Optimal Monetary and Fiscal Policy Analysis for Sri Lanka;
a DSGE Approach

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Abstract

This paper provides welfare maximizing optimal monetary and fiscal policy rules for Sri Lanka, in a New Keynesian Dynamic Stochastic General Equilibrium (DSGE) model, closely following Schmitt-Grohe and Uribe (2007). A standard Taylor rule type monetary policy reaction function where the nominal interest rate responds to inflation deviations and output gap, and a fairly simple fiscal policy reaction function in which tax revenue depends on the level of total government liabilities are used. The deep structural parameters of the model are calibrated to the Sri Lankan economy. To conduct welfare analysis, equilibrium solutions to the model are approximated up to second order accuracy. The optimal solution coefficients for the policy reaction functions are determined such that the welfare associated with the optimal policy rules delivers virtually the same level of welfare associated with the Ramsey optimal allocation. The monetary and fiscal policy rules that are optimal within a group of implementable and simple rules are then proposed for the Sri Lankan economy.

JEL Classification: C6; E5; E6; H2; I3

Key words: Dynamic Stochastic General Equilibrium (DSGE) Models, Monetary Policy, Fiscal Policy, Calibration, Welfare.

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I   INTRODUCTION

There is an increasing trend of using DSGE models in the central banks all over the world, as they provide coherent framework for policy discussion and analysis (Tovar, 2009). Even in the South Asian region, central banks of few countries have initiated use of DSGE models for the said purpose very recently (Ahmed et al (2013), for instance). In Sri Lanka, there is a growing awareness of DSGE literature among the central bankers/ macroeconomists and academics though there is only one published literature available so far on Sri Lanka specific DSGE studies, to best of my knowledge; Anand, Ding and Peiris (2011) [2]. The present paper, a medium scale closed economy DSGE model based study, is an attempt to fill this gap[3].

In this paper, optimal monetary/ fiscal policy rules which ensure welfare maximization, within a group of simple and implementable policy rules, in the Sri Lankan context is studied. Findings suggest that optimal monetary policy features an aggressive response to inflation, weak response to output and a fairly strong interest rate smoothing while fiscal policy features a moderate response of tax revenue to changes in government liabilities.

The rest of the paper is arranged as follows: Section II reviews literature, Section III explains the model, Section IV describes parameter calibrations and welfare calculations, Section V presents results of optimal policy with sensitivity analysis and Section VI concludes.

II   LITERATURE REVIEW

Modeling tools in macroeconomics have undergone remarkable changes over the last three decades. Failure of large-scale macroeconomic models in early 1970s, triggered the need for an alternative approach which is immune against the Lucas critique[4]. *Rational expectations hypothesis* revolution emerged during the same period lead to a paradigm shift in macroeconomic thinking. In this background, an innovative solution was suggested by Kydland and Prescott (1982), with a new form of a model where economic agents optimize their behaviors incorporating rational expectations in a Dynamic Stochastic General

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2 They develop a forecasting and policy analysis system (FPAS) and provide a forecast for inflation and a framework to evaluate policy trade-offs. Their model simulations suggest that an open-economy inflation targeting rule can reduce macroeconomic volatility and anchor inflationary expectations given the size and type of shocks faced by the economy.

3 In this 7th International Research Conference of the Central Bank of Sri Lanka, where the this paper is presented, another DSGE paper on the Sri Lankan economy has also presented (Karunaratne and Pathberiya, 2014), however, it abstracts from fiscal policy and optimal policy analysis.

4 The Lucas critique stress the importance that econometric policy evaluation procedures should be able to identify the corresponding variations in optimal decision rules of economic agents, with changes in policy (Lucas Jr (1979)).

Equilibrium (DSGE) framework. This innovation facilitated studying macroeconomic fluctuations effectively, leads to a novel family of macroeconomic models widely known as Real Business Cycle (RBC) models.

Improving the initial RBC framework, by incorporating imperfections and rigidities with new assumptions was a crucial step in macroeconomic modeling which eventually leads to the tradition of New-Keynesian (NK) Macroeconomics. These models still share the microfoundations and DSGE structure inherited from the RBC modeling, however, with nominal and real rigidities and various distortions. Some authors, for example Goodfriend and King (1997), therefore called the new paradigm as the *New Neoclassical Synthesis*. Previous restrictive assumptions in RBC models are relaxed under the scheme to accommodate various imperfections and Gali (2009), argues that monopolistic competition, nominal rigidities and short run non-neutrality of money are the three most important key elements of them[5].

The objective of monetary policy is to determine optimal rules which ensure welfare maximization while maintaining low and stable inflation and a level of output close as possible to its potential level. In achieving this objective many central banks use Taylor Rule[6] type policy reaction functions where the monetary policy instrument of the central bank, nominal interest rate, reacts to the desired target variables, inflation and output gap, in most of the cases. In contrast to pure RBC models, inclusion of nominal rigidities and the implied non-neutrality of monetary policy in the NK DSGE models allow monetary authority to make possible welfare improving interventions, by minimizing such distortions[7]. This desirable property influenced the usage of NK DSGE models widely in the central banks since the banks can now include the monetary policy reaction functions in the model connecting its objectives to the monetary policy instruments, effectively. Conduct of monetary policy under the NK school of thought is therefore characterized with maintaining low and stable inflation while making output as close as possible to its potential level (for examples in; Clarida et al. (1997, 1998, 1999, 2001), and Svensson (2000, 2002, 2003)).

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[5] For details, see for example Mankiw and Romer (1991).

[6] Taylor (1993) characterized the monetary policy rule followed by the Federal Reserve Bank of the USA (Fed) for the period 1987 to 1992, by modeling nominal interest rate as a liner function of inflation and output gap.

[7] Several early empirical studies including Cecchetti (1986), Kashyap and Stein (1995), Taylor (1993) and Woodford, 2001 for example concluded that there is ample evidence of price stickiness.

Development of the NK DSGE models with explicit theoretical foundations facilitated counter factual policy experiments (for instance, Christiano et al. (2005), Smets and Wouters (2003, 2007)) and explained transmission of various shocks across different sectors of the economy as well. This is a practically useful feature and Gali and Gertler (2007) state that a *tell-tale sign* which these frameworks possess is attributable for their widespread use at central banks in the process of monetary policy implementation.

