demand. When the relative price of a good increases, its demand falls relative to aggregate demand by an amount that depends on ε_t .

As in Calvo (1983) it is assumed that in every period only a fraction $1-\alpha$ of firms is free to reset its price while the remaining fraction maintains its old price. The aggregate price level can be stated as a function of newly set prices P^* and of past price index P_{t-1}

$$P_t = [(1-\alpha)P_t^*]^{(1-\varepsilon_t)} + \alpha P_{t-1}^{1-\varepsilon_t}]^{\frac{1}{1-\varepsilon_t}} \tag{10}$$

Firms update prices only upon receiving an exogenous idiosyncratic signal. In every period there is a constant probability of $(1-\alpha)\square(0,1)$ of receiving such a signal.

This probability is assumed to be independent of the time that has elapsed since the last update and of the current price level. Thus by the law of large numbers, a share of $(1-\alpha)$ of all firms receives the signal every period. Assume that firms at least break even ex ante and realizing that for any given demand the optimal factor input choice leads to marginal costs which are independent of the production level. Upon receiving the price update signal, the firm selects a price level, $P_t^*(i)$, so as to maximize the discounted stream of expected future profits. The objective function of the firm is

$$\text{Max}_{P_t(i)} E_t \sum_{s=0}^{\infty} (\alpha \beta)^s V_{t+s} \{ P_t(i) Y_{t+s}^r(i) - MC_{t+s}(i) Y_{t+s}^r(i) \} \tag{11}$$

subject to the production function (8) and the demand function at every point in time

$$Y_{t+s}^r(i) = Y_{t+s}^r \left(\frac{P_t(i)}{P_{t+s}} \right)^{-\epsilon_{t+s}} \tag{12}$$

MC_{t+s} is the firm's nominal marginal cost and $\beta^s V_{t+s}$ is the stochastic discount factor.

The first order condition of this optimisation problem is

$$E_t \left\{ \sum_{s=0}^{\infty} (\alpha \beta)^s V_{t+s} \left[\frac{P_t^*}{P_{t+s}} - \frac{\epsilon}{\epsilon - 1} MC_{t+s}^r \right] Y_{t+s}^r \right\} = 0, \tag{13}$$

where MC_{t+s}^r are real marginal costs and P_t^* is the optimal price.

The solution can be expressed as follows when it is log linearised

$$p_{it} = (1 - \beta\alpha) E_t \sum_{s=0}^{\infty} (\beta\alpha)^s mc_{it+s} \tag{14}$$

Small letters denote log deviation from the steady state. Equation (14) shows that when prices are rigid, rational firms will set prices as markup over a weighted sum of current and expected future marginal costs.

By quasi-differencing (14), the optimal price in period t can instead be expressed as a function of current marginal cost and expectations of future prices.

$$p_{it} = (1 - \beta\alpha) [mc_{it}] + \beta\alpha E_t p_{it+1} \tag{15}$$

Replacing p_{it} in equation (15) with p_t^f to signify that firms price setting is forward looking we get

$$p_t^f = (1 - \beta\alpha) [mc_t^r + p_t] + \beta\alpha E_t p_{t+1}^f \tag{16}$$

where mc^r is real marginal cost from its steady state value.

Assuming firms obey the rule of thumb and set prices based on recent pricing behavior of its competitors, adjusted for recent inflation we get the log-linearised form

$$p_t^b = p_{t-1}^* + \pi_{t-1} \quad (17)$$

where p_t^* is an index of prices reset in period t-1 and $\pi_{t-1} = p_{t-1} - p_{t-2}$.

From the definition of the general price level we get

$$p_t = (1 - \alpha) p_t^* + \alpha p_{t-1} \quad (18)$$

and

$$p_t^* = (1 - \omega) p_t^f + \omega p_t^b \quad (19)$$

where ω represents share of whole firms.

