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Abstract

This paper reproduces a version of the New Keynesian model developed by Ireland (2004) and then uses the Vietnamese data from January 1995 to December 2012 to estimate the model's parameters. The empirical results show that before August 2000 when the Taylor rule was adopted more firmly, the monetary policy shock made considerable contributions to the fluctuations in key macroeconomic variables such as the short-term nominal interest rate, the output gap, inflation, and especially output growth. By contrast, the loose adoption of the Taylor rule in the period of post-August 2000 leads to a fact that the contributions of the monetary policy shock to the variations in such key macroeconomic variables become less substantial. Thus, one policy implication is that adopting firmly the Taylor rule could strengthen the role of the monetary policy in driving movements in the key macroeconomic variables, for instance, enhancing economic growth and stabilizing inflation.

Key words: New Keynesian model, Monetary Policy, Technology Shock, Cost-Push Shock, Preference Shock.

JEL classification: E12, E32.

1. Introduction

Explaining dynamic behaviors of key macroeconomic variables has drawn a lot of interest from researchers. The literature on macroeconomics reveals that there have been a considerable number of seminal works doing so. Kydland and Prescott (1982) and Prescott (1986) are two seminal works that developed a real business cycle model to explain aggregate fluctuations. The real business cycle model implicitly assumes that markets are perfectly competitive and frictionless. Thus, cyclical fluctuations around the equilibrium are optimal responses to exogenous shocks, and fiscal and monetary stabilization is neither necessary nor desirable. Furthermore, technology shocks, variations in total factor productivity, explain business cycle fluctuations, and there is no reference to monetary policy because it is neutral.

However, empirical evidence shows that there is an effect of monetary policy at least in the short run (Christiano, L.J., Eichenbaum, M. and Evans, C.L, 1999; Bernanke, B. S. and Mihov, I., 1998; and Uhlig, H., 2005). The New Keynesian model was then developed working under certain assumptions. Specifically, in the New Keynesian model, monopolistically competitive markets exist; therefore, prices are set by private agents having some monopoly power. Another widespread assumption of the New Keynesian model is nominal rigidities, meaning that prices and wages are adjusted slowly. Most importantly, monetary policy is non-neutral in the short run, meaning that changes in interest rates are not immediately followed by changes in inflation expectations due to the nominal rigidities. This allows central banks to adjust the real interest rate and affect consumption and investment decisions. Taylor (1999), Bils and Klenow (2004), and Nakamura and Steinsson (2008) are typical studies using micro data, which suggest that the average frequency of price and wage adjustments is from four months to one year.

According to Ireland (2004), the simplest form of the New Keynesian model consists of just three equations. The first equation refers to the so-called expectational IS curve. This first equation refers to the log-linearization of an optimizing household’s Euler equation, linking consumption and output growth to the inflation-adjusted return on nominal bonds, that is, to the real interest rate. The second equation refers to a forward-looking version of the Phillips curve, describing the optimizing behavior of monopolistically competitive firms that either set prices in a randomly staggered fashion, as suggested by Calvo (1983), or face explicit costs of nominal price adjustment, as suggested by Rotemberg (1982). The third equation corresponds to a monetary policy rule proposed by Taylor (1993). This final equation indicates that the central bank should adjust the short-term nominal interest rate in response to changes in output growth, output gap and, especially, inflation. With these three equations, the New Keynesian model characterizes the dynamic behavior of three key macroeconomic variables: output growth, inflation, and the nominal interest rate. Ireland (2004) developed a version of the New Keynesian model in which three additional shocks to households’ preference, firms’ desired markups, and the central bank’s monetary policy rule compete with the real business cycle model’s technology shock in explaining fluctuations in output growth, inflation, and the short-term nominal interest rate. The author then used the postwar United States data to estimate the model’s parameters and found that the monetary policy shock has played an important role in driving movements in output growth, inflation, and the short-term nominal interest rate, whereas the technology shock has only performed a supporting role.

This paper aims at addressing the question: *What is role of the State Bank of Vietnam’s monetary policy in driving fluctuations in output growth, inflation, and the short-term nominal interest rate*? In order to address this question, this paper reproduces the New Keynesian model developed by Ireland (2004) in the subsequent section. Section 3 of the paper then uses the Vietnamese data from January 1995 to December 2012 to estimate the model’s parameters. In this section, impulse responses and variance decomposition analysis is conducted to assess the role of the State Bank’s monetary policy. Section 4 conducts the robustness check by re-estimating the model with two subsamples: the first running from January 1995 to July 2000, and the second running from

August 2000 through December 2012. The last section concludes by summarizing key results and highlighting their implications.

2. The model

In this section, we rebuild the model developed by Ireland (2004) with detailed mathematical derivation presented in Appendix. The model consists of a representative household, a continuum of intermediate-goods firms indexed by $i\in[0,1]$, a final-goods firm, and a central bank. During each period $t=0,1,2, ...$, each intermediate-goods firm produces a differentiated intermediate good. Hence, intermediate goods may also be indexed by $i\in[0,1]$, where firm i produces good i. Intermediate-goods firms are able to set prices but they face a friction in doing so. In order to focus on the analysis in the activities of the representative intermediate-goods firm, the model is assumed to feature enough symmetry.

The representative household

We first formulate the budget constraint faced by the representative household. In each period $t=0,1,2, \ldots$, the representative household possesses m_{t-1} units of money and b_{t-1} units of bonds, which is issued in period t-1 and have the maturity in period t. In addition, the household receives a lump-sum monetary transfer τ_t from the central bank at the beginning of the period. During period t, the household supplies n_t units of labor to the various intermediate-goods firms, earning $w_t n_t$ in total labor income, where w_t denotes the nominal wage. At the end of period t, the household receives nominal profits d_t from the intermediate goods-producing firms.

During period t, the household consumes c_t units of final goods, which are sold at prices p_t by the representative finished goods-producing firm. Also, the household uses some money to purchase new bonds of value b_t/r_t, where r_t denotes the gross nominal interest rate between t and t+1. Finally, the household brings m_t units of money to period t+1. Thus, the budget constraint faced by the representative household is given by

$$p_t c_t + \frac{b_t}{r_t} + m_t = m_{t-1} + b_{t-1} + \tau_t + w_t n_t + d_t$$

for all $t\in[0, +\infty)$.

The expected utility function of the representative household is given by

$$U = E\sum_{t=0}^{\infty} \beta^t \left\{a_t \ln c_t + \ln\frac{m_t}{p_t} - \frac{{n_t}^{\xi}}{\xi}\right\}$$

where $\beta \in (0,1)$ and $\xi \geq 1$. In this utility function, the preference shock a_t follows the autoregressive process

$$\ln(a_t) = (1-\rho_a)\ln(\bar{a}) + \rho_a \ln(a_{t-1}) + \varepsilon_{at}$$

where $\bar{a} \geq 1;\ 1 > \rho_a \geq 0$; ε_{at} is the zero-mean, serially uncorrelated innovation, and is normally distributed with standard deviation σ_a.

In each period $t=0,1,2, \ldots$, the household chooses b_t, c_t, m_t and n_t to maximize the expected utility. Thus, the maximization problem of the representative household is given by

$$\max_{b_t,c_t,m_t,n_t} E\sum_{t=0}^{\infty}\beta^t\left\{a_t\ln c_t+\ln\frac{m_t}{p_t}-\frac{n_t{}^{\xi}}{\xi}\right\}$$

subject to

$$p_tc_t+\frac{b_t}{r_t}+m_t=m_{t-1}+b_{t-1}+\tau_t+w_tn_t+d_t$$

The first-order conditions for the household's maximization problem include

$$n_t^{\xi-1}=\left(\frac{a_t}{c_t}\right)\left(\frac{w_t}{p_t}\right) \tag{1}$$

$$\beta E_t\left\{\left(\frac{a_{t+1}}{c_{t+1}}\right)\left(\frac{1}{p_{t+1}}\right)\right\}=\left(\frac{a_t}{c_t}\right)\left(\frac{1}{r_tp_t}\right) \tag{2}$$

$$\frac{1}{m_t}+E_t\left\{\left(\frac{a_{t+1}}{c_{t+1}}\right)\left(\frac{1}{p_{t+1}}\right)\right\}=\left(\frac{a_t}{c_t}\right)\left(\frac{1}{p_t}\right) \tag{3}$$

$$p_tc_t+\frac{b_t}{r_t}+m_t=m_{t-1}+b_{t-1}+\tau_t+w_tn_t+d_t \tag{4}$$

for all t=0,1,2, …

The intratemporal optimality condition (1) presents the relation between the marginal rate of substitution of leisure for consumption and the real wage while the intertemporal optimality condition (2) links inflation-adjusted nominal interest rate–that is, the real interest rate–to the intertemporal marginal rate of substitution. Equation (3) is the optimality condition for money holdings, and equation (4) presents the budget constraint.

The representative final goods-producing firm

The representative finished goods-producing firm is assumed to operate in a competitive environment. During each period t=0,1,2, …, the firm uses y_{it} units of each intermediate good $i\in[0,1]$ purchased at the nominal price p_{it} to produce y_t units of the final good according to the constant-return-to-scale technology given by

$$y_t=\left\{\int_0^1 y_{it}^{\frac{\theta_t-1}{\theta_t}}\,di\right\}^{\frac{\theta_t}{\theta_t-1}}$$

where θ_t as shown below reflects the time-varying elasticity of demand for each intermediate good. Remember that the markup of price above the marginal cost depends negatively on the price elasticity of demand. As shown in Clarida, Gali, and Gertler (1999), randomness in the markup provides the notion of cost-push shock in the New Keynesian model. Thus, it is especially notable that an increase in θ_t really refers to a decrease in the markup of price above the marginal cost, that is, a negative cost-push shock. This "cost-push" shock follows the autoregressive process

$$\ln(\theta_t)=(1-\rho_\theta)\ln(\bar{\theta})+\rho_\theta\ln(\theta_{t-1})+\varepsilon_{\theta t},\ \ \bar{\theta}\geq 1 \text{ and } \rho_\theta\in[0,1)$$

where $\varepsilon_{\theta t}$ is the zero-mean, serially uncorrelated innovation, which is normally distributed with standard deviation σ_θ.

The profit maximization problem of the representative finished goods-producing firm is given by

$$\max_{y_{it}} \ \pi_t^F = p_t y_t - \int_0^1 p_{it} y_{it} di$$

subject to

$$y_t = \left\{ \int_0^1 y_{it}^{\frac{\theta_t - 1}{\theta_t}} di \right\}^{\frac{\theta_t}{\theta_t - 1}}$$

The first-order conditions for the final-goods firm's problem is then given by

$$y_{it} = y_t \left(\frac{p_{it}}{p_t} \right)^{-\theta_t} \tag{5}$$

for all $i \in [0,1]$ and $t=0,1,2, \ldots$

Equation (5) confirms that θ_t is the time-varying elasticity of demand for each intermediate good. Because the representative finished goods-producing firm operates in a competitive environment, competition causes its profit to be zero in equilibrium. Therefore, we obtain an equation, in which p_t is determined:

$$p_t = \left(\int_0^1 p_{it}{}^{1-\theta_t} di \right)^{\frac{1}{1-\theta_t}} \qquad \text{for all } t = 0,1,2, \ldots$$

The representative intermediate goods-producing firm

In order to produce y_{it} units of intermediate good i, the representative intermediate goods-producing firm employs n_{it} units of labor. Thus, the constant-return-to-scale technology the firm uses could be described by

$$y_{it} = z_t n_{it} \tag{6}$$

z_t in this relation refers to the aggregate technology shock, which follows a random walk with positive drift:

$$\ln(z_t) = \ln(\bar{z}) + \ln(z_{t-1}) + \varepsilon_{zt}, \ \ \bar{z} \geq 1$$

where ε_{zt} is the zero-mean, serially uncorrelated innovation, which is normally distributed with standard deviation σ_z.