As pointed out by Schmitt-Grohe and Uribe (2007), early studies of optimal monetary policy with NK DSGEs, however, use highly stylized theoretical policy environments, where; (i) government can subsidize factor inputs, financed with lump-sum taxes, aimed at removing inefficiency introduced by imperfect competition in product and factor markets, (ii) absence of capital accumulation, (iii) fiscal policy is always non-distorting and passive[8] in the sense of Leeper (1991) (iv) restrictions on inflation such as long run inflation is zero, and (v) zero demand for money. These unrealistic assumptions are made purely due to a technical reason. With these rigid restrictions, first order approximations to the equilibrium conditions are sufficient to evaluate welfare. With the use of second order approximations to the equilibrium conditions, Schmitt-Grohe and Uribe (2007) relax all of the above strong assumptions and to approximate welfare up to second order accuracy[9].

III MODEL

This is a closed economy DSGE model in the spirit of Schmitt-Grohe and Uribe (2007). Variations thereof have been incorporated in to the parameter values such that the model matches with Sri Lankan economy.

The economic environment of the model is a standard neoclassical growth model augmented with a number of real and nominal frictions (neo-Keynesian features). The main structure of the model is a real business cycle (RBC) framework incorporated with capital accumulation and endogenous labor hours. Technology and government purchase shocks act as the driving forces in the model while the following five factors of inefficiencies differentiate the model from the conventional RBC model: (i) nominal rigidities due to price stickiness (ii) a demand for money by the firms due to working capital constraints on labour costs (iii) a demand for

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[8] Empirical studies, however, show that post war US fiscal policy is not passive always (for example, Favero and Monacelli (2003, 2005)).

[9] For second order approximations to welfare, the methodology specified in Schmitt-Grohe and Uribe (2004) is used.

money by the households motivated by a cash in advance constraint (iv) monopolistically competitive product market and (v) time dependent distortionary taxation.

III A. Households

The economy consists of a continuum of identical households each of which has preferences that depends on consumption, c_t, and labor hours, h_t. The corresponding utility function which explains preferences is given by,

$$E_t \sum_{t=0}^{\infty} \beta^t U (c_t , h_t) \tag{1}$$

where, E_t represents the expectations operator, conditional on information accessible at time t, the subjective discount factor $\beta \in (0, 1)$ and U represents a period utility function, strictly concave and, strictly increasing with the first argument, c_t, and strictly decreasing with the second argument, h_t. The consumption good is a combination of goods (composite good) assumed to be produced by a continuum of differentiated goods, cit , where $i \in (0, 1)$. By using the Dixit Stiglitz aggregator (Dixit Stiglitz, 1977) consumption can be represented as;

$$c_t = \left[\int_0^1 c_{it}^{1-1/n} \, di \right]^{1/(1-1/\eta)} \tag{2}$$

where η denotes the intertemporal elasticity of substitution across different varieties of consumption goods. Purchases made in any variety i, in period t must solve the twin problem of minimizing the total expenditure; $\int_0^1 P_{it} C_{it} di$, subject to the condition (2) above, for a given level of consumption of the composite good, where P_{it} represent the nominal price of a good variety i at time t. Accordingly, the optimal price level of c_{it} can be represented as;

$$c_{it} = \left(\frac{P_{it}}{P_t} \right)^{-\eta} c_t \tag{3}$$

where P_t is a nominal price index of the form;

$$P_t \equiv \left[\int_0^1 P_{it}^{1-\eta} \, di \right]^{1/(1-\eta)} \tag{4}$$

Households expenditure on consumption are subjected to a cash in advance constraint given by;
$$m_t^h \geq v^h c_t \tag{5}$$

where m_t^h represents real money stock held by the household in given period t and v^h is a positive parameter which represents the fraction of consumption that can be covered by the money holdings.

The households are then subject to the period by period budget constraint given by,

$$E_t d_{t,t+1} \frac{x_{t+1}}{P_t} + m_t^h + c_t + i_t + \tau_t^L = \frac{x_t}{P_t} + \frac{P_{t-1}}{P_t} m_{t-1}^h + (1 - \tau_t^D)[\omega_t h_t + u_t k_t] + \delta \tilde{q}_t \tau_t^D k_t + \tilde{\emptyset}_t \quad (6)$$

where $d_{t,s}$ is a stochastic discount factor such that $E_t d_{t,s} x_s$, is the nominal value of a random nominal payment x_s in period t, such that $s \geq t$. Also, i_t denotes gross investment, τ_t^L represents lump-sum taxes, τ_t^D represents distortionary taxes, k_t denotes capital, $\delta \tilde{q}_t \tau_t^D k_t$ denotes a depreciation allowances for tax purposes, $\tilde{\emptyset}_t$ denotes profits received from the firms, after income tax. Capital stock depreciates at a constant rate δ and the capital stock is assumed to be evolved as follows;

$$k_{t+1} = (1 - \delta)k_t + i_t \, \Psi\left(\frac{i_t}{i_{t-1}}\right) \quad (7)$$

Few assumptions are made on the function Ψ to make sure that no adjustment cost in the vicinity of the deterministic steady state[10].

The investment good is also a composite one made with the same aggregate function given above. The demand for the intermediate good $i \in (0,1)$ for investments i_{it} is given $i_{it} = \left(\frac{P_{it}}{P_t}\right)^{-\eta} i_{it}$. The households are facing with the problem of maximizing utility, subject to the three constraints given above (equations 5, 6 and 7). Further, households are also facing with a borrowing limit to ensure that they do not engage in Ponzi schemes. Selecting $\varsigma_t \lambda_t \beta^t, \lambda_t \beta^t, \lambda_t \beta^t$ and $q_t \lambda_t \beta^t$ as the Lagrange multipliers corresponding to the above three constraints respectively, the Lagrangian for the households can be expressed as;

$$L = E_t \sum_{t=0}^{\infty} \left\{ \beta^t U\left(c_t, h_t\right) - \varsigma_t \lambda_t \beta^t \left(v^h c_t - m_t^h\right) \right.$$

$$-\lambda_t \beta^t \left[E_t d_{t,t+1} \frac{x_{t+1}}{P_t} + m_t^h + c_t + i_t + \tau_t^L - \frac{x_t}{P_t} - \frac{P_{t-1}}{P_t} m_t^h - (1 - \tau_t^D)(w_t h_t + u_t k_t) - \right.$$

$$\delta \tilde{q}_t \tau_t^D k_t + \tilde{\emptyset}_t \left] - q_t \lambda_t \beta^t \left[k_{t+1} - (1 - \delta)k_t - i_t \psi\left(\frac{i_t}{i_{t-1}}\right) \right] \right\}$$