Combining equations (17) – (19) with (16) yields the hybrid Phillips curve with current inflation as a function of both lagged inflation and expected inflation as well as real marginal costs:

$$\pi_t = \xi mc_t^r + \lambda_f E_t \pi_{t+1} + \lambda_b \pi_{t-1} \quad (20)$$

where

$$\begin{aligned} \xi &= \frac{(1-\beta\alpha)(1-\alpha)(1-\omega)}{\phi} \\ \lambda_f &= \frac{\beta\alpha}{\phi} \\ \lambda_b &= \frac{\alpha}{\phi} \end{aligned} \quad (21)$$

and $\phi = \alpha + \omega [1 - \alpha(1 - \beta)]$

To relate inflation to the output gap, we follow Galí and Gertler (1999) and assume a proportionate relationship between real marginal cost and the output gap. Thus, the following relationship will hold:

$$mc_t^r = kx_t$$

where k is the output elasticity of real marginal cost. Equation (20) can be rewritten in terms of the output gap as follows

$$\pi_t = \lambda_a x_t + \lambda_f E_t \pi_{t+1} + \lambda_b \pi_{t-1} + u_t \quad (22)$$

where u_t is the inflation shock.

The Monetary Authority

The model assumes the monetary authority sets the interest rate according to the forward-looking monetary policy rule similar to that of Christiano et al. (2005):

$$i_t = \gamma_i i_{t-1} + \gamma_\pi \pi_{t+1} + \gamma_y \bar{y}_t + \eta_t^i \quad (23)$$

where i_t is the interest rate, π_t is the inflation rate and \bar{y}_t is the output gap. η_t^i is a monetary policy shock.

The monetary authority adjusts the interest rate in a gradual manner and so the parameter γ_i captures the degree of interest rate smoothing. The values of the parameter estimates chosen are consistent with the post-1979 era estimates reported by Clarida, Gali and Gertler (1999), hence the parameters are assigned the values $\gamma_i = 0.8$, $\gamma_\pi = 0.3$ and $\gamma_y = 0.02$.

3. The Impact of Monetary Policy Shocks Across Models

Equations (7) and (22) are used to obtain a solution for the model. The numerical values of the parameters used are the same as in Wieland, Cwik, Muller, Schmidt and Wolters (2012). The numerical values for parameters of the Phillips curve that are used in the simulations are the same as in Wieland et al (2012). The model is added to the model base where comparison with other models is easier because variables, shocks and parameters are defined in a comparable manner across models. Figure 1 presents information concerning the impact of a monetary policy shock, when there is a sudden increase in the short-term nominal interest rate. It displays the effect on output (left side of sections) and inflation (right side) with three different monetary policy rules: the Taylor (1993b) rule, the Smets and Wouters (2007) (SW) rule and the Christiano et al. (2005) (CEE) rule (see appendix).

Each section has three lines which show the results in three different models: (i) the baseline calibrated New Keynesian DSGE model described above (blue line: *NK_FSN18*); (ii) the New Keynesian DSGE model of Ireland (2004) (red line: *NK_IR04*); (iii) the New Keynesian DSGE model of Gali and Monacelli (2005) (green line: *NK_GM05*). After the unexpected shock the nominal interest rate continues to be set according to the specified monetary policy rule.

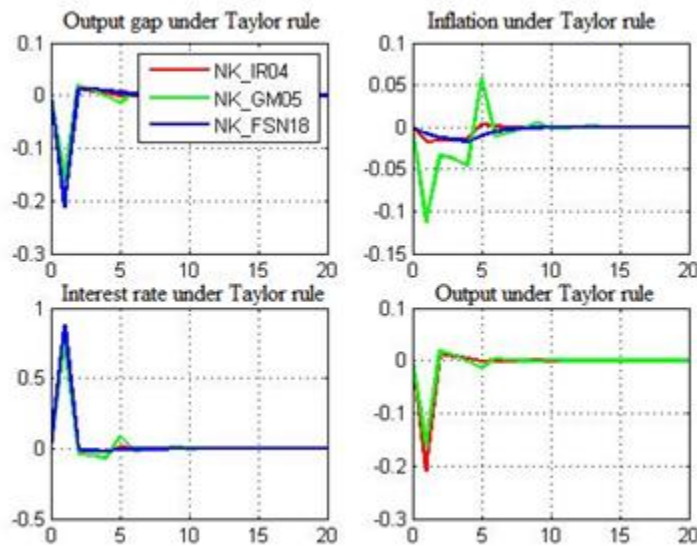
All the three models indicate that a rise in the central bank policy rate causes real GDP to decline. A higher real interest rate results when there is an increase in the nominal interest rate because of the assumption of sticky prices. There is a fall in current consumption and investment which leads to a fall in production. The magnitude and timing of the GDP impact of the monetary policy shock differs across models and policy rules.