Because intermediate goods are differentiated, they cannot be substituted perfectly for one another to manufacture the final good. Therefore, the intermediate goods-producing firm is able to set the price p_{it} for its output on the condition that it fulfills the demand of the finished goods-producing firm at its predetermined price. This means that the representative intermediate goods-producing firm sells its output in a monopolistically competitive market. Since the firm is owned by the representative household, its objectives are aligned with the household's. The firm chooses the selling price p_{it} to pursue the objectives, subject to a quadratic adjustment cost. Thus, the maximization problem of the intermediate goods-producing firm is described by

$$\max_{p_{it}} \pi_t^I = E\sum_{t=0}^{\infty} \beta^t \left(\frac{a_t}{c_t}\right)\left(\frac{d_t}{p_t}\right)$$

subject to

$$y_{it} = z_t n_{it}$$

$$y_{it} = y_t \left(\frac{p_{it}}{p_t}\right)^{-\theta_t}$$

$$\chi(p_{it}, p_{it-1}) = \frac{\phi}{2}\left[\frac{p_{it}}{\bar{\pi} p_{it-1}} - 1\right]^2 y_t$$

where $\bar{\pi} \geq 1$ is the gross steady-state rate of inflation and ϕ measures the magnitude of the price adjustment cost; the real value of dividends is given by

$$\frac{d_t}{p_t} = \left\{\frac{p_{it}y_{it} - w_t n_{it}}{p_t} - \chi(p_{it}, p_{it-1})\right\} \tag{7}$$

The associated first-order condition is written as

$$\begin{aligned}
(\theta_t - 1)\frac{y_t}{p_t}\left(\frac{p_{it}}{p_t}\right)^{-\theta_t} \\
&= \theta_t \left(\frac{p_{it}}{p_t}\right)^{-\theta_t - 1} \frac{w_t}{p_t}\frac{y_t}{z_t}\frac{1}{p_t} - \phi\left[\frac{p_{it}}{\bar{\pi} p_{it-1}} - 1\right]\frac{y_t}{\bar{\pi} p_{it-1}} \\
&+ \beta\phi E_t\left\{\frac{a_{t+1}}{a_t}\frac{c_t}{c_{t+1}}\left[\frac{p_{it+1}}{\bar{\pi} p_{it}} - 1\right]\left[\frac{y_{t+1}p_{it+1}}{\bar{\pi} {p_{it}}^2}\right]\right\} \qquad (8)
\end{aligned}$$

for all t=0,1,2, …

The left-hand side of (8) reflects the marginal revenue to the intermediate goods-producing firm generated by an increase in price; the right-hand side reflects the associated marginal costs. Under perfect price flexibility ($\phi = 0$), the price-setting rule collapses to

$$p_{it} = \frac{\theta_t}{\theta_t - 1}\frac{w_t}{z_t},$$

which measures the standard markup of price above the marginal cost w_t/z_t. Under sticky price ($\phi \neq 0$), the marginal cost of an increase in price has two additional components: the direct cost of a price adjustment, and an expected discounted cost of a price change adjusted by the marginal utility to the household of making such a change.

The central bank

The central conducts monetary policy by adopting the Taylor rule. With all variables expressed in terms of logged deviations from steady state values, the rule is given by

$$\tilde{r}_t - \tilde{r}_{t-1} = \rho_\pi \tilde{\pi}_t + \rho_g \tilde{g}_t + \rho_o \tilde{o}_t + \varepsilon_{rt} \qquad (9)$$

where ε_{rt} is the zero-mean, serially uncorrelated innovation, which is normally distributed with standard deviation σ_r. In equation (9), $\tilde{r}_t$, $\tilde{\pi}_t$, $\tilde{g}_t$ and $\tilde{o}_t$ refer to the short-term nominal interest rate, inflation rate, output growth and the output gap (defined below), respectively. According to this rule, the central bank raises or lowers the short-term nominal interest rate $\tilde{r}_t$ in response to fluctuations of inflation $\tilde{\pi}_t$, output growth $\tilde{g}_t$, and output gap $\tilde{o}_t$.

The output gap is defined as the ratio of actual output y_t to capacity output $\hat{y}_t$. Capacity output is defined to be the efficient level of output, which is equivalent to the level of output chosen by a social planner who can overcome the frictions that cause real money balances to appear in the representative household's utility function and that raise the cost of nominal price adjustment faced by the representative intermediate goods-producing firm. The social planner chooses $\hat{y}_t$ and n_{it} to maximize the household's welfare, as measured by

$$E \sum_{t=0}^{\infty} \beta^t \left\{ a_t \ln \hat{y}_t - \frac{1}{\xi} \left(\int_0^1 n_{it} di \right)^{\xi} \right\}$$

subject to the feasibility constraint

$$\hat{y}_t = z_t \left(\int_0^1 n_{it}^{\frac{\theta_t - 1}{\theta_t}} di \right)^{\frac{\theta_t}{\theta_t - 1}}$$

for all t=0,1,2, …

The first-order condition to this problem defines the efficient level of output as

$$\hat{y}_t = z_t a_t^{\frac{1}{\xi}} \qquad (10)$$

for all t=0,1,2, … This definition shows that shocks to preference a_t and technology z_t have positive impacts on the efficient level of output, and that the cost-push shock θ_t has no effect on the efficient level of output. The output gap can therefore be calculated as

$$o_t \equiv \frac{y_t}{\hat{y}_t} = \frac{1}{a_t^{\frac{1}{\xi}}} \times \frac{y_t}{z_t}$$

for all t=0,1,2, …

The nonlinear system

A symmetric equilibrium requires that all intermediate goods-producing firms make identical decisions, so that $y_{it}=y_t$, $n_{it}=n_t$, $p_{it}=p_t$, and $d_{it}=d_t$ for all $i\in[0,1]$ and t=0,1,2, … The second requirement is that the money and bond markets clear, meaning that $m_t=m_{t-1}+\tau_t$ and $b_t=b_{t-1}=0$ must hold for all t=0,1,2, … In its current form, the model consists of 12 equations: the household's first-order conditions and the budget constraint, the aggregate production function, the real profits paid to the household, the intermediate goods-producing firm's first-order condition, the stochastic specifications for the structural shocks, and the expression for capacity. The system could be reduced using the following normalized variables:

$\ddot{y}_t = \frac{y_t}{z_t}$, $\ddot{c}_t = \frac{c_t}{z_t}$, $\ddot{\hat{y}}_t = \frac{\hat{y}_t}{z_t}$, $\pi_t = \frac{p_t}{p_{t-1}}$, $\ddot{d}_t = \frac{d_t/p_t}{z_t}$,

$\ddot{w}_t = \frac{w_t/p_t}{z_t}$, $\ddot{m}_t = \frac{m_t/p_t}{z_t}$, and $\ddot{z}_t = \frac{z_t}{z_{t-1}}$

With these equilibrium conditions imposed and the expression for the real profits given by (7), the budget constraint in equilibrium is written as

$$\ddot{y}_t = \ddot{c}_t + \frac{\phi}{2}\left[\frac{\pi_t}{\bar{\pi}} - 1\right]^2 \ddot{y}_t$$

The household's first-order condition (2) is rewritten using the normalized terms as

$$\beta r_t E_t\left\{\left(\frac{a_{t+1}}{\ddot{c}_{t+1}}\right)\left(\frac{1}{\ddot{z}_{t+1}}\right)\left(\frac{1}{\pi_{t+1}}\right)\right\} = \left(\frac{a_t}{\ddot{c}_t}\right)$$

Next, using the equilibrium conditions, (1), (3) (6), (7), and (10) can be used to eliminate real wage w_t/p_t, work hours n_t, money m_t, real profits d_t/p_t, and capacity output $\hat{y}_t$ from the system. Having done this, the output gap can be rewritten as

$$o_t = \frac{1}{a_t^{\frac{1}{\xi}}} \times \frac{y_t}{z_t} = \frac{\ddot{y}_t}{a_t^{\frac{1}{\xi}}}$$

Finally, having normalized all of the equations, the model consists of the following nonlinear system

$$\ddot{y}_t = \ddot{c}_t + \frac{\phi}{2}\left[\frac{\pi_t}{\bar{\pi}} - 1\right]^2 \ddot{y}_t \tag{11}$$

$$\beta r_t E_t\left\{\left(\frac{a_{t+1}}{\ddot{c}_{t+1}}\right)\left(\frac{1}{\ddot{z}_{t+1}}\right)\left(\frac{1}{\pi_{t+1}}\right)\right\} = \left(\frac{a_t}{\ddot{c}_t}\right) \tag{12}$$

$$\begin{aligned} 0 = 1 - \theta_t + \theta_t \ddot{y}_t^{\xi-1}\frac{\ddot{c}_t}{a_t} - \phi\left[\frac{\pi_t}{\bar{\pi}} - 1\right]\frac{\pi_t}{\bar{\pi}} \\ + \beta\phi E_t\left\{\frac{a_{t+1}}{a_t}\frac{\ddot{c}_t}{\ddot{c}_{t+1}}\left[\frac{\pi_{t+1}}{\bar{\pi}} - 1\right]\left[\frac{\ddot{y}_{t+1}\pi_{t+1}}{\bar{\pi}\ddot{y}_t}\right]\right\} \end{aligned} \tag{13}$$

$$g_t = \frac{\ddot{y}_t \ddot{z}_t}{\ddot{y}_{t-1}} \tag{14}$$

$$o_t = \frac{\ddot{y}_t}{a_t^{\frac{1}{\xi}}} \tag{15}$$

$$\ln(a_t) = (1 - \rho_a)\ln(\bar{a}) + \rho_a \ln(a_{t-1}) + \varepsilon_{at} \tag{16}$$

$$\ln(\theta_t) = (1 - \rho_\theta)\ln(\bar{\theta}) + \rho_a \ln(\theta_{t-1}) + \varepsilon_{\theta t} \tag{17}$$

$$\ln(\ddot{z}_t) = \ln(\bar{z}) + \varepsilon_{zt} \tag{18}$$

Log-linearization

In order to log-linearize the model, the first step is to calculate steady state values of endogenous variables which are output, consumption, inflation, interest rate and output gap. In steady state, stationary variables are constant over time. Therefore, $\ddot{y}_t = \bar{y}$, $\ddot{c}_t = \bar{c}$, $r_t = \bar{r}$, $\pi_t = \bar{\pi}$, $o_t = \bar{o}$, $g_t = \bar{g}$, $a_t = \bar{a}$, $\theta_t = \bar{\theta}$, and $\ddot{z}_t = \bar{z}$. Steady state values of endogenous variables are given by

$$\bar{y} = \bar{c} = \left(\bar{a}\frac{\bar{\theta} - 1}{\bar{\theta}}\right)^{\frac{1}{\xi}}$$

$$\bar{r} = \bar{\pi}\frac{\bar{z}}{\beta}$$

$$\bar{o} = \left(\frac{\bar{\theta} - 1}{\bar{\theta}}\right)^{\frac{1}{\xi}}$$

Next, equations (11)-(18) will be log-linearized around the steady state values. Let $\tilde{y}_t = \ln(\ddot{y}_t/\bar{y})$, $\tilde{c}_t = \ln(\ddot{c}_t/\bar{c})$, $\tilde{o}_t = \ln(o_t/\bar{o})$, $\tilde{g}_t = \ln(g_t/\bar{g})$, $\tilde{\pi}_t = \ln(\pi_t/\bar{\pi})$, $\tilde{r}_t = \ln(r_t/\bar{r})$, $\tilde{a}_t = \ln(a_t/\bar{a})$, $\tilde{\theta}_t = \ln(\theta_t/\bar{\theta})$, and $\tilde{z}_t = \ln(\ddot{z}_t/\bar{z})$ denote the percentage deviation of each variable from its steady-state level; the log-linearized version of the model is given by

$$\tilde{o}_t = E_t\tilde{o}_{t+1} - (\tilde{r}_t - E_t\tilde{\pi}_{t+1}) + (1 - \omega)(1 - \rho_a)\tilde{a}_t \tag{19}$$

$$\tilde{\pi}_t = \beta E_t\tilde{\pi}_{t+1} + \psi\tilde{o}_t - \tilde{e}_t \tag{20}$$

$$\tilde{g}_t = \tilde{y}_t - \tilde{y}_{t-1} + \tilde{z}_t \tag{21}$$

$$\tilde{o}_t = \tilde{y}_t - \omega\tilde{a}_t \tag{22}$$

$$\tilde{a}_t = \rho_a\tilde{a}_{t-1} + \varepsilon_{at} \tag{23}$$

$$\tilde{e}_t = \rho_e\tilde{e}_{t-1} + \varepsilon_{et} \tag{24}$$

$$\tilde{z}_t = \varepsilon_{zt} \tag{25}$$

where $\omega = \frac{1}{\xi}$, $\psi = \frac{\xi(\bar{\theta}-1)}{\phi}$ and $\tilde{e}_t = \frac{1}{\phi}\tilde{\theta}_t$. This last equality is a normalization of the cost-push shock; like the cost-push shock itself, the normalized shock follows an AR(1) process with persistent parameter $\rho_\theta = \rho_e$, and innovation's standard deviation $\sigma_e = \frac{1}{\phi}\sigma_\theta$.

The objective of the model is to measure the contributions made by the various shocks in driving fluctuations in the model's observable and unobservable variables. Therefore, Ireland (2004) added lagged output gap and inflation terms to the model's IS and Phillips curves, so that (19) and (20) are replaced by

$$\tilde{o}_t = \alpha_o\tilde{o}_{t-1} + (1 - \alpha_o)E_t\tilde{o}_{t+1} - (\tilde{r}_t - E_t\tilde{\pi}_{t+1}) + (1 - \omega)(1 - \rho_a)\tilde{a}_t$$

$$\tilde{\pi}_t = \beta\alpha_\pi\tilde{\pi}_{t-1} + \beta(1 - \alpha_\pi)E_t\tilde{\pi}_{t+1} + \psi\tilde{o}_t - \tilde{e}_t$$

for all t=0,1,2, … The reason for these modifications is because estimates of the purely forward-looking specification might falsely attribute dynamics found in the data to serial correlation in the shocks when instead those dynamics are more accurately modeled as the product of additional frictions that give rise to backward-looking behavior on the part of households and firms.