Then the first order condition (FOC) with respect to consumption yields,

$$U_c(c_t, h_t) = \lambda_t \left(1 + v^h \varsigma_t\right) \quad (8)$$

Similarly, FOC w.r.t. labour hours (h_t) and money holdings (m^h) produces,

$$-U_h(c_t, h_t) = w_t \, (1 - \tau_t^D)\lambda_t \quad (9)$$

$$\lambda_t\left(1 - \varsigma_t\right) = \beta E_t \left\{\lambda_{t+1} \frac{P_t}{P_{t+1}}\right\} \quad (10)$$

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[10] It is assumed that the function Ψ satisfies $\Psi(1) = 1$, $\Psi'(1) = 0$, $\Psi''(1) < 0$.

The FOC w.r.t. x_{t+1} is given by; $\lambda_t d_{t,t+1} = \beta \lambda_{t+1} \frac{P_t}{P_{t+1}}$ and this relationship will be used in the next section. The FOCs w.r.t. investment (i_t) and capital (k_t) and can then be reduced to;

$$\lambda_t = \lambda_t q_t \left[\Psi\left(\frac{i_t}{i_{t-1}}\right) + \frac{i_t}{i_{t-1}} \Psi'\left(\frac{i_t}{i_{t-1}}\right) \right] - \beta E_t \left\{ \lambda_{t+1} q_{t+1} \left(\frac{i_{t+1}}{i_t}\right)^2 \Psi'\left(\frac{i_{t+1}}{i_t}\right) \right\} \tag{11}$$

$$\lambda_t q_t = \beta E_t \lambda_{t+1}[(1 - \tau_{t+1}^D)u_{t+1} + q_{t+1}(1 - \delta) + \delta \tilde{q}_{t+1}\tau_{t+1}^D] \tag{12}$$

Above first order conditions reveal that both the leisure/labor choice and capital accumulation over time are affected by income tax. Further, opportunity cost of holding money, $1/(1 - \zeta t)$, which is equal to the gross nominal interest rate. This distorts both the leisure/labor choice and intertemporal consumption allocation.

III B. The Government

The consolidated government in the model acts both as the monetary and fiscal authority. It prints money M_t, issues one-period nominally risk-free bonds B_t, receives tax revenue amounting to $(P_t \tau_t)$, and makes expenditure amounting to g_t. Hence, the period by period government budget constraint is given by;

$$M_t + B_t = R_{t-1}B_{t-1} + M_{t-1} + P_t g_t - P_t \tau_t$$

Where R_t is the risk free one period nominal interest rate (gross) in period t. It can be shown that $R_t = 1/E_t d_{t,t+1}$, when arbitrage is not allowed. Then, using the household first order conditions above, we get the Euler equation,

$$\lambda_t = \beta R_t R E_t \frac{\lambda_{t+1}}{\pi_{t+1}} \tag{13}$$

where $\lambda_t \equiv P_t/P_{t-1}$ is the gross inflation. We also assume that the public demand for each type i intermediate good is given by $g_{it} = \left(\frac{P_{it}}{P_t}\right)^{-\eta} g_t$, where g_t is the per capita government spending on a composite good produced by the Dixit Stieglitz aggregator[11].

$$l_t = \frac{R_t}{\pi_t} l_{t-1} + R_t(g_t - \tau_t) - m_t(R_t - 1) \tag{14}$$

where, $l_t \equiv (M_{t-1} + R_{t-1}B_{t-1})/P_{t-1}$ denote the outstanding real government liabilities at the end of the period $t-1$ and $m_t = M_t/P_t$, read money balance in circulation.

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[11] following Dixit and Stiglitz (1977).

Total tax revenue of the government consists of lump-sum tax revenue, τ_t^L and distortionary tax revenue $\tau_t^D y_t$, where τ_t^D and y_t represent distortionary tax rate and aggregate demand respectively. Accordingly, the aggregate government revenue can be denoted as,

$$\tau_t = \tau_t^D + \tau_t^D y_t \tag{15}$$

Fiscal authority sets a policy rule where the level of tax revenue in period t as a linear function of the outstanding total government liabilities as follow,

$$\tau_t - \tau^* = \gamma_1(l_{t-1} - l^*) \tag{16}$$

where, γ_1 is a parameter and the deterministic Ramsey steady-state values of τ_t and l_{t-1} are denoted by τ^* and l^* respectively. Fiscal policy rule, combined with the budget constraint above will then yield, $l_t = \frac{R_t}{\pi_t}(1 - \pi_r\gamma_1)\, l_{t-1} + R_t\,(\gamma_1 l^* - \tau^*)R_t g_t - m_t(R_t - 1)$. Following the active/ passive terminology of Leeper (1991), for monetary/ fiscal policy regimes, fiscal policy is said to be passive when $\gamma_1 \in (0, 2/\pi^*)$. When γ_1 falls in this region, in a stationary equilibrium near the deterministic steady state, deviations of real government liabilities from the steady-state level, grow at a rate less than the real interest rate. Thus, the present discounted government liabilities converge to zero over time, irrespective of the monetary policy stance. On contrary, when γ_1 falls outside this region, where fiscal policy is active, government liabilities will grow contentiously without diminishing over time.