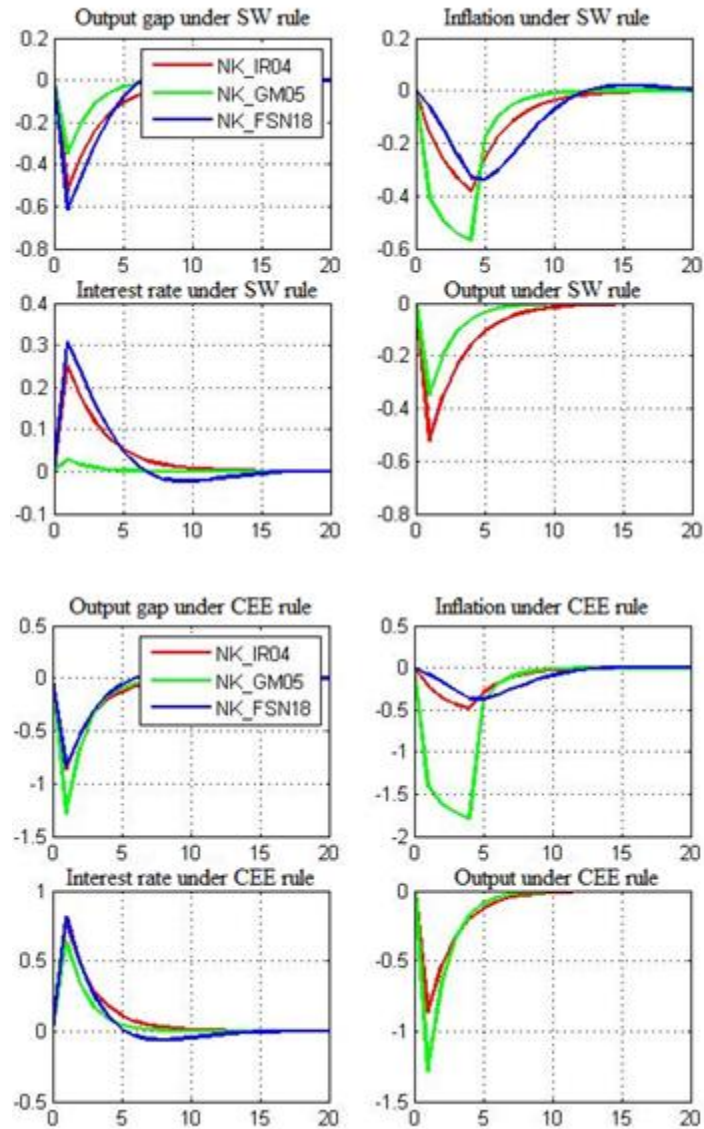
Under the Taylor rule, the effect on output is for a short period for all the models. If interest rates in subsequent periods are set according to the SW or CEE rule the decrease in output lasts much longer, between two and five years in the different models.

Contrary to the Taylor rule, these rules incorporate interest rate smoothing in the form of the lagged interest rate. Thus, the initial interest rate increase is followed by a period during which the interest rate slowly returns to its long-run equilibrium value.

There is no much difference in the GDP effect of the monetary policy shock across models under the Taylor rule. However, under the SW rule the effect appears to be greater in the NK_IR04 model while under the CEE rule the impact is greater in the NK_GM05 model.