Finally, the log-linearized version of the model is written as

$$\tilde{o}_t = \alpha_o \tilde{o}_{t-1} + (1 - \alpha_o) E_t \tilde{o}_{t+1} - (\tilde{r}_t - E_t \tilde{\pi}_{t+1}) + (1 - \omega)(1 - \rho_a) \tilde{a}_t \tag{26}$$

$$\tilde{\pi}_t = \beta \alpha_\pi \tilde{\pi}_{t-1} + \beta (1 - \alpha_\pi) E_t \tilde{\pi}_{t+1} + \psi \tilde{o}_t - \tilde{e}_t \tag{27}$$

$$\tilde{g}_t = \tilde{y}_t - \tilde{y}_{t-1} + \tilde{z}_t \tag{28}$$

$$\tilde{o}_t = \tilde{y}_t - \omega \tilde{a}_t \tag{29}$$

$$\tilde{a}_t = \rho_a \tilde{a}_{t-1} + \varepsilon_{at} \tag{30}$$

$$\tilde{e}_t = \rho_e \tilde{e}_{t-1} + \varepsilon_{et} \tag{31}$$

$$\tilde{z}_t = \varepsilon_{zt} \tag{32}$$

and the Taylor rule

$$\tilde{r}_t - \tilde{r}_{t-1} = \rho_\pi \tilde{\pi}_t + \rho_g \tilde{g}_t + \rho_o \tilde{o}_t + \varepsilon_{rt} \tag{33}$$

3. Estimation strategy and results

Equations (26)-(33) formulate a system involving three observable variables−output growth $\tilde{g}_t$, inflation $\tilde{\pi}_t$, and the short-term nominal interest rate $\tilde{r}_t$−two unobservable variables−stochastically detrended output $\tilde{y}_t$, and the output gap $\tilde{o}_t$−and four unobservable shocks−demand shock $\tilde{a}_t$, normalized cost-push shock $\tilde{e}_t$, technology shock $\tilde{z}_t$, and monetary policy shock ε_{rt}. Since the solution to this system can be presented in the form of a state-space econometric model, the model's parameters could be estimated by employing the Bayesian method. Thanks to the revolution of Dynare, the model's parameters can be estimated without any difficulty.

The econometric exercise uses monthly Vietnamese data running from January 1995 to December 2012. In these data, annualized monthly percent changes in seasonally-adjusted figures for real GDP serve to measure output growth. Since the monthly data of real GDP is unavailable, it is interpolated using Chow and Lin's (1971) approach from its annual series. Annualized monthly percent changes in seasonally-adjusted consumer prices index measure inflation, and monthly averages of the short-term lending interest rate provide the measure of the nominal short-term interest rate.

The linearized model consisting of equations (16)-(33) has 14 parameters estimated: β, ψ, ω, α_o, α_π, ρ_a, ρ_e, ρ_π, ρ_g, ρ_o, σ_a, σ_e, σ_z, and σ_r. In order to facilitate the estimation in Dynare, it is really necessary to declare priors by indicating the parameters' probability density function. Among parameters estimated, β can be determined via the formula $\beta = (\bar{\pi} \times \bar{z})/\bar{r}$, where $\bar{\pi}$, $\bar{z}$, and $\bar{r}$ are calibrated to the average inflation rate, average growth rate of real GDP, and average nominal interest rate in the data, respectively. Accordingly, the prior mean of β is set equal to 0.367 because the calibrated values of $\bar{\pi}$, $\bar{z}$, and $\bar{r}$ are 7.10 percent, 6.80 percent, and 13.17 percent, respectively. In the model, $1/(\xi - 1)$ serves to measure the elasticity of labor supply. Thus, I propose calibrating the elasticity of labor supply to the ratio of labor force growth to real GDP growth. Accordingly, the calibrated elasticity of labor supply over the period is 0.30, resulting in the prior mean of ω of 0.23 since $\omega = 1/\xi$. Parameter ψ has a gamma distribution with the range of $[0, +\infty)$ because $\xi \geq 1$, $\phi \geq 0$, and $\bar{\theta} \geq 1$. Declaration of the priors is presented in Table 1 (see Appendix).

Table 1. Priors

Parameter	Probability density function	Range
β	Beta	[0,1]
ψ	Gamma	[0, +∞)
ω	Beta	[0,1]
α_o	Beta	[0,1]
α_π	Beta	[0,1]
ρ_π	Normal	R
ρ_g	Normal	R
ρ_o	Normal	R
ρ_a	Beta	(0,1)
ρ_e	Beta	(0,1)
σ_a	Inverse Gamma	R^+
σ_e	Inverse Gamma	R^+
σ_z	Inverse Gamma	R^+
σ_r	Inverse Gamma	R^+

Table 2 (see Appendix) shows the Bayesian estimates of the model's parameters together with their confidence intervals. The estimate of β=0.3470 is smaller than the prior mean value of 0.367, meaning that the discounted factor is smaller than expected. Since ψ inversely depends on the costs of nominal price adjustment, the significant estimate of ψ=0.1043 implies that the costs of nominal price adjustment are relatively large. It is interesting that this estimate of ψ is almost similar to the value set in Ireland (2004), which equals 0.1[1]. As $\omega = 1/\xi$ by definition, this estimate of ω=0.2305 results in the estimate of ξ=4.34, which is relatively smaller than the estimate by Ireland (2004) for the US economy, meaning that Vietnamese labor supply is more elastic than the US labor supply. In addition, according to (29), the significant estimate of ω=0.2305 implies that the efficient level of output is considerably affected by the preference shock, if any. The estimates of α_o=0.0400 and α_π=0.1595 are statistically significant, meaning that backward-looking terms in the IS and Phillips curves are relevant. Furthermore, comparing α_o and α_π indicates that the information on past inflation is much more important than the information on past output gap in influencing behaviors of firms and households. In contrast to the significance of α_o and α_π for Vietnam, Ireland (2004) found that the IS and Phillips curves for the US are purely forward looking. The estimates of parameters of the Taylor rule are all statistically significant, meaning that the State Bank of Vietnam has responded to movements in inflation, output growth, and the output gap. Furthermore, the fairly small estimate of ρ_o=0.0030 indicates that the output gap as defined by the New Keynesian model has played less of a role in the policymaking process. However, one notable thing is that the estimates of the Taylor rule's parameters are fairly small, implying that the State Bank of Vietnam has adopted the Taylor rule quite loosely throughout the period. The estimate of ρ_e=0.9878 implies that, like the technology shock, the cost-push shock is highly persistent. The estimate of ρ_a=0.7803 shows that the preference shock is less persistent than the cost-push and technology shocks. Finally, the estimates of σ_a=0.2193, σ_e=4.9736, σ_z=26.3163, and σ_r=1.0433 are statistically significant, suggesting that the technology, cost-push and monetary policy shocks contribute in some way towards explaining movements in the data. However, the estimate of σ_a=0.2193 is relatively smaller than the other shocks, suggesting that the preference shock might have trivial importance in explaining movements

[1] Ψ is not estimated in Ireland (2004); it is fixed at 0.1.

in the data. This estimate also implies that, historically, the preference of Vietnamese households has been fairly stable.

Table 2. Bayesian estimates and their confidence intervals

Parameter	Estimate	Confidence interval
β	0.3470	[0.2656 0.4277]
ψ	0.1043	[0.0526 0.1554]
ω	0.2305	[0.0681 0.3862]
α_o	0.0400	[0.0099 0.0686]
α_π	0.1595	[0.0917 0.2250]
ρ_π	0.0668	[0.0581 0.0753]
ρ_g	0.0221	[0.0127 0.0312]
ρ_o	0.0030	[0.0022 0.0039]
ρ_a	0.7803	[0.6145 0.9457]
ρ_e	0.9878	[0.9785 0.9975]
σ_a	0.2193	[0.0453 0.3532]
σ_e	4.9736	[4.2643 5.6968]
σ_z	26.3163	[23.6263 29.0093]
σ_r	1.0433	[0.8772 1.1996]

Thus, like in the real business cycle model, the technology shock continues to play an important role in the New Keynesian model. In addition, the cost-push, preference and monetary policy shocks also take on some importance. In order to have insight into the role of the shocks, impulse response and forecast error variance decomposition analysis will be conducted in the following part.

Figure 1 plots the impulse responses of output growth, inflation, the nominal interest rate and the output gap to the four shocks. Accordingly, a one-standard-deviation preference shock causes output growth to rise by about 0.14 percent in the first month. Output growth then decreases slightly in the second month and the effect of the preference shock dies off over a period of about one year. A one-standard-deviation preference shock has positive impacts on inflation and the nominal interest rate. However, such effects are quite small, which are approximately 0.0125 percent, and 0.0042 percent, respectively. The output gap also increases after a one-standard-deviation preference shock.

Interpreting effects of the cost-push shock in this estimated model requires a little carefulness because an increase in e_t really means a negative cost-push shock. Thus, Figure 1 shows that a one-standard-deviation rise in e_t, a negative cost-push shock in other words, raises output growth by about 5.8 percent in the second month. The effect wears off since then and becomes slightly negative after about one year and a half. This negative cost-push shock, in contrast, has a negative impact on inflation, leading to an approximately 6.3 percent decrease in inflation. Since Ireland (2004) did not clarify the relationship between e_t and the cost-push shock, the author treated e_t as the cost-push shock and concluded that "a one-standard-deviation cost-push shock increases output growth and reduces the annualized inflation rate" for the case of the US. This conclusion has a flaw actually. Coming back to my study, the fall in inflation due to the negative cost-push shock allows for an easing of monetary policy under which the short-term nominal interest rate declines about 1.39 percent. The output gap increases due to this negative cost-push shock. The reason is that the efficient level of output does not depend on the cost-push shock while the equilibrium level of output goes up significantly owing to the negative cost-push shock and the monetary easing.

A one-standard-deviation technology shock leads to a significant increase of 18.6 percent in output growth and lowers the inflation rate by about 1.1 percent. The effect of the technology shock on output growth is substantial because output growth greatly depends on the technology shock according to (28), and the magnitude of the technology shock (σ_z=26.3163) is fairly considerable. The changes in output growth and inflation, therefore, generate a small increase of 0.31 percent in the short-term nominal interest rate. Since (10) shows that the efficient level of output crucially depends on the technology shock, the output gap declines even though output growth increases.

Finally, a one-standard-deviation monetary policy shock leads to an exogenous 0.56 percent increase in the short-term nominal interest rate, which dies off over a period of about two years. This monetary tightening causes output growth to sharply decrease by approximately 13.7 percent in the first month, but output growth starts increasing since the second month. On average, output growth falls in response to the tightening monetary policy since the negative effect dominates the positive effect. The monetary tightening leads to a 1.9 percent decrease in inflation and causes the output gap to fall as well.

<Insert Figure 1 around here>

There are several notable things about identifying the various shocks in the estimated New Keynesian model according to the impulse responses above. First, both the preference shock and the monetary shock work to increase the nominal interest rate. However, in the case of the preference shock, the increase in the interest rate occurs with the rise in output growth and inflation. In contrast, the monetary shock causes output growth and inflation to decline. Second, the (negative) cost-push shock and the technology shock both work to increase the rate of output growth and lower the inflation rate, but the (negative) cost-push shock leads to a fall in the nominal interest rate and leaves a positive output gap while the technology shock causes the nominal interest rate to increase and creates a negative output gap. Furthermore, the nature of the technology shock indicates that only it can have permanent impact on the level of output. Hence, the impulse response of output growth shows that the increase in output growth in response to a favorable technology shock is never reversed while the positive response of output growth that follows immediately from a negative cost-push shock must be offset later by a sustained period of slightly negative output growth.

In this estimated New Keynesian model, the impulse responses analysis above suggests that the technology shock continues to play the most important role in driving the fluctuations in output growth. In addition, Figure 1 shows that the cost-push shock generates the largest movements in inflation, the nominal interest rate and the output gap. The monetary policy shock also generates considerable changes in output growth and inflation. These findings are confirmed by decomposing the forecast error variances in output growth, inflation, the short-term nominal interest rate, and the output gap into components attributable to each of the four shocks.

The results of the variance decompositions are presented in Table 3, which shows that the technology shock plays the most important role in explaining the movements in output growth, accounting for about 50.53 percent of fluctuations in that variable across all forecast horizons. It is notable that the cost-push shock accounts for 98.97 percent, 98.72 percent and 94.17 percent of variations in the short-term nominal interest rate, the output gap and inflation, respectively. Approximately 29.24 percent of fluctuations in output growth and 4.47 percent of movements in inflation are attributed to the monetary policy shock. In this estimated New Keynesian model, the role of the preference shock in explaining the data is almost insignificant.