Again, following Schmitt-Grohe and Uribe (2007), a monetary policy rule analogues to that of Taylor (1993) type rules, where monetary authority sets nominal interest rate according to the following simple feedback rule is considered.

$$ln(R_t/R^*) = \alpha_R\, ln(R_{t-1}/R^*) + \alpha_\pi E_t ln(\pi_{t-i}/\pi^*) + \alpha_y E_t ln(y_{t-i}/y^*); \quad i = -1,0,1 \tag{17}$$

where, y^* represents the level of aggregate demand at Ramsey steady-state and $R^*, \pi^*, \alpha_R, \alpha_\pi$ and α_y are parameters. This analysis is, however, limited to contemporaneous case $(i = 1)$, to make this study simple.

III C. Firms

In this economy, each good variety $i \in (0,1)$ is produced by a single firm using capital and labor as factor inputs. These firms operate in a monopolistically competitive environment. Thus the production function takes the following form;

$$z_t F\left(k_{it}, h_{it}\right) - \chi,$$

where, z_t represents the aggregate productivity shock which is exogenous. The function F is concave and strictly increasing in both capital and labor and the parameter χ represents the fixed costs of production. The summation of private and public absorption of good i (the aggregate demand for the good i) is then given by;

$$a_{it} = \left(\frac{P_{it}}{P_t}\right)^{-\eta} a_{t,}$$

where, $a_{it} \equiv c_{it} + i_{it} + g_{it}$. Wage payments in the firms are governed by the cash in advance constrain, as follows;

$$m_{it}^f \geq v^f w_t h_t, \tag{18}$$

where $m_{it}^f \equiv M_{it}^f / P^t$ is the real money balance demanded by the firm i in period t and $v^f \geq 0$ is a parameter denoting the fraction of wages supported with money.

The period-by-period budget constraint for the firm i can then be represented as,

$$M_{it}^f + B_{it}^f = M_{it-1}^f + R_{t-1}^f + P_{it}a_{it} - P_t u_t k_{it} - P_t w_t h_{it} - P_t \emptyset_{it}$$

where, B_{it}^f is the bond holdings of firm i in the period t and we assume that the initial financial wealth of the firm is zero (i.e. $M_{i,-1}^f + R_{-1}B_{i,-1}^f = 0$). Moreover, firms hold no financial wealth in the beginning of any period (i.e. $M_{it}^f + R_t B_{it}^f = 0$). With these assumptions, the budget constraint given above can be used to obtain the real profits of firm i at time t, as follows;

$$\emptyset_{it} \equiv \frac{P_{it}}{P_t} a_{it} - u_t k_{it} - w_t h_{it} - \left(1 - R_t^{-1}\right) m_{it} \tag{19}$$

It is further assumed that firms produce to meet the demand at the given price, which implies that,

$$z_t F\left(k_{it}, h_{it}\right) - \chi \geq \left(\frac{P_{it}}{P_t}\right)^{-\eta} a_{t,} \tag{20}$$

Now, the objective of the firm is to maximize the present discounted value of the profits;

$$E_t \sum_{s=t}^{\infty} d_{t,s} P_s \emptyset_{is,}$$

Choosing the contingent plans for P_{it}, h_{it}, k_{it} and m_{it}^f.

An equilibrium with strictly positive nominal interest rate is desired since this ensures that the cash-in-advance constraint is always binding. The first order conditions with respect to capital and labor services, for the firm's profit maximization problem are then given by,

$$mc_{it}z_{it}F_h(k_{it}, h_{it}) = w_t \left[1 + \; v^f \frac{R_t - 1}{R_t}\right],$$

$$mc_{it}z_t F_k(k_{it}, h_{it}) = u_t$$

respectively. Here we select the Lagrangian multiplier corresponding to the constraint given in the equation (20) above as $d_{ts}P_s mc_{is}$.

In line with Calvo (1983) and Yun (1996), prices are assumed to be sticky where a randomly selected portion of the firms, $\alpha \in [0,1)$ is not allowed to adjust price of the goods it produces, in each period. The remaining $(1 - \alpha)$ firms, thus, selects prices optimally. Therefore, the chosen price $(\tilde{P}_t)$ maximizes.

$$E_t \sum_{s=t}^{\infty} d_{t,s} P_s \, \alpha^{s-t} \left\{\left[\left(\frac{\tilde{P}_{it}}{P_s}\right)^{-1-\eta} a_s - u_s k_{is} - w_s h_{is}\left[1 + v^f\left(1 - R_s^{-1}\right)\right]\right]\right.$$

$$\left.+mc_{is}\left[z_s F(k_{is}, h_{is}) - \; \chi \; - \; \left(\tfrac{\tilde{P}_{it}}{P_s}\right)^{-\eta} a_s\right]\right\} \tag{21}$$

Corresponding first order condition with respect to $\tilde{P}_{it}$ is given by,

$$E_t \sum_{s=t}^{\infty} d_{t,s} \, \alpha^{s-t} \left(\frac{\tilde{P}_{it}}{P_s}\right)^{-1-\eta} a_s \left[mc_{is} - \frac{\eta - 1}{\eta} \frac{\tilde{P}_{it}}{P_s}\right] \tag{22}$$

Above equation implies that a firm who can decide the price in current period will choose the price in such a way that a weighted average of the current and future expected differences between marginal costs and marginal revenue equal to zero.

IV COMPUTATION, CALIBRATION, AND WELFARE MEASURE

The aim of this study is to find the monetary and fiscal policy rules which are optimal and implementable, within a simple family defined by the above two policy equations. In line with Schmitt-Grohe and Uribe (2007), implementability requires satisfying three conditions; (a) The rule must ensure a unique solution in the vicinity of the of the rational expectations equilibrium. (b) The rule should produce non-negative equilibrium dynamics for the nominal

interest rate (since perturbation method used to approximate the solution demand non-negativity of equilibrium). (c) The policy coefficients should be in the range [0,3], for practical purposes[12].

The contingent plans for consumption and labor hours associated with an optimal policy should deliver the highest level of unconditional welfare (lifetime utility). Mathematically, we are interested in maximizing $E[V_t]$ which is given by;

$$V_t \equiv E_t \sum_{j=0}^{\infty} \beta^j U \left(c_{t+j}, h_{t+j}\right)$$

Time-invariant equilibrium of Ramsey optimal allocation is used as a benchmark for policy evaluation and welfare costs of conditional/ unconditional optimal policy relative to the Ramsey optimal allocation is then calculated.