Figure 1: IMPULSE RESPONSE FUNCTIONS TO MONETARY POLICY SHOCK





As shown by the inflation panels, an unexpected interest rate increase leads to a fall in inflation. In the NK_IR04 and NK_FSN18 models, under the Taylor rule, the decline in is very slight followed by a gradual increase back to the equilibrium level.

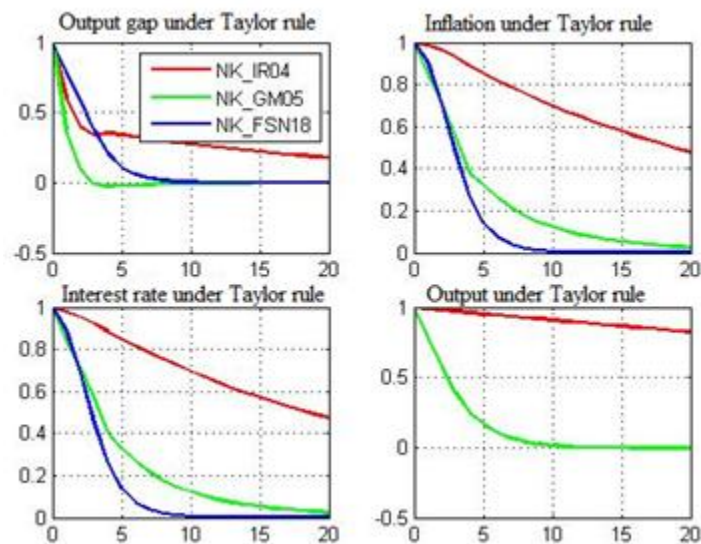
However, in the case of the NK_GM05 model, there is a sharp fall in inflation followed by a gradual rise above the equilibrium level before eventually declining back to equilibrium. Under both the SW and CEE rules, the greatest fall in inflation again is in the NK_GM05 model. In all the models inflation rises gradually to equilibrium after the initial decline.

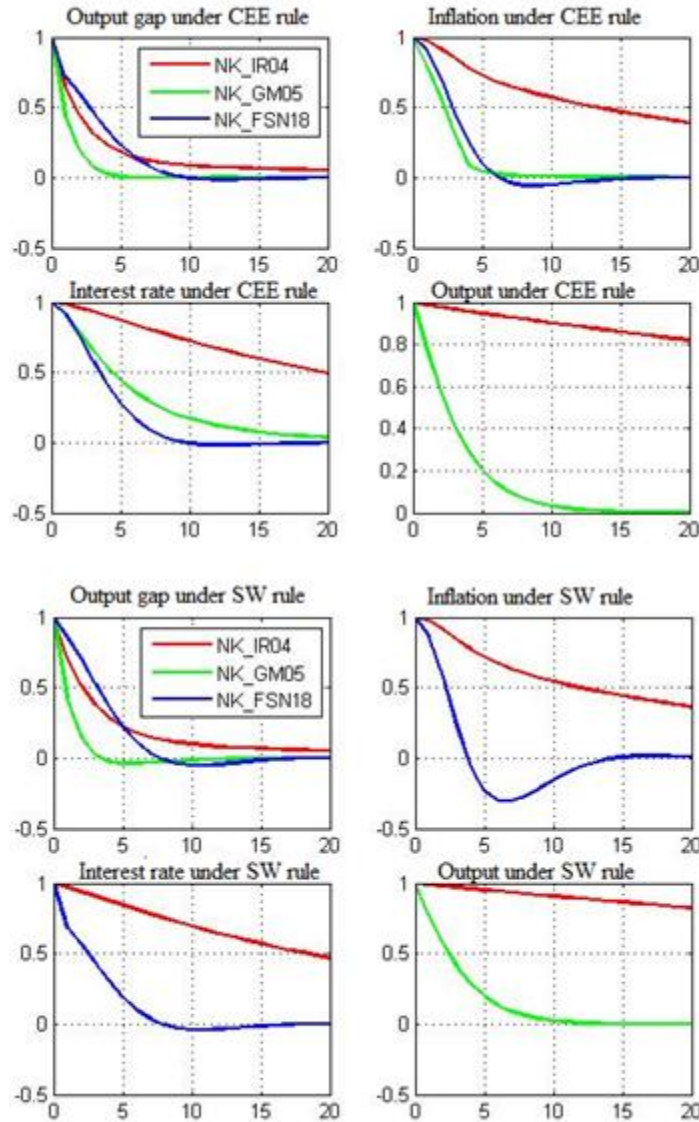
Figure 2 shows the autocorrelation functions that are obtained under structural shocks—excluding the monetary policy shock—in the different models. They measure the degree of persistence in output and inflation across models and monetary rules. The NK_IR04 model shows the highest degree of output and inflation persistence for any of the three monetary rules.