Table 3. Forecast error variance decompositions

Output growth				
Months ahead	Preference shock	Cost-push shock	Technology shock	Monetary shock
1	0.01	2.71	62.81	34.47
6	0.01	17.91	52.12	29.96
12	0.00	19.37	51.07	29.56
24	0.00	19.49	50.98	29.53
48	0.00	19.82	50.78	29.40
∞	0.00	20.23	50.53	29.24
Inflation				
Months ahead	Preference shock	Cost-push shock	Technology shock	Monetary shock
1	0.00	89.98	2.29	7.73
6	0.00	90.83	2.10	7.07
12	0.00	91.65	1.92	6.43
24	0.00	92.40	1.75	5.85
48	0.00	93.09	1.60	5.31
∞	0.00	94.17	1.36	4.47
Interest rate				
Months ahead	Preference shock	Cost-push shock	Technology shock	Monetary shock
1	0.00	24.02	18.09	57.89
6	0.00	80.01	4.82	15.17
12	0.00	92.59	1.79	5.62
24	0.00	96.96	0.73	2.31
48	0.00	98.34	0.40	1.26
∞	0.00	98.97	0.25	0.78
Output gap				
Months ahead	Preference shock	Cost-push shock	Technology shock	Monetary shock
1	0.00	5.71	22.72	71.57
6	0.00	70.80	7.16	22.04
12	0.00	89.82	2.49	7.69
24	0.00	96.02	0.96	3.02
48	0.00	97.89	0.51	1.60
∞	0.00	98.72	0.31	0.97

4. Are the results robust[2]?

On August 2nd, 2000, there was a significant change in the State Bank of Vietnam's monetary policy. That is, the State Bank of Vietnam started to use the base interest rate as a replacement for the ceiling interest rate to regulate the money market[3]. This change made the interest rate policy of the State Bank of Vietnam more liberalized. Thus, the best way to conduct the robustness check is to re-estimate the model with data from two disjoint subsamples: the first running from January 1995 through July 2000, the second running from August 2000 through December 2012.

Table 4 shows that the change in the monetary policy produces significantly different estimates of ρ_π, ρ_g, and ρ_o. Specifically, before August 2000, the State Bank of Vietnam appeared to be more responsive to movements in all three variables, output growth, inflation, and output gap. Moreover, evidence of instability is found for other parameters as well. For instance, the estimate of α_o=0.0143 for the period before August 2000 is quite small compared to the post-August 2000 estimate of α_o=0.0564, implying that backward-looking behavior on the part of consumers is of less importance in explaining the data from the earlier subsample. In addition, the estimate of ψ=0.1826 for the latter subsample suggests that the costs of nominal price adjustment have been decreasing from the first subsample to the second. The estimate of ω=0.2430 for the earlier subsample implies that the labor supply was more elastic in the period of prior-August 2000. Another change in the estimation result is that the preference shock is more persistent in the period of prior-August 2000 than in the period of post-August 2000. Finally, the size of the preference and monetary shocks becomes considerably smaller while the size of the technology shock becomes considerably bigger moving from the first subsample to the second. The size of the cost-push shock increases slightly as well.

Table 4. Subsample estimates and confidence intervals

Parameter	Pre-August 2000 estimate	Confidence interval	Post-August 2000 estimate	Confidence interval
β	0.3602	[0.2785 0.4416]	0.3546	[0.2739 0.4368]
ψ	0.0696	[0.0298 0.1071]	0.1826	[0.0789 0.2835]
ω	0.2430	[0.0736 0.4049]	0.2295	[0.0685 0.3856]
α_o	0.0143	[0.0022 0.0249]	0.0564	[0.0153 0.0959]
α_π	0.1916	[0.1125 0.2691]	0.1667	[0.0991 0.2391]
ρ_π	0.3440	[0.1907 0.5156]	0.0860	[0.0716 0.1001]
ρ_g	0.3135	[0.1617 0.4895]	0.0177	[0.0108 0.0242]
ρ_o	0.0082	[0.0039 0.0130]	0.0051	[0.0033 0.0069]
ρ_a	0.8829	[0.7991 0.9727]	0.7988	[0.6476 0.9600]
ρ_e	0.9854	[0.9729 0.9979]	0.9805	[0.9662 0.9956]
σ_a	11.5357	[5.0750 18.8024]	0.1953	[0.0449 0.3464]
σ_e	5.0076	[4.0654 5.9274]	5.6363	[4.5722 6.7039]
σ_z	0.1974	[0.0447 0.3549]	24.6929	[22.1291 27.1988]
σ_r	9.1850	[4.6422 14.3618]	0.8609	[0.7466 0.9728]

[2] In order to ensure the "technical" robustness of the estimates of the model's parameters, both proper and improper priors are used to obtain posteriors. The estimates generated from the two types of priors are almost the same, implying that the estimates of the model's parameters are technically robust. This robustness check procedure is applied to the whole sample and the two subsamples as well.

[3] The document number is 242/2000/QD-NHNN-02/08/2000.

Figure 2 displays the impulse responses generated from the model estimated with the first subsample, and Table 5 shows the forecast error variance decompositions for that subsample. The results of the variance decompositions reveal that the monetary policy shock takes the most important role in explaining the movements in output growth, accounting for more than 85 percent of variations in output growth. The monetary policy shock also reflects an equally considerable importance in driving variations in the output gap, the short-term nominal interest rate, and inflation. The cost-push shock continues to show their greatest importance in explaining fluctuations in the short-term nominal interest rate, the output gap, and inflation. Considerable fluctuations in the short-term nominal interest rate are attributed to the preference shock. In this earlier subsample, the technology shock has limited importance in explaining the movements in the data.

<Insert Figure 2 around here>

Table 5. Forecast error variance decompositions: Pre-August 2000 subsample

Output growth				
Months ahead	Preference shock	Cost-push shock	Technology shock	Monetary shock
1	1.03	2.96	0.00	96.01
6	0.98	10.84	0.00	88.18
12	0.95	12.55	0.00	86.50
24	0.95	12.82	0.00	86.23
48	0.95	13.08	0.00	85.97
∞	0.94	13.58	0.00	85.48
Inflation				
Months ahead	Preference shock	Cost-push shock	Technology shock	Monetary shock
1	0.04	74.77	0.00	25.19
6	0.03	75.39	0.00	24.58
12	0.03	76.08	0.00	23.89
24	0.03	76.81	0.00	23.16
48	0.03	77.37	0.00	22.60
∞	0.03	78.40	0.00	21.57
Interest rate				
Months ahead	Preference shock	Cost-push shock	Technology shock	Monetary shock
1	53.33	4.64	0.00	42.03
6	45.87	23.13	0.00	31.00
12	32.38	45.42	0.00	22.20
24	18.48	67.99	0.00	13.53
48	10.91	80.24	0.00	8.85
∞	6.85	86.70	0.00	6.45
Output gap				
Months ahead	Preference shock	Cost-push shock	Technology shock	Monetary shock
1	0.00	2.99	0.23	96.78
6	0.00	35.13	0.09	64.78
12	0.01	63.20	0.03	36.76

24	0.00	81.78	0.02	18.20
48	0.00	89.26	0.01	10.73
∞	0.00	92.58	0.00	7.42

The results of impulse responses and variance decompositions for the second subsample are shown in Figure 3 and Table 6. In this subsample, the cost-push shock continues to make the largest contributions in explaining variations in the short-term nominal interest rate, the output gap, and inflation, and it also explains considerable movements in output growth. The technology shock becomes the most important factor that generates the greatest changes in output growth, accounting for more than 66 percent of variations in output growth. Even though the monetary policy shock only generates more than 4 percent of movements in inflation, it is still the second largest contributor to variations in inflation. The monetary policy shock also produces considerable movements in the short-term nominal interest rate and the output gap during the beginning periods but it is then dominated quickly by the cost-push shock. The preference shock performs no importance in explaining the data of the second subsample.

Thus, moving from the first subsample to the second, the cost-push shock explains most of the movements in the short-term nominal interest rate, the output gap, and inflation. It also produces considerable variations in output growth. Most of the fluctuations in output growth in the first subsample are attributed to the monetary policy shock, whereas the technology shock generates the largest movements in output growth in the second subsample. The preference shock only shows some importance in driving the fluctuations in the short-term nominal interest rate and output growth in the first subsample but performs no importance in the second subsample.

<Insert Figure 3 around here>

Table 6. Forecast error variance decompositions: Post-August 2000 subsample

Output growth				
Months ahead	Preference shock	Cost-push shock	Technology shock	Monetary shock
1	0.00	7.88	78.56	13.56
6	0.00	19.38	67.75	12.87
12	0.00	19.64	67.46	12.90
24	0.00	19.89	67.25	12.86
48	0.00	20.24	66.97	12.79
∞	0.01	20.44	66.80	12.75
Inflation				
Months ahead	Preference shock	Cost-push shock	Technology shock	Monetary shock
1	0.00	90.62	1.94	7.44
6	0.00	91.45	1.77	6.78
12	0.00	92.08	1.64	6.28
24	0.00	92.65	1.52	5.83
48	0.00	93.19	1.41	5.40
∞	0.01	93.76	1.29	4.94
Interest rate				

Months ahead	Preference shock	Cost-push shock	Technology shock	Monetary shock
1	0.00	40.66	12.63	46.71
6	0.00	91.28	1.87	6.85
12	0.00	96.64	0.72	2.64
24	0.00	98.33	0.35	1.32
48	0.00	98.89	0.23	0.88
∞	0.01	99.08	0.20	0.71
Output gap				
Months ahead	Preference shock	Cost-push shock	Technology shock	Monetary shock
1	0.00	30.75	14.97	54.28
6	0.00	90.04	2.17	7.79
12	0.00	96.32	0.80	2.88
24	0.00	98.21	0.38	1.41
48	0.00	98.83	0.25	0.92
∞	0.01	99.08	0.20	0.71

5. Concluding remarks

This paper reproduces a New Keynesian model developed by Ireland (2004) in which the preference, cost-push, and monetary policy shocks compete with the real business cycle's technology shock in generating aggregate fluctuations. The paper then employs the Bayesian method to estimate the parameters of this New Keynesian model using Vietnamese data in the period 1995-2012. Subsequently, the paper uses the estimated model to evaluate relative importance of these various shocks in driving movements in output growth, inflation, and the short-term nominal interest rate between 1995 and 2012.

The empirical results described in detail above show that the cost-push shock is the major source of the fluctuations in the short-term nominal interest rate, inflation, and the output gap. Throughout, the technology shock is identified as the most important contributor to movements in output growth. However, the robustness check shows that, for the prior-August 2000 period, the monetary policy shocks dominate the technology shocks and emerge as a principal factor that produces most of the movements in output growth. Furthermore, throughout the period 1995-2012, in addition to the cost-push shock, the monetary policy shock makes more contributions in driving the variations in inflation than the technology shock does. Thus, overall, the role of the cost-push and monetary policy shocks in this estimated New Keynesian model is more significant than that of the technology shock. The technology shock only plays a supporting role. The preference shock only demonstrates some importance in generating the variations in the short-term nominal interest rate and output growth in the first subsample but performs no importance in explaining the data of the second subsample. Thus, it can be inferred that Vietnamese households' preference has been fairly stable over the period of post-August 2000.

One significant conclusion with regard to the monetary policy could be drawn from these findings. Specifically, before August 2000 when the Taylor rule was adopted more firmly, the monetary policy shock made considerable contributions to the fluctuations in key macroeconomic variables such as the short-term nominal interest rate, the output gap, inflation, and especially output growth. By contrast, loose adoption of the Taylor rule in the period of post-August 2000 leads to a fact that the contributions of the monetary policy shock to the variations in such key macroeconomic variables become less substantial. Thus, one policy implication is that adopting firmly the Taylor rule could strengthen the role of the monetary policy in driving movements in the key macroeconomic variables, for instance, enhancing economic growth and stabilizing inflation.

As indicated by Ireland (2004), Clarida, Gali, and Gertler (1999), Gali (2002), and Woodford (2003) show that in the presence of the cost-push shock, monetary authorities face a painful trade-off between stabilizing the inflation rate and stabilizing a welfare-theoretic measure of the output gap; the technology shock alone does not create conflict between these two goals. The empirical results described above show that the cost-push shock takes the most important role in explaining the fluctuations in the short-term nominal interest rate, inflation, and the output gap. This therefore implies that the State Bank of Vietnam's policymakers have actually faced difficult tradeoffs over the period 1995-2012.

Alternative interpretations could however be drawn from these results. Ireland (2004) points out that one could argue that the basic New Keynesian model used in this study does not take account of capital accumulation, an important process through which the technology shock is propagated in most real business cycle models. Hence, a suggestion for further research is to develop the analysis conducted in this study so as to capture the effects of capital accumulation. One could further argue that the additional shocks introduced here – the cost-push, preference and monetary policy shocks – in fact serve to soak up specification errors in the microfounded, New Keynesian model. Nevertheless, even under this alternative interpretation, Ireland (2004) presumes that one would still be led towards other specifications that go even farther beyond the original, real business cycle model.