The lifetime utility V_t is approximated, provided that the fairly complex nature of the economic setup in the model. A first order approximation is, however, insufficient since the policy regimes considered here deliver the same non-stochastic steady states up to first order. Up to first order, all those policies imply the same level of welfare. Therefore, V_t is approximated up to second order accuracy, to compare higher-order welfare effects corresponding to different policy rules. This, necessitates that the solution to the equilibrium conditions (policy functions) also be approximated up to second order. Hence, policy functions are calculated up to second-order accuracy, according to Schmitt-Grohe and Uribe (2004).

IV A.   Calibration and functional forms

The model is calibrated with Sri Lankan economy assigning suitable values for the deep structural parameters[13]. One challenge in applying the methodology to Sri Lanka is, however, the use of suitable deep structural parameters for the model, matching the actual characteristics of the Sri Lankan economy. When relevant information are not available for necessary parameters within Sri Lanka, thus, alternative approaches such as searching for suitable proxies or similar parameters from other studies on developing or developed countries together with intuition are used as applicable.

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[12] A policy rule with coefficients larger than 3 would probably be difficult to justify or convince when it comes to implementation.

[13] We use the unit of time as one quarter, in these calculations.

Quarterly subjective discount factor (β): This is one of the main structural parameter in the model and it is a measure of the economic agent's willingness to sacrifice their current utility for future utility. From the consumption Euler equation above (equation 13), it can be shown that, $1 = \beta R_t E_t \frac{1}{\pi_{t+1}}$, and at the steady state it reduces to, $\beta = 1/(1 + r)$, where r is the long run average net real interest rate. The quarterly subjective discount factor is computed by taking the inverse of the average real interest rate. The discount rate has been estimated using quarterly data from 1996 to 2012. Return on government treasury bills and change in CPI have been used to measure the nominal interest rate and inflation respectively and a value of 0.9854 is obtained for it. In a related study, Ahmed et al. (2012b) calculate the subjective discount factor For the US, Pakistan, South Africa, Thailand Korea and Malaysia as 0.9919, 0.9968, 0.9913, 0.9878, 0.9835 and 0.9841 respectively which are comparable with the value obtained here.

Fractions of consumption held in money (v^h) and wage payments held in money (v^f): A method for estimating the household's preference for holding money is given in Christiano et al. (2005). They estimate it by utilizing the money specific first order condition of the utility function. As in most of the other developing countries, limitation in data prevents using this method in Sri Lanka. Hence, results from similar studies in other developing countries are adopted and used here. In a recent study on the Pakistani economy, Ahmed et al. (2012b) used the value 0.25 for v^h. This value is taken from DiCecio and Nelson (2007) for UK, after experiencing the hindrance of data issues in Pakistan and failing to find any similar study in a developing country. The corresponding value used in Schmitt-Grohe and Uribe (2007), is 0.3496. Therefore, the average of the above two values (v^h)= 0.2998 seems to be reasonable for Sri Lankan economy. This says that households keep money balances capable of covering 29.98 percent of their quarterly consumption. The same value used by Schmitt-Grohe and Uribe (2007), for (v^f) (= 0.63) is adopted here due to unavailability of any similar study in a developing country.

Price Elasticity of demand (η): Following Basu and Fernald (1997), Schmitt-Grohe and Uribe (2007) set price elasticity of demand to 5, ensuring that at the steady state, the value added markup over marginal cost is at 25 percentage points. In a South African study, Fedderke and Schaling (2005) select a markup of 30 percent thereby ensuing price elasticity of demand to be 4.33. In his cross country study for a set of developing countries, on the contrary, Peters (2009) set markup to 20 percent imposing η to be 6, following Cook and Devereux (2006).

Accordingly, a value of 6 is assigned for η since it would be more suitable for a developing country like Sri Lanka.

The annual depreciation rate (δ): Typically in the business cycle literature, the annual depreciation rate is taken as 10 percent, for instance, Schmitt-Grohe and Uribe (2007) and Cook and Devereux (2006) etc. For developing countries, however, a slightly larger value is used in practice; for instance, 12.55 percent for Mexico by Garcia-Cicco et al. (2006) and 15 percent for Pakistan, by Ahmed et al. (2012a). In a recent study, Hevia and Loayza (2013) argue that given the war-related destruction of factories, transport facilities, buildings, and other forms of capital, a low depreciation rate (0.04 to 0.08, as in most of the literature) cannot be used for Sri Lanka. Accordingly, 15 percent (i.e. 3.75 percent quarterly) is used for the annual depreciation rate, which is in agreement with the above arguments.

Cost share of capital (θ): Empirical evidence in the U.S. reflects that wages represent about 70 percent of total cost. Accordingly, Schmitt-Grohe and Uribe (2007) set theta θ equals to 0.3. In a Pakistani study, Ahmed et al. (2012a) use a value of 0.5 for Pakistan. In another study on Monetary-Fiscal interaction in Indonesia, Hermawan and Munro (2008), use 0.38 for the cost share of capital. In line with these, a value of 0.40 is proposed for θ, which seems to be reasonable and comparable with the figures used in similar developing countries.

Price stickiness parameter (α): The Share of firms that can change their prices in each period, a measure of price stickiness, is a value that lies between 0 and 1. For Pakistan, Ahmed et al. (2012b) set 0.75 for it. In the related studies in the US, price stickiness parameter is commonly assigned a value of around 0.8 and a slightly lower value of 0.75 is adopted here, accommodating the fact a developing country with high inflation (compared to the most of the developed countries) may adjust prices quicker than that in a developed country. This value for α implies that on average, firms change prices in every 4 quarters.

Risk aversion parameter (σ): In a field experiments based study, Cardenas and Carpenter (2008), report that the coefficient of relative risk aversion in developing countries lies between 0.05 to 2.57. Harrison et al. (2005), estimate the risk aversion parameter in India to be 0.841. In a recent study, Ahmed et al. (2012b), estimate the parameter of constant relative risk aversion (CRRA) by using the Generalized Method of Moments (GMM) approach and use a value of 2 for σ, for simulations. Following these together with Schmitt-Grohe and Uribe (2007), a value of 2 for the risk aversion parameter is suggested to be reasonable for Sri Lanka. This is still within the range for a developing country, specified in Cardenas and

Carpenter (2008) and falls well within the range of values used in the business cycle literature.