The NK_FSN18 model exhibits low level of inflation persistence but no output persistence under all monetary rules. This is because this model does not include lagged terms of inflation and output in the New-Keynesian IS and Phillips curves. Only the exogenous shocks incorporate persistence.

The NK_GM05 model exhibits low output and inflation persistence. The output persistence in this model is less under the CEE rule than under the other two rules. This is an indication that the choice of monetary policy rule determines the degree of output and inflation persistence.

Figure 2: AUTOCORRELATION FUNCTIONS





4. Conclusion

This study evaluates the impact of monetary policy shock on an economy. The key questions focused on are what effect a monetary policy shock will have and how persistent inflation and output are. To enhance the robustness of the results a comparative approach is adopted. A DSGE model was developed to serve as a benchmark for comparison with models used by Ireland (2004) and Galí and Monacelli (2005).

From the simulation of the benchmark model the results indicate that a monetary policy shock in the form of an unexpected rise in the interest rate causes real output and inflation to fall. The effect of the monetary policy shock on output was short-lived under the Taylor rule but the effect persisted much longer under the SW and CEE rules. This is due to the capturing of interest rate smoothing by the later rules which means the adjustment of the interest rate was gradual. These results are consistent with those of the other two models. As far as inflation is concerned the benchmark model indicates a gradual rise to equilibrium after the initial decline. This result is analogous to the results obtained from the other models and thus signifying the robustness of the findings.

With respect to the degree of inflation and output persistence the benchmark model shows low level of inflation persistence but no output persistence under all monetary rules. The NK_IR04 model shows the highest degree of output and inflation persistence for any of the three monetary rules. However, the NK_GM05 model exhibits low output and inflation persistence. It appears that the choice of monetary policy rule determines the degree of output and inflation persistence as the output persistence in the NK_GM05 model is less under the CEE rule than under the other two rules. The policy implication is that central banks pursuing inflation targeting monetary policy should take into account the likely effects of monetary policy shocks and also adopt interest rate smoothing policy to avoid sharp swings in macroeconomic variables. A major limitation of this research is that no model has been able to adequately capture realism. Hence, it is recommended that continued investigation should be carried out into the issues as new models are developed.

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Appendix

Monetary Policy Rules in terms of Common Model base Variables

Taylor (1993)	$i_t^z = \sum_{j=0}^3 0.375 p_{t-j}^z + 0.50 q_t^z + \eta_t^i$
Smets and Wouters (2007)	$i_t^z = 0.81 i_{t-1}^z + 0.39 p_t^z + 0.97 q_t^z - 0.90 q_{t-1}^z + \eta_t^i$
Christiano et al. (2005)	$i_t^z = 0.8 i_{t-1}^z + 0.3 E_t p_{t+1}^z + 0.08 q_t^z + \eta_t^i$

In all rules, i_t^z denotes the annualized quarterly money market rate, p_t^z refers to the annualized quarter-to-quarter rate of inflation, q_t^z is the quarterly output gap which is defined as the deviation of actual output from the level of output that would be realized if prices were flexible. η_t^i denotes the common monetary policy shock.