Appendix

Figure 1. Impulse responses

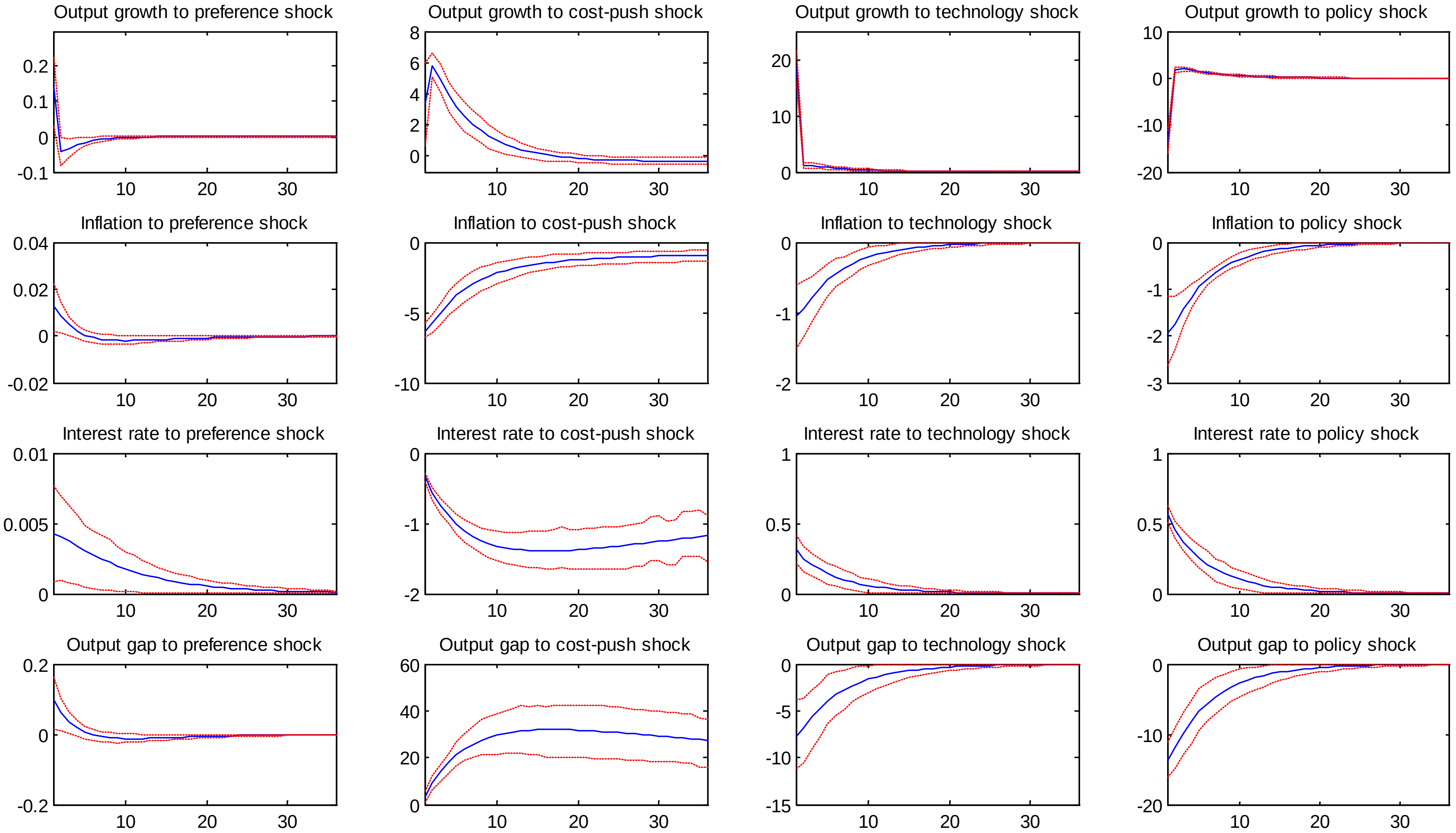


Figure 2. Impulse responses: Pre-August 2000 subsample

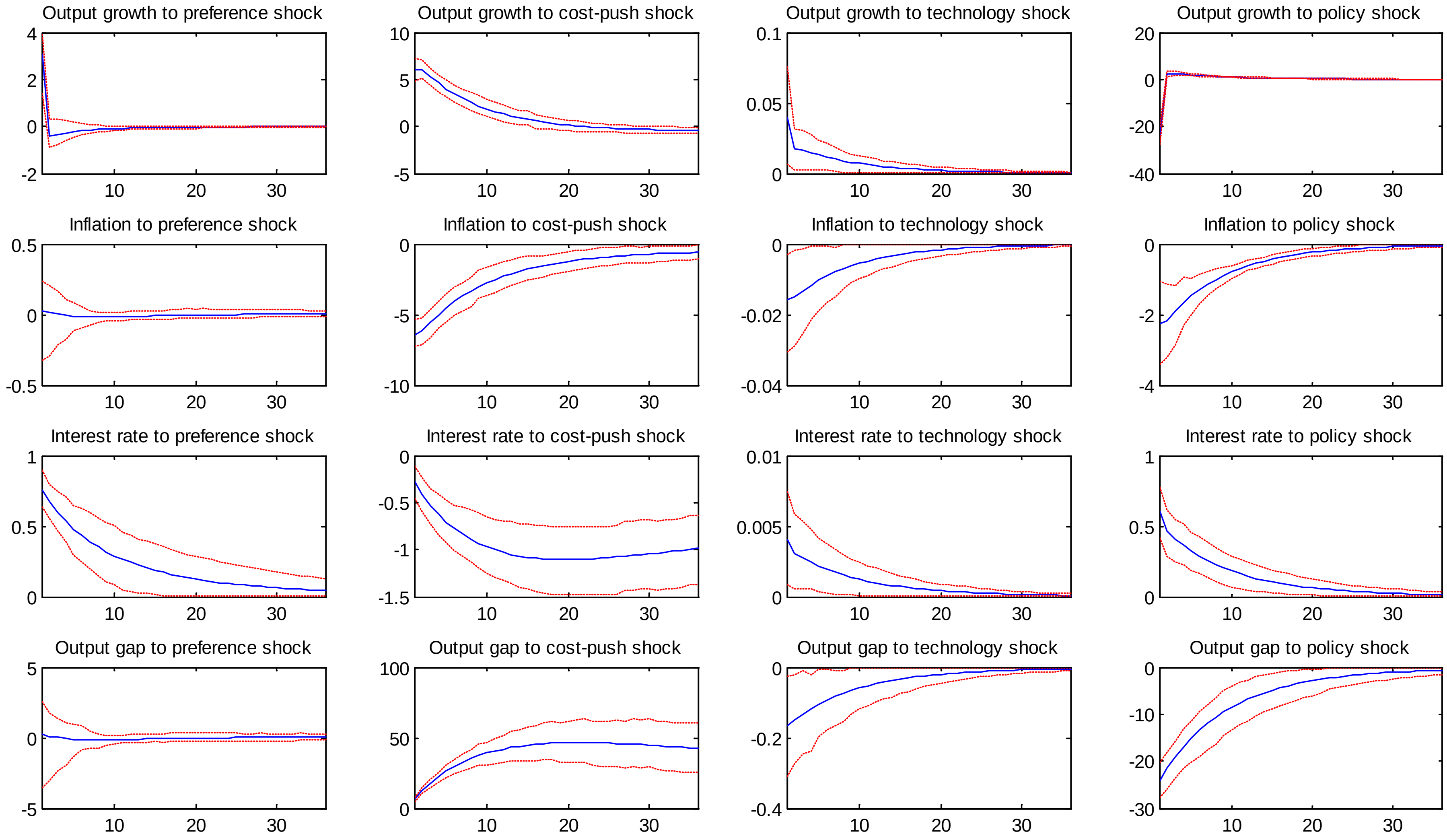
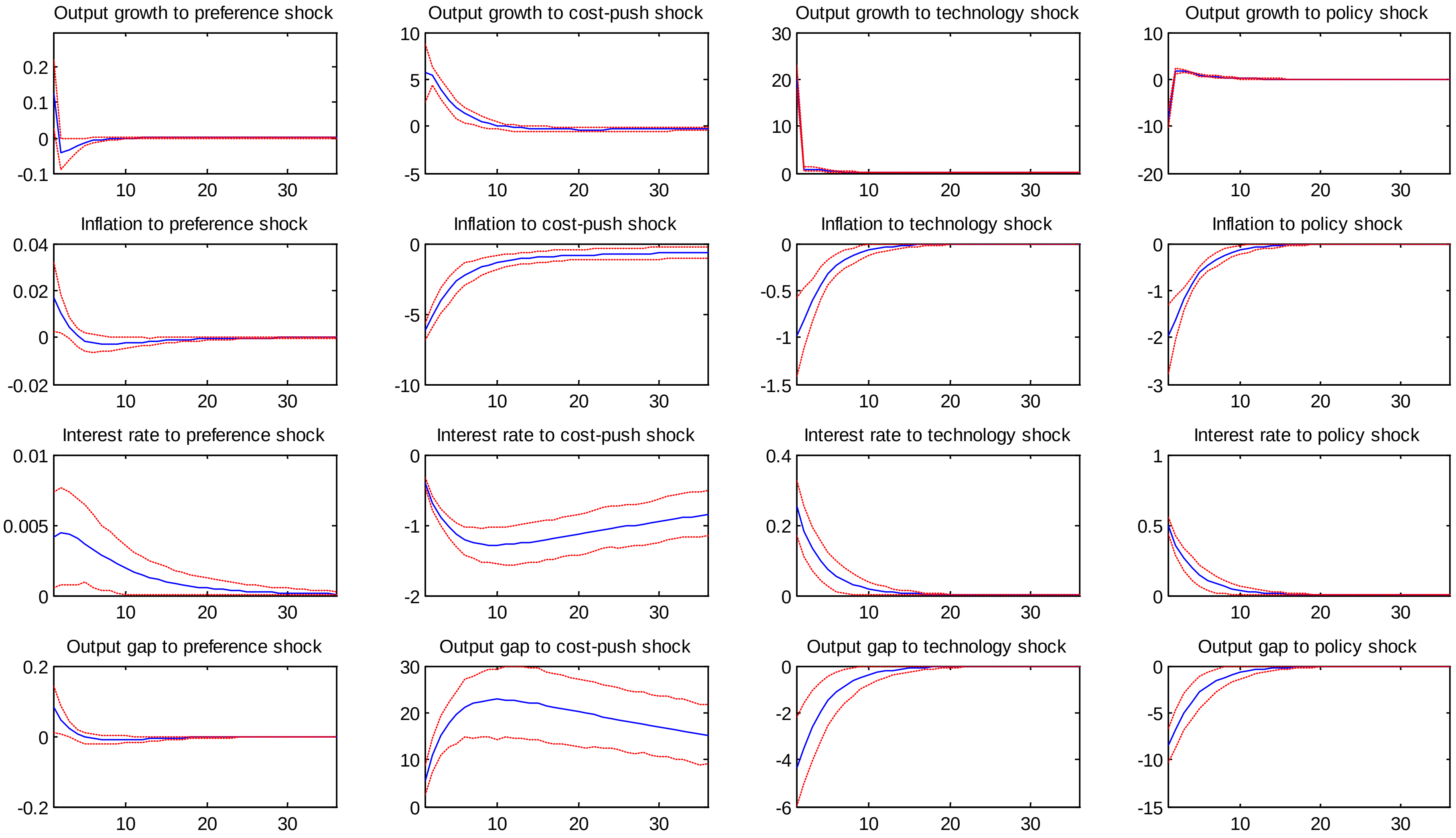


Figure 3. Impulse responses: Post-August 2000 subsample



Mathematical derivations of the model

1. The representative household

$$\max_{b_t,c_t,m_t,n_t} E\sum_{t=0}^{\infty}\beta^t\left\{a_t\ln c_t+\ln\frac{m_t}{p_t}-\frac{{n_t}^{\xi}}{\xi}\right\}$$

subject to

$$p_tc_t+\frac{b_t}{r_t}+m_t=m_{t-1}+b_{t-1}+\tau_t+w_tn_t+d_t$$

Lagrangian:

$$L=E\left\{\sum_{t=0}^{\infty}\beta^t\left[a_t\ln c_t+\ln\frac{m_t}{p_t}-\frac{{n_t}^{\xi}}{\xi}+\lambda_t(m_{t-1}+b_{t-1}+\tau_t+w_tn_t+d_t-p_tc_t-\frac{b_t}{r_t}-m_t\right]\right\}$$

First-order conditions:

$$\frac{\partial L}{\partial c_t}:\frac{a_t}{c_t}=\lambda_tp_t\qquad\Rightarrow\lambda_t=\frac{a_t}{c_tp_t}$$

$$\frac{\partial L}{\partial n_t}: n_t^{\xi-1}=\lambda_tw_t$$

$$\frac{\partial L}{\partial m_t}:\frac{1}{m_t}-\lambda_t+E_t(\lambda_{t+1})=0$$

$$\frac{\partial L}{\partial b_t}:\frac{\lambda_t}{r_t}=\beta E_t(\lambda_{t+1})$$

$$\frac{\partial L}{\partial \lambda_t}:p_tc_t+\frac{b_t}{r_t}+m_t=m_{t-1}+b_{t-1}+\tau_t+w_tn_t+d_t$$