Steady-state level of government purchase ($\bar{g}$): This can be approximated by the long-run average of the government final consumption expenditure which covers all government current expenditures for purchases of goods and services (including compensation of employees)[14]. Accordingly, the average of the government consumption expenditure, as a percentage of GDP, for the period of 1980 to 2013 which is for the purpose[15]

For the remaining deep structural parameters, the values used in Schmitt-Grohe and Uribe (2007) are used and the summary is given in the Table 1.

Table 1: Deep structural parameters

Parameter	Value	Description
σ	2	risk aversion parameter
θ	0.40	cost share of capital
β	0.9854	quarterly subjective discount rate
η	6	price elasticity of demand
$\bar{g}$	0.1014	steady-state level of government purchase
δ	0.0375	quarterly depreciation rate
v^f	0.6307	fraction of wage payment held in money
v^h	0.2998	fraction of consumption held in money
α	0.75	share of firms that can change their price in each period
γ	3.6133	preference parameter
ψ	0	investment adjustment cost parameter
χ	0.0968	fixed cost parameter
ρ_g	0.87	fiscal shock persistence parameter
$\sigma^{\in,g}$	0.016	standard deviation of innovation to government purchases
ρz	0.8556	productivity shock persistence parameter
$\sigma^{\in,z}$	0.0064	standard deviation of innovation to productivity

Source: various sources[16]

The steady-state debt to GDP ratio is assumed to be 69.1 percent. This is the average value of the debt to GDP ratio of Sri Lanka, between 1950 and 2013 period[17].

The period utility function used is in the following form,

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[14] It also includes most of the expenditure on national defense and security, but excludes government military expenditures that are part of government capital formation.

[15] source: The World Bank data: http://data.worldbank.org/indicator/NE.CON.GOVT.ZS/countries

[16] Different sources consists of authors calculations/ estimations and many other past studies, as explained above.

[17] source: Special Appendix Table 6, Annual Report - 2013, Central Bank of Sri Lanka

$$U(c, h) = \frac{[c(1 - h)^\gamma]}{1 - \sigma}$$

Excluding fixed costs, we assume a Cobb-Douglas type production function, F, which is given by; $(k, h) = k^\theta h^{1-\theta}$. The two shock processes, g_t and z_t are the driving forces of the model. Accordingly, government purchases takes a univariate autoregressive process of one lag (AR(1)),

$$\ln(g_t/\bar{g}) = \rho_g \, ln(g_{t-1}/\bar{g}) + \in_t^g$$

where, $\bar{g}$ is the steady state level of government purchases, which is a constant, and the AR(1) process co-efficient, ρ_g and the standard deviation of $\in_t^g$ are assigned values of 0.87 and 0.016 respectively. A similar AR(1) process is assumed for the productivity shock as well,

$$ln(z_t) = \rho_z \, ln(z_{t-1}) + \in_t^z$$

where, the co-efficient of the AR(1) process (ρ_z) and the standard deviation of $(\in_t^z)$ are set to 0.856 and 0.0064 respectively.

IV B. Welfare analysis

In line with the business cycles literature, welfare is defined as the lifetime utility, computed by taking the infinite discounted sum of single period utilities. The welfare cost of a given monetary/ fiscal regime against the time invariant equilibrium implied by the Ramsey policy (r) is first calculated and then the welfare loss associated with implementation of an alternative policy is evaluated. Therefore, welfare is defined under the Ramsey policy, conditional on a given state of the economy in the initial period, as follows;

$$V_0^r \equiv E_0 \sum_{t=0}^{\infty} \beta^t U \, (c_t^r, h_t^r)$$

where c_t^r and h_t^r are contingent plans of consumption and hours associate with Ramsey policy. Conditional welfare related to an alternative policy regime (a) can then be defined in a similar manner as,

$$V_0^a \equiv E_0 \sum_{t=0}^{\infty} \beta^t U \, (c_t^a, h_t^a)$$

All state variables are equal to their corresponding non-stochastic Ramsey steady state values at time zero. Thus, computing expected welfare conditional on the initials state

implies that we start from the same point for all different policies, Welfare cost of implementing an alternative policy regime, instead of the Ramsey policy, λ^c can then be defined as the fraction of Ramsey policy regime's consumption that a house hold would like to give up to be well off under regime '*a*', as under regime '*r*'.

Therefore, the welfare cost conditional on the initial state can be introduced to the above relationship as follows;

$$V_0^a \equiv E_0 \sum_{t=0}^{\infty} \beta^t U \ (1 - \lambda^c)(c_t^r, h_t^r) \tag{23}$$

The unconditional welfare cost measure cost measure λ^u is then introduced similarly by,

$$V_0^a \equiv E_0 \sum_{t=0}^{\infty} \beta^t U \ (1 - \lambda^u)(c_t^r, h_t^r) \tag{24}$$

Welfare costs, λ^c and λ^u are calculated up to second order accuracy by employing the method specified in Schmitt-Grohe and Uribe (2004 and 2007).

V   Results and Discussion

Three scenarios where monetary/ fiscal stances are different from each other, namely, a cashless economy, a monetary economy and an economy with cash and distortionary tax are analyzed here. In each of the three scenarios, two policy rules, one with a constrained optimal interest-rate feedback rule and the other with a non-optimized simple Taylor type rule, are considered. In the constrained optimal rule, the policy coefficients α_π, α_y and α_R which ensure welfare as close as possible to the level of welfare delivered by the time invariant Ramsey policy are determined. Welfare costs, both conditional and unconditional, associated with each of the policies are calculated as per the equations (23) and (24) above.

The properties of '*cashless*' and '*without fiscal policy*' economies are useful in understanding the properties of the economy, in a comparably simplified setup. The interest is however on the more realistic case where the economy contains both cash and distortionary tax. Accordingly, the main focus of the analysis is on the monetary economy with fiscal policy.