These are equivalent to

$$n_t^{\xi-1}=\left(\frac{a_t}{c_t}\right)\left(\frac{w_t}{p_t}\right)$$

$$\beta E_t\left\{\left(\frac{a_{t+1}}{c_{t+1}}\right)\left(\frac{1}{p_{t+1}}\right)\right\}=\left(\frac{a_t}{c_t}\right)\left(\frac{1}{r_tp_t}\right)$$

$$\frac{1}{m_t}+E_t\left\{\left(\frac{a_{t+1}}{c_{t+1}}\right)\left(\frac{1}{p_{t+1}}\right)\right\}=\left(\frac{a_t}{c_t}\right)\left(\frac{1}{p_t}\right)$$

$$p_tc_t+\frac{b_t}{r_t}+m_t=m_{t-1}+b_{t-1}+\tau_t+w_tn_t+d_t$$

for all t=0,1,2, …

2. The representative final goods-producing firm

$$\max_{y_{it}} \pi_t^F = p_t y_t - \int_0^1 p_{it} y_{it} di$$

subject to

$$y_t = \left\{\int_0^1 y_{it}^{\frac{\theta_t - 1}{\theta_t}} di\right\}^{\frac{\theta_t}{\theta_t - 1}}$$

This constraint maximization problem could be transformed into an unconstraint maximization problem as follows

$$\max_{y_{it}} \pi_t^F = p_t \left\{\int_0^1 y_{it}^{\frac{\theta_t - 1}{\theta_t}} di\right\}^{\frac{\theta_t}{\theta_t - 1}} - \int_0^1 p_{it} y_{it} di$$

First-order condition:

$$\frac{\partial \pi_t^F}{\partial y_{it}} : p_t \frac{\theta_t}{\theta_t - 1} \left\{\int_0^1 y_{it}^{\frac{\theta_t - 1}{\theta_t}} di\right\}^{\frac{1}{\theta_t - 1}} \frac{\theta_t - 1}{\theta_t} y_{it}^{\frac{-1}{\theta_t}} = p_{it}$$

$$\Rightarrow p_t y_t^{\frac{1}{\theta_t}} y_{it}^{\frac{-1}{\theta_t}} = p_{it}$$

$$\Rightarrow y_{it} = y_t \left(\frac{p_{it}}{p_t}\right)^{-\theta_t}$$

for all $i \in [0,1]$ and $t=0,1,2, \ldots$

Since the representative final goods-producing firm operates in a competitive environment, competition causes its long run profit to be zero, i.e. $\pi_t^F = 0$. Thus,

$$p_t y_t - \int_0^1 p_{it} y_t \left(\frac{p_{it}}{p_t}\right)^{-\theta_t} di = 0$$

$$\Rightarrow p_t = \left(\int_0^1 {p_{it}}^{1-\theta_t} di\right)^{\frac{1}{1-\theta_t}}$$

for all $t=0,1,2, \ldots$

3. The representative intermediate goods-producing firm

$$\max_{p_{it}} \pi_t^I = E \sum_{t=0}^{\infty} \beta^t \left(\frac{a_t}{c_t}\right) \left(\frac{d_t}{p_t}\right)$$

subject to

$$y_{it} = z_t n_{it}$$

$$y_{it} = y_t \left(\frac{p_{it}}{p_t}\right)^{-\theta_t}$$

$$\chi(p_{it}, p_{it-1}) = \frac{\emptyset}{2}\left[\frac{p_{it}}{\overline{\pi} p_{it-1}} - 1\right]^2 y_t$$

The real value of profits is given by

$$\frac{d_t}{p_t} = \left\{\frac{p_{it}y_{it} - w_t n_{it}}{p_t} - \chi(p_{it}, p_{it-1})\right\}$$

This constraint maximization problem could be rewritten as an unconstraint maximization problem:

$$\max_{p_{it}} \pi_t^I = E\sum_{t=0}^{\infty} \beta^t \left(\frac{a_t}{c_t}\right)\left(\frac{p_{it}y_t\left(\frac{p_{it}}{p_t}\right)^{-\theta_t} - w_t n_{it}}{p_t} - \frac{\emptyset}{2}\left[\frac{p_{it}}{\overline{\pi} p_{it-1}} - 1\right]^2 y_t\right)$$

or

$$\max_{p_{it}} \pi_t^I = E\sum_{t=0}^{\infty} \beta^t \left(\frac{a_t}{c_t}\right)\left(\frac{p_{it}^{1-\theta_t}}{p_t^{1-\theta_t}} y_t - \frac{w_t}{p_t}\frac{y_t}{z_t}\frac{p_{it}^{-\theta_t}}{p_t^{-\theta_t}} - \frac{\emptyset}{2}\left[\frac{p_{it}}{\overline{\pi} p_{it-1}} - 1\right]^2 y_t\right)$$

First-order condition:

$$\begin{aligned}\frac{\partial \pi_t^I}{\partial p_{it}}\colon \beta^t \frac{a_t}{c_t}\frac{y_t}{p_t^{1-\theta_t}}(1-\theta_t)p_{it}^{-\theta_t} - \beta^t \frac{\emptyset}{2} y_t \frac{2a_t}{c_t}\left[\frac{p_{it}}{\overline{\pi} p_{it-1}} - 1\right]\frac{1}{\overline{\pi} p_{it-1}} \\ - \beta^t(-\theta_t)\frac{a_t}{c_t}\frac{w_t}{p_t}\frac{y_t}{z_t}\frac{p_{it}^{-\theta_t-1}}{p_t^{-\theta_t}} \\ - E_t\left\{\beta^{t+1}\frac{\emptyset}{2} y_{t+1}\frac{2a_{t+1}}{c_{t+1}}\left[\frac{p_{it+1}}{\overline{\pi} p_{it}} - 1\right]\left[-\frac{p_{it+1}}{\overline{\pi} {p_{it}}^2}\right]\right\} = 0\end{aligned}$$

$$\begin{aligned}\Rightarrow (\theta_t - 1)\frac{y_t}{p_t}\left(\frac{p_{it}}{p_t}\right)^{-\theta_t} \\ = \theta_t\left(\frac{p_{it}}{p_t}\right)^{-\theta_t-1}\frac{w_t}{p_t}\frac{y_t}{z_t}\frac{1}{p_t} - \emptyset\left[\frac{p_{it}}{\overline{\pi} p_{it-1}} - 1\right]\frac{y_t}{\overline{\pi} p_{it-1}} \\ + \beta\emptyset E_t\left\{\frac{a_{t+1}}{a_t}\frac{c_t}{c_{t+1}}\left[\frac{p_{it+1}}{\overline{\pi} p_{it}} - 1\right]\left[\frac{y_{t+1}p_{it+1}}{\overline{\pi} {p_{it}}^2}\right]\right\}\end{aligned}$$

for all t=0,1,2, …

Under perfect price flexibility ($\emptyset = 0$):

$$p_{it} = \frac{\theta_t}{\theta_t - 1}\frac{w_t}{z_t}$$

4. The social benevolent planner

$$\max_{\hat{y}_t, n_{it}} U = E_0 \sum_{t=0}^{\infty} \beta^t \left\{ a_t \ln \hat{y}_t - \frac{1}{\xi}\left(\int_0^1 n_{it} di\right)^{\xi} \right\}$$

subject to

$$\hat{y}_t = z_t \left(\int_0^1 n_{it}^{\frac{\theta_t - 1}{\theta_t}} di\right)^{\frac{\theta_t}{\theta_t - 1}}$$

Lagrangian:

$$L = E \sum_{t=0}^{\infty} \beta^t \left\{ a_t \ln \hat{y}_t - \frac{1}{\xi}\left(\int_0^1 n_{it} di\right)^{\xi} + \lambda_t \left(z_t \left(\int_0^1 n_{it}^{\frac{\theta_t - 1}{\theta_t}} di\right)^{\frac{\theta_t}{\theta_t - 1}} - \hat{y}_t \right) \right\}$$

First-order conditions:

$$\frac{\partial L}{\partial \hat{y}_t}: \lambda_t = \frac{a_t}{\hat{y}_t}$$

$$\frac{\partial L}{\partial n_{it}}: \left(\int_0^1 n_{it} di\right)^{\xi - 1} = \lambda_t z_t \left(\int_0^1 n_{it}^{\frac{\theta_t - 1}{\theta_t}} di\right)^{\frac{1}{\theta_t - 1}} n_{it}^{\frac{-1}{\theta_t}}$$

$$\frac{\partial L}{\partial \lambda_t}: \hat{y}_t = z_t \left(\int_0^1 n_{it}^{\frac{\theta_t - 1}{\theta_t}} di\right)^{\frac{\theta_t}{\theta_t - 1}}$$

These are equivalent to

$$\left(\int_0^1 n_{it} di\right)^{\xi - 1} = \frac{a_t}{\hat{y}_t} z_t \left(\frac{\hat{y}_t}{z_t}\right)^{\frac{1}{\theta_t}} n_{it}^{\frac{-1}{\theta_t}}$$

$$\hat{y}_t = z_t \left(\int_0^1 n_{it}^{\frac{\theta_t - 1}{\theta_t}} di\right)^{\frac{\theta_t}{\theta_t - 1}}$$

Note that the first of these two optimality conditions implies that the social planner will choose $n_{it}=n_t$ for all $i \in [0,1]$ and $t=0,1,2,...$, since none of the other objects in that expression depends on i. Hence,

$$\hat{y}_t = z_t n_t$$

$$n_t^{\xi-1} = \frac{a_t}{n_t} n_t^{\frac{1}{\theta_t}} n_t^{\frac{-1}{\theta_t}}$$

Finally, we obtain

$$n_t = a_t^{\frac{1}{\xi}}$$

$$\hat{y}_t = z_t a_t^{\frac{1}{\xi}}$$

5. Stochastic specifications

$$\ln(a_t) = (1-\rho_a)\ln(\bar{a}) + \rho_a \ln(a_{t-1}) + \varepsilon_{at} \quad \bar{a} \geq 1$$

$$\ln(z_t) = \ln(\bar{z}) + \ln(z_{t-1}) + \varepsilon_{zt} \quad \bar{z} \geq 1$$

$$\ln(\theta_t) = (1-\rho_\theta)\ln(\bar{\theta}) + \rho_\theta \ln(\theta_{t-1}) + \varepsilon_{\theta t} \quad \bar{\theta} \geq 1$$

6. Nonlinear system

In a symmetric equilibrium, the following conditions must be satisfied:

$y_{it}=y_t$, $n_{it}=n_t$, $p_{it}=p_t$, $d_{it}=d_t$.

$m_t=m_{t-1} + \tau_t$

$b_t=b_{t-1}=0$

Now, let's normalize variables as follows

$$\ddot{y}_t = \frac{y_t}{z_t}, \ddot{c}_t = \frac{c_t}{z_t}, \ddot{\hat{y}}_t = \frac{\hat{y}_t}{z_t}, \pi_t = \frac{p_t}{p_{t-1}},$$

$$\ddot{d}_t = \frac{d_t/p_t}{z_t}, \ddot{w}_t = \frac{w_t/p_t}{z_t}, \ddot{m}_t = \frac{m_t/p_t}{z_t}, \ddot{z}_t = \frac{z_t}{z_{t-1}}$$

6.1. Budget constraint

$$p_t c_t + \frac{b_t}{r_t} + m_t = m_{t-1} + b_{t-1} + \tau_t + w_t n_t + d_t$$

Applying the equilibrium conditions, we have

$$p_t c_t = w_t n_t + d_t$$

$$\Rightarrow c_t = \frac{w_t n_t}{p_t} + \frac{d_t}{p_t}$$

$$\Rightarrow c_t = \frac{w_t n_t}{p_t} + \left\{\frac{p_t y_t - w_t n_t}{p_t} - \frac{\emptyset}{2}\left[\frac{p_t}{\bar{\pi} p_{t-1}} - 1\right]^2 y_t\right\}$$

$$\Rightarrow c_t = y_t - \frac{\emptyset}{2}\left[\frac{p_t}{\bar{\pi} p_{t-1}} - 1\right]^2 y_t$$

Dividing both sides by z_t, finally we obtain

$$\ddot{y}_t = \ddot{c}_t + \frac{\emptyset}{2}\left[\frac{\pi_t}{\bar{\pi}} - 1\right]^2 \ddot{y}_t$$

6.2. Household's first order condition

$$\beta E_t\left\{\left(\frac{a_{t+1}}{c_{t+1}}\right)\left(\frac{1}{p_{t+1}}\right)\right\} = \left(\frac{a_t}{c_t}\right)\left(\frac{1}{r_t p_t}\right)$$

$$\Rightarrow \beta r_t E_t\left\{\left(\frac{a_{t+1}}{c_{t+1}}\right)\left(\frac{p_t}{p_{t+1}}\right)\right\} = \left(\frac{a_t}{c_t}\right)$$