V A. Cashless economy

An economy without cash is considered here and accordingly, the condition, $v^h = v^f = 0$ is imposed in the model. Fiscal authority is passive and it collects lump-sum tax while there is no distortionary tax ($\tau^d = 0$). Fiscal policy rule is given by the equations (15) and (16) above where $\gamma_1 \in (0, 2/\pi^*)$. This model resembles the canonical neo-Keynesian model[18] descried in the studies, including Clarida et al (1999).

Fist panel in the Table 2 (Panel A), contains the results for the cashless case. The comparisons are made against the time invariant allocation associated with the Ramsey policy. Under cashless scenario, first we consider a constrained optimal monetary policy rule with interest rate smoothing (to allow for interest rate inertia). The optimal rule implies aggressive response to inflation with the highest possible value allowed for the coefficients[19] $\alpha_\pi = 3$. Numerical optimization delivers following values for the remaining two coefficients $\alpha_y = 0.003$ and $\alpha_R = 0.866$. These values are comparable with the results of Schmitt-Grohe and Uribe (2007)[20]. Welfare cost of the Taylor policy is considerably large, compared to the optimal policy which is also observed in Schmitt-Grohe and Uribe (2007), though the numbers are slightly different. These differences in the numbers are attributable to the corresponding difference in the parameters values used in the two studies.

Table 2: Optimal Policy Rules[21]

Description	α_π	α_y	α_R	γ_1	$(\lambda^c \times 100)$	$(\lambda^u \times 100)$
Panel A. *Cashless Economy*						
Ramsey Policy	-	-	-	-	0.000	0.000
Optimized Rule	3	0.003	0.866	-	0.002	0.006
Taylor Rule	1.5	0.5	-	-	0.366	0.458
Panel B. *Monetary economy*						
Optimized Rule	3	0.002	0.841	-	0.002	0.005
Taylor Rule	1.5	0.5	-	-	0.524	0.679

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[18] Technically, modeling the economy with a lump-sum tax under passive fiscal policy is equivalent to absence of the fiscal authority in the model.

[19] Considering the policy implementability in practice, the largest value of any coefficient in the policy rules is limited to 3.

[20] They report co-efficient values of α_y and α_R to the first two decimal places as 0.01 and 0.86 respectively.

[21] Results are reported up to three decimal places for all cases except for the pre-imposed values for the coefficients in the rules.

Panel C. *Monetary economy with Fiscal Policy with distortionary tax*					
Optimized Rule	3	0.012	0.621	0.423	0.013	0.015
Taylor Rule	1.5	0.5	-	0.691	0.024	0.035

Source: author's calculations

The significantly large value for interest-rate inertia suggested by the optimality condition means that the monetary policy reacts to interest rate intensively in the long run, rather than in the short run. Further, the coefficient of the lagged interest rate being less than unity suggests that the monetary authority is backward looking. Welfare cost in the optimal policy, compared to the Ramsey policy is negligibly small. The difference between the welfare associated with the optimal policy and the Ramsey policy implies that agents would be willing to sacrifice less than 0.003 percent (i.e. less than 3/1000 of a one percent) of their consumption stream under the Ramsey policy to be as well off as under the optimized policy.

V B. Monetary economy

In this section, values 0.6307 and 0.2998 are assigned for the fraction of wages held in money (v^f) and fraction of consumption held in money (v^h), respectively. The rest of the features of the model remain the same, as in the cashless case. The results of the monetary economy are shown in the panel B in the Table 2 above.

Now, there is a tradeoff between inflation stabilization and nominal interest rate stabilization. Inflation stabilization focuses on minimizing the distortion introduced by sluggish price adjustment while nominal interest rate stabilization aimed at reducing the distortions arising due to the two monetary frictions. Holding money is an opportunity cost which affects both the effective wage rate, through the working capital constraint of the firms and the leisure-consumption decision, through the cash-in-advance constraint faced by the households. Now, the desired inflation is not zero as in the cashless case; instead it is very slightly negative. The panel B, however, indicates that the above tradeoff is not quantitatively significant since there is no difference between the welfare losses in the two optimal policies; the one with cash and the other without cash (panel A and panel B optimal policy results). Similar to the cashless scenario, the inflation coefficient α_π takes its highest value 3 while the coefficient on output is negligible, ($\alpha_y = 0.003$), and the interest rate smoothing parameter is significantly large ($\alpha_R = 0.84$). Also, the welfare cost associated with the Taylor rule is greater in panel B, compared to that of panel A. This is attributable to the monetary distortions in the monetary economy.

V C.   Monetary economy with a fiscal feedback rule

The results discussed up to now are limited to the cases of passive fiscal policy where government solvency is guaranteed for any possible path of the price level. It is, however, important to know why the active fiscal policy scenario is not desirable. Thus, the economy is examined with a simple fiscal policy rule, which can either be active or passive[22], under lump-sum and distortionary taxes.

V C.1. Lump-sum taxation

First, passive fiscal policy scenario is considered. As in the above case, when $\gamma_I \in (0, 2/\pi*)$ and $(\tau^d = 0)$, the fiscal policy is passive (and when γ_I lies outside the range, fiscal policy is active). In the previous section it is found that optimal monetary/ fiscal rule combination characterizes an active monetary and a passive fiscal policy stance. In this scenario, the government collects lump-sum taxes and the fiscal policy which satisfies solvency using lump-sum tax is non-distorting. This is what happens when fiscal policy is passive. Accordingly, this case (passive fiscal policy with lump-sum tax) is same as the monetary economy without fiscal policy case above. Hence, the results are identical to that is given under panel B in the Table 2 above.

When fiscal policy is active, however, a different channel, unexpected variations in the price level on nominal asset holdings of the private households, is used to maintain fiscal solvency. For instance consider a simple case where all three policy coefficients are zero ($\alpha_\pi = \alpha_y = 0$ and $\gamma_1 = 0$) so that the primary fiscal balance is exogenous and the monetary policy is passive (takes a form of an interest rate peg). Now, to ensure fiscal solvency, the only action the government can do is to influence on the real value of the government liabilities which requires unexpected changes in the price level. In the economy which we consider here, price level increases amplify the magnitude of the distortions arising from the nominal rigidities present in the model. Therefore active fiscal policy where fiscal solvency is guaranteed by surprise inflations is suboptimal.