Multiplying both sides by z_t:

$$\Rightarrow \beta r_t E_t\left\{\left(\frac{a_{t+1}}{c_{t+1}} z_{t+1}\frac{z_t}{z_{t+1}}\right)\left(\frac{p_t}{p_{t+1}}\right)\right\} = \left(\frac{a_t}{c_t} z_t\right)$$

$$\Rightarrow \beta r_t E_t\left\{\left(\frac{a_{t+1}}{\ddot{c}_{t+1}}\right)\left(\frac{1}{\ddot{z}_{t+1}}\right)\left(\frac{1}{\pi_{t+1}}\right)\right\} = \left(\frac{a_t}{\ddot{c}_t}\right)$$

6.3. The first order condition of the intermediate goods firm

$$(\theta_t - 1)\frac{y_t}{p_t}\left(\frac{p_t}{p_t}\right)^{-\theta_t}$$

$$= \theta_t\left(\frac{p_t}{p_t}\right)^{-\theta_t - 1}\frac{w_t}{p_t}\frac{y_t}{z_t}\frac{1}{p_t} - \emptyset\left[\frac{p_t}{\bar{\pi} p_{t-1}} - 1\right]\frac{y_t}{\bar{\pi} p_{t-1}} + \beta\emptyset E_t\left\{\frac{a_{t+1}}{a_t}\frac{c_t}{c_{t+1}}\left[\frac{p_{t+1}}{\bar{\pi} p_t} - 1\right]\left[\frac{y_{t+1} p_{t+1}}{\bar{\pi} {p_t}^2}\right]\right\}$$

$$\Rightarrow (\theta_t - 1)\frac{y_t}{p_t} = \theta_t\frac{w_t}{p_t}\frac{y_t}{z_t}\frac{1}{p_t} - \emptyset\left[\frac{\pi_t}{\bar{\pi}} - 1\right]\frac{y_t}{\bar{\pi} p_{t-1}} + \beta\emptyset E_t\left\{\frac{a_{t+1}}{a_t}\frac{c_t}{c_{t+1}}\left[\frac{\pi_{t+1}}{\bar{\pi}} - 1\right]\left[\frac{y_{t+1}\pi_{t+1}}{\bar{\pi} p_t}\right]\right\}$$

Multiply two sides by p_t/y_t:

$$\Rightarrow \theta_t - 1 = \theta_t\frac{w_t}{p_t}\frac{1}{z_t} - \emptyset\left[\frac{\pi_t}{\bar{\pi}} - 1\right]\frac{p_t}{\bar{\pi} p_{t-1}} + \beta\emptyset E_t\left\{\frac{a_{t+1}}{a_t}\frac{c_t}{c_{t+1}}\left[\frac{\pi_{t+1}}{\bar{\pi}} - 1\right]\left[\frac{y_{t+1}\pi_{t+1}}{\bar{\pi} y_t}\right]\right\}$$

$$\Rightarrow 0 = 1 - \theta_t + \theta_t\ddot{w}_t - \emptyset\left[\frac{\pi_t}{\bar{\pi}} - 1\right]\frac{\pi_t}{\bar{\pi}} + \beta\emptyset E_t\left\{\frac{a_{t+1}}{a_t}\frac{\ddot{c}_t}{\ddot{c}_{t+1}}\left[\frac{\pi_{t+1}}{\bar{\pi}} - 1\right]\left[\frac{\ddot{y}_{t+1}\pi_{t+1}}{\bar{\pi}\ddot{y}_t}\right]\right\}$$

$$\Rightarrow 0 = 1 - \theta_t + \theta_t \ddot{y}_t^{\xi-1} \frac{\ddot{c}_t}{a_t} - \emptyset \left[\frac{\pi_t}{\overline{\pi}} - 1\right] \frac{\pi_t}{\overline{\pi}} + \beta\emptyset E_t \left\{\frac{a_{t+1}}{a_t} \frac{\ddot{c}_t}{\ddot{c}_{t+1}} \left[\frac{\pi_{t+1}}{\overline{\pi}} - 1\right] \left[\frac{\ddot{y}_{t+1}\pi_{t+1}}{\overline{\pi}\ddot{y}_t}\right]\right\}$$

6.4. Solutions to work hours, wages, capacity output, profits, and money

We can solve for work hours, real wages, capacity output, real profits, and money from the following equations

- $y_t = z_t n_t$

$$\Rightarrow n_t = \frac{y_t}{z_t} = \ddot{y}_t$$

- $n_t^{\xi-1} = \left(\frac{a_t}{c_t}\right)\left(\frac{w_t}{p_t}\right)$

$$\Rightarrow \frac{w_t}{p_t} = \left(\frac{y_t}{z_t}\right)^{\xi-1} \left(\frac{c_t}{a_t}\right) \Rightarrow \ddot{w}_t = \ddot{y}_t^{\xi-1} \frac{\ddot{c}_t}{a_t}$$

- $\hat{y}_t = z_t a_t^{\frac{1}{\xi}}$

$$\Rightarrow \ddot{\hat{y}}_t = a_t^{\frac{1}{\xi}}$$

- $\frac{d_t}{p_t} = y_t - \frac{w_t}{p_t}\frac{y_t}{z_t} - \frac{\emptyset}{2}\left[\frac{\pi_t}{\overline{\pi}} - 1\right]^2 y_t$

$$\Rightarrow \frac{d_t}{p_t} = y_t - \left(\frac{y_t}{z_t}\right)^{\xi} \left(\frac{c_t}{a_t}\right) - \frac{\emptyset}{2}\left[\frac{\pi_t}{\overline{\pi}} - 1\right]^2 y_t$$

Dividing both sides by z_t, finally we obtain

$$\Rightarrow \ddot{d}_t = \ddot{y}_t - \ddot{y}_t^{\xi} \frac{\ddot{c}_t}{a_t} - \frac{\emptyset}{2}\left[\frac{\pi_t}{\overline{\pi}} - 1\right]^2 \ddot{y}_t$$

- $\frac{1}{m_t} + E_t\left\{\left(\frac{a_{t+1}}{c_{t+1}}\right)\left(\frac{1}{p_{t+1}}\right)\right\} = \left(\frac{a_t}{c_t}\right)\left(\frac{1}{p_t}\right)$

$$\Rightarrow \frac{z_t p_t}{m_t} + E_t\left\{\left(\frac{z_{t+1}a_{t+1}}{c_{t+1}}\right)\left(\frac{z_t}{z_{t+1}}\right)\left(\frac{p_t}{p_{t+1}}\right)\right\} = \left(\frac{z_t a_t}{c_t}\right)$$

$$\Rightarrow \frac{1}{\ddot{m}_t} + E_t\left\{\left(\frac{a_{t+1}}{\ddot{c}_{t+1}}\right)\left(\frac{1}{\ddot{z}_{t+1}}\right)\left(\frac{1}{\pi_{t+1}}\right)\right\} = \left(\frac{a_t}{\ddot{c}_t}\right)$$

$$\Rightarrow \ddot{m}_t = \left\{\left(\frac{a_t}{\ddot{c}_t}\right) - E_t\left\{\left(\frac{a_{t+1}}{\ddot{c}_{t+1}}\right)\left(\frac{1}{\ddot{z}_{t+1}}\right)\left(\frac{1}{\pi_{t+1}}\right)\right\}\right\}^{-1}$$

Since work hours, real wages, capacity output, real profits, and money are expressed in terms of other variables, they could be eliminated from the system.

Finally, we have a non-linear system as follows:

$$\ddot{y}_t = \ddot{c}_t + \frac{\emptyset}{2}\left[\frac{\pi_t}{\overline{\pi}} - 1\right]^2 \ddot{y}_t$$

$$\beta r_t E_t\left\{\left(\frac{a_{t+1}}{\ddot{c}_{t+1}}\right)\left(\frac{1}{\ddot{z}_{t+1}}\right)\left(\frac{1}{\pi_{t+1}}\right)\right\} = \left(\frac{a_t}{\ddot{c}_t}\right)$$

$$0 = 1 - \theta_t + \theta_t \ddot{y}_t{}^{\xi-1}\frac{\ddot{c}_t}{a_t} - \emptyset\left[\frac{\pi_t}{\overline{\pi}} - 1\right]\frac{\pi_t}{\overline{\pi}} + \beta\emptyset E_t\left\{\frac{a_{t+1}}{a_t}\frac{\ddot{c}_t}{\ddot{c}_{t+1}}\left[\frac{\pi_{t+1}}{\overline{\pi}} - 1\right]\left[\frac{\ddot{y}_{t+1}\pi_{t+1}}{\overline{\pi}\ddot{y}_t}\right]\right\}$$

$$g_t = \frac{y_t}{y_{t-1}} = \frac{\frac{y_t}{z_t}\frac{z_t}{z_{t-1}}}{\frac{y_{t-1}}{z_{t-1}}} = \frac{\ddot{y}_t \ddot{z}_t}{\ddot{y}_{t-1}}$$

$$o_t \equiv \frac{y_t}{\hat{y}_t} = \frac{\ddot{y}_t}{\ddot{\hat{y}}_t} = \frac{\ddot{y}_t}{a_t^{\frac{1}{\xi}}}$$

$$\ln(a_t) = (1 - \rho_a)\ln(\overline{a}) + \rho_a \ln(a_{t-1}) + \varepsilon_{at}$$

$$\ln(\theta_t) = (1 - \rho_\theta)\ln(\overline{\theta}) + \rho_a \ln(\theta_{t-1}) + \varepsilon_{\theta t}$$

$$\ln(\ddot{z}_t) = \ln(\overline{z}) + \varepsilon_{zt}$$

7. Log-linearization

The first step of log-linearization is to solve for steady state values of endogenous variables. In steady state, endogenous variables are constant over time. Therefore,

$$\overline{y} = \overline{c} + \frac{\emptyset}{2}\left[\frac{\overline{\pi}}{\overline{\pi}} - 1\right]^2$$

$$\beta\overline{r}E_t\left\{\left(\frac{\overline{a}}{\overline{c}}\right)\left(\frac{1}{\overline{z}}\right)\left(\frac{1}{\overline{\pi}}\right)\right\} = \left(\frac{\overline{a}}{\overline{c}}\right)$$

$$0 = 1 - \overline{\theta} + \overline{\theta}\overline{y}^{\xi-1}\frac{\overline{c}}{\overline{a}}$$

$$\overline{o} = \frac{\overline{y}}{\overline{a}^{\frac{1}{\xi}}}$$

Consequently, we obtain

$$\overline{y} = \overline{c} = \left(\overline{a}\frac{\overline{\theta} - 1}{\overline{\theta}}\right)^{\frac{1}{\xi}}$$

$$\bar{r} = \bar{\pi}\frac{\bar{z}}{\beta}$$

$$\bar{o} = \left(\frac{\bar{\theta} - 1}{\bar{\theta}}\right)^{\frac{1}{\xi}}$$

Next, we log-linearize the non-linear system above by applying first-order Taylor approximation.

- $\ddot{y}_t = \ddot{c}_t + \frac{\emptyset}{2}\left[\frac{\pi_t}{\bar{\pi}} - 1\right]^2 \ddot{y}_t$

Taking natural logarithm of both sides results in

$$\ln(\ddot{y}_t) = \ln\left(\ddot{c}_t + \frac{\emptyset}{2}\left[\frac{\pi_t}{\bar{\pi}} - 1\right]^2 \ddot{y}_t\right)$$

First-order Taylor approximation of the right hand side around the steady state values is given as

$$\ln\left(\ddot{c}_t + \frac{\emptyset}{2}\left[\frac{\pi_t}{\bar{\pi}} - 1\right]^2 \ddot{y}_t\right) \approx \ln\bar{y} + \frac{\ddot{c}_t - \bar{c}}{\bar{c}}$$

Hence,

$$\ln(\ddot{y}_t) = \ln\bar{y} + \frac{\ddot{c}_t - \bar{c}}{\bar{c}} \Rightarrow \ln(\ddot{y}_t) - \ln\bar{y} = \frac{\ddot{c}_t - \bar{c}}{\bar{c}} \Rightarrow \tilde{y}_t = \tilde{c}_t$$

- $\beta r_t E_t\left\{\left(\frac{a_{t+1}}{\ddot{c}_{t+1}}\right)\left(\frac{1}{\ddot{z}_{t+1}}\right)\left(\frac{1}{\pi_{t+1}}\right)\right\} = \left(\frac{a_t}{\ddot{c}_t}\right)$

Taking natural logarithm of both sides gives

$$\ln\beta + \ln r_t + E_t\ln(a_{t+1}) - E_t\ln(\ddot{c}_{t+1}) - E_t\ln(\ddot{z}_{t+1}) - E_t\ln(\pi_{t+1}) = \ln a_t - \ln\ddot{c}_t$$

At steady state:

$$\ln\beta + \ln\bar{r} + E_t\ln\bar{a} - E_t\ln\bar{c} - E_t\ln\bar{z} - E_t\ln\bar{\pi} = \ln\bar{a} - \ln\bar{c}$$

$$\Rightarrow \ln r_t - \ln\bar{r} + E_t(\ln(a_{t+1}) - \ln\bar{a}) - E_t(\ln(\ddot{c}_{t+1}) - \ln\bar{c}) - E_t(\ln(\pi_{t+1}) - \ln\bar{\pi}) - E_t(\ln(\ddot{z}_{t+1}) - \ln\bar{z}) - (\ln(a_t) - \ln\bar{a}) + (\ln(\ddot{c}_t) - \ln\bar{c}) = 0$$

$$\Rightarrow \tilde{r}_t + E_t\tilde{a}_{t+1} - E_t\tilde{c}_{t+1} - E_t\tilde{\pi}_{t+1} - E_t\tilde{z}_{t+1} - \tilde{a}_t + \tilde{c}_t = 0$$

$$\Rightarrow \tilde{r}_t - (E_t\tilde{y}_{t+1} - \tilde{y}_t) - E_t\tilde{\pi}_{t+1} + E_t\tilde{a}_{t+1} - \tilde{a}_t = 0 \text{ since } E_t\tilde{z}_{t+1} = 0$$

$$\Rightarrow \tilde{r}_t - \left(\frac{1}{\xi}E_t\tilde{a}_{t+1} + E_t\tilde{o}_{t+1} - \frac{1}{\xi}\tilde{a}_t - \tilde{o}_t\right) - E_t\tilde{\pi}_{t+1} + E_t\tilde{a}_{t+1} - \tilde{a}_t = 0$$

$$\Rightarrow \tilde{o}_t = E_t\tilde{o}_{t+1} - (\tilde{r}_t - E_t\tilde{\pi}_{t+1}) + (1-\rho_a)\tilde{a}_t - \frac{1}{\xi}(1-\rho_a)\tilde{a}_t$$

$$\Rightarrow \tilde{o}_t = E_t\tilde{o}_{t+1} - (\tilde{r}_t - E_t\tilde{\pi}_{t+1}) + \left(1-\frac{1}{\xi}\right)(1-\rho_a)\tilde{a}_t$$

- $0 = 1 - \theta_t + \theta_t\ddot{y}_t^{\xi-1}\frac{\ddot{c}_t}{a_t} - \emptyset\left[\frac{\pi_t}{\overline{\pi}} - 1\right]\frac{\pi_t}{\overline{\pi}} + \beta\emptyset E_t\left\{\frac{a_{t+1}}{a_t}\frac{\ddot{c}_t}{\ddot{c}_{t+1}}\left[\frac{\pi_{t+1}}{\overline{\pi}} - 1\right]\left[\frac{\ddot{y}_{t+1}\pi_{t+1}}{\overline{\pi}\ddot{y}_t}\right]\right\}$

Re-arranging the equation, we obtain

$$1 = \theta_t - \theta_t\ddot{y}_t^{\xi-1}\frac{\ddot{c}_t}{a_t} + \emptyset\left[\frac{\pi_t}{\overline{\pi}} - 1\right]\frac{\pi_t}{\overline{\pi}} - \beta\emptyset E_t\left\{\frac{a_{t+1}}{a_t}\frac{\ddot{c}_t}{\ddot{c}_{t+1}}\left[\frac{\pi_{t+1}}{\overline{\pi}} - 1\right]\left[\frac{\ddot{y}_{t+1}\pi_{t+1}}{\overline{\pi}\ddot{y}_t}\right]\right\} \quad (7.1)$$

Taking natural logarithm of both sides gives

$$0 = \ln\left[\theta_t - \theta_t\ddot{y}_t^{\xi-1}\frac{\ddot{c}_t}{a_t} + \emptyset\left[\frac{\pi_t}{\overline{\pi}} - 1\right]\frac{\pi_t}{\overline{\pi}} - \beta\emptyset E_t\left\{\frac{a_{t+1}}{a_t}\frac{\ddot{c}_t}{\ddot{c}_{t+1}}\left[\frac{\pi_{t+1}}{\overline{\pi}} - 1\right]\left[\frac{\ddot{y}_{t+1}\pi_{t+1}}{\overline{\pi}\ddot{y}_t}\right]\right\}\right]$$

Denote

$$f(\theta_t, \ddot{c}_t, a_t, \ddot{y}_t, \pi_t, a_{t+1}, \ddot{c}_{t+1}, \pi_{t+1}, \ddot{y}_{t+1})$$
$$= \ln\left[\theta_t - \theta_t\ddot{y}_t^{\xi-1}\frac{\ddot{c}_t}{a_t} + \emptyset\left[\frac{\pi_t}{\overline{\pi}} - 1\right]\frac{\pi_t}{\overline{\pi}} - \beta\emptyset E_t\left\{\frac{a_{t+1}}{a_t}\frac{\ddot{c}_t}{\ddot{c}_{t+1}}\left[\frac{\pi_{t+1}}{\overline{\pi}} - 1\right]\left[\frac{\ddot{y}_{t+1}\pi_{t+1}}{\overline{\pi}\ddot{y}_t}\right]\right\}\right]$$

Note that at steady state, the right hand side of (7.1) equals one, and the value of function $f(\cdot)$ equals zero.

First-order Taylor approximation of the function $f(\cdot)$ around the steady state values

$$\begin{aligned} f(\cdot) \approx f(\cdot)|_{ss} &+ \left[\frac{df(\cdot)}{d\theta_t}\right]_{ss}(\theta_t - \overline{\theta}) + \left[\frac{df(\cdot)}{d\ddot{c}_t}\right]_{ss}(\ddot{c}_t - \overline{c}) + \left[\frac{df(\cdot)}{da_t}\right]_{ss}(a_t - \overline{a}) \\ &+ \left[\frac{df(\cdot)}{d\ddot{y}_t}\right]_{ss}(\ddot{y}_t - \overline{y}) + \left[\frac{df(\cdot)}{d\pi_t}\right]_{ss}(\pi_t - \overline{\pi}) + \left[\frac{df(\cdot)}{d\ddot{c}_{t+1}}\right]_{ss}(\ddot{c}_{t+1} - \overline{c}) \\ &+ \left[\frac{df(\cdot)}{da_{t+1}}\right]_{ss}(a_{t+1} - \overline{a}) + \left[\frac{df(\cdot)}{d\ddot{y}_{t+1}}\right]_{ss}(\ddot{y}_{t+1} - \overline{y}) \\ &+ \left[\frac{df(\cdot)}{d\pi_{t+1}}\right]_{ss}(\pi_{t+1} - \overline{\pi}) \end{aligned}$$

$$\begin{aligned} f(\cdot) \approx 0 &+ \left(1 - \frac{\overline{c}}{\overline{a}}\overline{y}^{\xi-1}\right)(\theta_t - \overline{\theta}) - \frac{\overline{\theta}}{\overline{a}}\overline{y}^{\xi-1}(\ddot{c}_t - \overline{c}) + \frac{\overline{\theta}\overline{c}}{\overline{a}^2}\overline{y}^{\xi-1}(a_t - \overline{a}) \\ &- (\xi-1)\frac{\overline{\theta}\overline{c}}{\overline{a}}\overline{y}^{\xi-2}(\ddot{y}_t - \overline{y}) + \frac{\phi}{\overline{\pi}}(\pi_t - \overline{\pi}) + 0 + 0 + 0 \\ &- \beta\phi\frac{(\pi_{t+1} - \overline{\pi})}{\overline{\pi}} \end{aligned}$$

$$f(\cdot) \approx \left(\frac{1}{\bar{\bar{\theta}}}\right)(\theta_t - \bar{\theta}) + \phi\frac{\pi_t - \bar{\pi}}{\bar{\pi}} - \beta\phi\frac{(\pi_{t+1} - \bar{\pi})}{\bar{\pi}} - \frac{\bar{\theta}}{\bar{a}}\bar{y}^{\xi}\frac{\ddot{c}_t - \bar{c}}{\bar{c}} - (\xi - 1)\frac{\bar{\theta}}{\bar{a}}\bar{y}^{\xi}\frac{\ddot{y}_t - \bar{y}}{\bar{y}} + \frac{\bar{\theta}}{\bar{a}}\bar{y}^{\xi}\frac{a_t - \bar{a}}{\bar{a}}$$

$$f(\cdot) \approx \tilde{\theta}_t + \phi\tilde{\pi}_t - \beta\phi\tilde{\pi}_{t+1} - \frac{\bar{\theta}}{\bar{a}}\bar{y}^{\xi}(\xi\tilde{y}_t - \tilde{a}_t) = \tilde{\theta}_t + \phi\tilde{\pi}_t - \beta\phi\tilde{\pi}_{t+1} - \xi(\bar{\theta} - 1)\tilde{o}_t$$

Thus,

$$0 = \tilde{\theta}_t + \phi\tilde{\pi}_t - \beta\phi E_t\tilde{\pi}_{t+1} - \xi(\bar{\theta} - 1)\tilde{o}_t$$

Finally,

$$\tilde{\pi}_t = \beta E_t\tilde{\pi}_{t+1} + \psi\tilde{o}_t - \tilde{e}_t$$

where

$$\psi = \frac{\xi(\bar{\theta} - 1)}{\phi} \text{ and } \tilde{e}_t = \frac{1}{\phi}\tilde{\theta}_t$$

- $g_t = \dfrac{\ddot{y}_t\ddot{z}_t}{\ddot{y}_{t-1}}$

Taking natural logarithm of both sides gives

$$\ln(g_t) = \ln(\ddot{y}_t) + \ln(\ddot{z}_t) - \ln(\ddot{y}_{t-1})$$

At steady state:

$$\ln(\bar{g}) = \ln(\bar{y}) + \ln(\bar{z}) - \ln(\bar{y})$$

$$\Rightarrow \ln(g_t) - \ln(\bar{g}) = \ln(\ddot{y}_t) - \ln(\bar{y}) + \ln(\ddot{z}_t) - \ln(\bar{z}) - (\ln(\ddot{y}_{t-1}) - \ln(\bar{y}))$$

$$\Rightarrow \tilde{g}_t = \tilde{y}_t - \tilde{y}_{t-1} + \tilde{z}_t$$

- $o_t = \dfrac{\ddot{y}_t}{a_t^{\frac{1}{\xi}}}$

Applying the same method as above we obtain

$$\tilde{y}_t = \frac{1}{\xi}\tilde{a}_t + \tilde{o}_t \Rightarrow E_t\tilde{y}_{t+1} = \frac{1}{\xi}E_t\tilde{a}_{t+1} + E_t\tilde{o}_{t+1}$$

- $\ln(a_t) = (1 - \rho_a)\ln(\bar{a}) + \rho_a\ln(a_{t-1}) + \varepsilon_{at}$

$$\Rightarrow \ln(a_t) - \ln(\bar{a}) = \rho_a(\ln(a_{t-1}) - \ln(\bar{a})) + \varepsilon_{at}$$

$$\Rightarrow \tilde{a}_t = \rho_a\tilde{a}_{t-1} + \varepsilon_{at}$$

$$E_t \ln(a_{t+1}) - \ln(\bar{a}) = \rho_a[\ln(a_t) - \ln(\bar{a})] \Rightarrow E_t\tilde{a}_{t+1} = \rho_a\tilde{a}_t$$

- $\ln(\theta_t) = (1 - \rho_\theta)\ln(\bar{\theta}) + \rho_a \ln(\theta_{t-1}) + \varepsilon_{\theta t}$

Applying the same method as above results in

$$\tilde{\theta}_t = \tilde{\theta}_{t-1} + \varepsilon_{\theta t}$$

Furthermore,

$$E_t \ln(\theta_{t+1}) - \ln(\bar{\theta}) = \rho_\theta[\ln(\theta_{t-1}) - \ln(\bar{\theta})] \Rightarrow E_t\tilde{\theta}_{t+1} = \rho_\theta\tilde{\theta}_t$$

- $\ln(\ddot{z}_t) = \ln(\bar{z}) + \varepsilon_{zt} \Rightarrow \tilde{z}_t = \varepsilon_{zt}$

Finally, the following linear system is obtained:

$$\tilde{o}_t = \alpha_o\tilde{o}_{t-1} + (1 - \alpha_o)E_t\tilde{o}_{t+1} - (\tilde{r}_t - E_t\tilde{\pi}_{t+1}) + (1 - \omega)(1 - \rho_a)\tilde{a}_t$$

$$\tilde{\pi}_t = \beta E_t\tilde{\pi}_{t+1} + \psi\tilde{o}_t - \tilde{e}_t$$

$$\tilde{g}_t = \tilde{y}_t - \tilde{y}_{t-1} + \tilde{z}_t$$

$$\tilde{o}_t = \tilde{y}_t - \omega\tilde{a}_t$$

$$\tilde{a}_t = \rho_a\tilde{a}_{t-1} + \varepsilon_{at}$$

$$\tilde{\theta}_t = \tilde{\theta}_{t-1} + \varepsilon_{\theta t}$$

$$\tilde{z}_t = \varepsilon_{zt}$$

and the Taylor rule

$$\tilde{r}_t = \rho_r\tilde{r}_{t-1} + \rho_\pi\tilde{\pi}_t + \rho_g\tilde{g}_t + \rho_o\tilde{o}_t + \varepsilon_{rt}$$

where $\omega = \frac{1}{\xi}$

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