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[22] Active, passive monetary / fiscal policy definitions as per Leeper (1991)

V C.2. Distortionary taxation

This is the case where distortionary taxes are used to finance government expenditure while lump-sum taxes are absent. Thus, the equation (15) reduces to, $\tau_t = \tau_t^D y_t$. As in the above two cases, here also the Ramsey policy is used as the benchmark for comparison. The debt-to-GDP ratio is set to 69 percent at the non-stochastic steady state of the Ramsey equilibrium, which is the average value of it for Sri Lanka over the period 1950 to 2013. Again, there exists a tradeoff between the two policies: price stability, aiming at dampening the distortion due to price stickiness and zero nominal interest rate, focusing on minimization of the opportunity cost of holding money. Thus, the Ramsey steady state inflation rate is found to be -0.002 percent per year.

Given the fiscal and monetary policy rules are of the form specified in equations (16) and (17), we find the coefficients of them as follows;

$$ln(R_t/R^*) = 3ln(\pi_t/\pi^*) + 0.0.12\,ln\big((y_t/y^*) + 0.621\,ln(R_{t-1}/R^*\big)$$

and,

$$\tau_t - \tau^* = 0.423\,(1_{t-1} - l^*)$$

The key features of the optimal policy with distortionary tax case are much similar to that of lump-sum tax case. The optimized interest rule characterized with aggressive response to inflation and nearly-zero response to output. Optimal fiscal policy is passive since the response of tax revenue to change in government liabilities is about 42 percent only. The difference between welfare delivered by the optimal policy and Ramsey policy is negligible (only 0.015 percent of consumption per period).

The main features of the optimized monetary policy rule obtained in this economy are much similar to that we obtained for the economy with lump-sum taxes. It suggests an aggressive response to inflation and an extremely mild response to output; these features are in good agreement with the corresponding results of Schmitt-Grohe and Uribe (2007). It also features with a fairly strong interest rate smoothing characteristics. In contrast to Schmitt-Grohe and Uribe (2007), optimal fiscal policy rule suggests a little larger value of 0.423 for the policy coefficient γ_1. This, however, is still small enough to ensure that the fiscal policy is passive. The fairly large steady state level of debt for Sri Lanka (69 percent) is attributable to the difference in the values of the coefficients in the optimal fiscal policy rules in the two studies.

V D.   Sensitivity analysis of the parameters

Parameter values in any model are associated with some degree of uncertainty. This uncertainty is not limited to their forecasts, but to contemporaneous values that they yield as well. Sensitivity analysis is thus a useful tool in evaluating the results generated by models with inherent uncertainties, prior to making decisions and recommendations based on them. If parameters are uncertain, Pannell (1997) states that sensitivity analysis can give several helpful information, out of which one is the robustness of the optimal solution, in the face of different parameter values. Accordingly, in the optimal policy case for the monetary economy with fiscal policy, single factor sensitivity analysis is employed to check the change in welfare cost in response to a ten percent increase in the parameter values and the results are given in the Table 3 given below.

Table 3: Change in welfare cost, in response to a 10 percent

change in parameter values

Parameter	Value	Impact	
		Conditional	Unconditional
risk aversion parameter (σ)	2	0.006	0.001
cost share of capital (θ)	0.40	0.009	0.006
price elasticity of demand (η)	6	0.001	0.000
quarterly depreciation rate (δ)	0.0375	0.003	0.002
fraction of money-firms (v^f)	0.6307	0.004	0.003
fraction of money-household (v^h)	0.2998	0.004	0.003
price stickiness (α)	0.75	0.001	0.002
preference parameter (γ)	3.6133	0.011	0.007
fixed cost parameter (χ)	0.0968	0.005	0.003
persistence parameter (ρ_g)	0.87	0.023	0.035
std. dev. of innovation to g ($\sigma_{\epsilon,g}$)	0.016	0.008	0.007
persistence parameter (ρ_z)	0.8556	0.017	0.018
std. dev. of innovation to z ($\sigma_{\epsilon,z}$)	0.0064	0.001	0.002

Source: author's calculations

Results suggest that welfare cost is highly sensitive to the changes in some parameter values such as ρ_g and ρ_z while welfare cost is weakly sensitive to the changes in some other parameters, for instance, η and α. Accordingly, it is important to pay careful attention in

calibrating the former set of parameters since a minor deviation of such parameter values from their true value will reflect a large impact on welfare cost. The latter parameters set, on contrary, are more robust since a small change in their value alter the welfare cost outcome only marginally.

VI   Conclusion

In the present paper, an effort is made to characterize an optimal, simple and implementable policy rules for Sri Lanka, in a New Keynesian Dynamic Stochastic General Equilibrium framework (NK DSGM). Welfare maximizing monetary and fiscal policy rules are studied in a model with sticky prices, money and distortionary taxation with the deep structural parameters calibrated to the Sri Lankan economy.

Three scenarios where monetary/ fiscal stances are different from each other, namely, a cashless economy, a monetary economy and an economy with cash and distortionary tax are analyzed and the optimal policy rules in all three scenarios suggest that: (1) an aggressive response to inflation in the interest rate feedback rule, (2) a negligibly small response to output gap and (3) a significantly large response to interest rate inertia. Optimized simple monetary and fiscal policy rules deliver virtually the same welfare level as in the Ramsey optimal policy.

Sensitivity analysis of the parameters reveals that the welfare cost is highly sensitive to few of the parameters stressing the importance of calibrating parameters with caution.

Present study, however, is subjected to several challenges and limitations. To make the study simple, the analysis is restricted to only two forms of policy rules each with only contemporaneous variables. One can extend this study with lagged and forward looking terms in the monetary policy rules with different functional forms suitable for Sri Lanka[23]. Values for most of the deep structural parameters of the economy are obtained by calibrations, mostly adopted from similar studies in other countries, due to unavailability of necessary information in Sri Lanka. One can instead estimate the model parameters (at least some of them) by using Sri Lankan data, probably with Bayesian estimates in future studies. This study may also be extended to an open economy setup to see the possible dependencies of the policy rules on key external sector variables.

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[23] Results of the Sri Lankan studies on characterization of monetary policy rules, for instance Perera and Jayawickrama (2014), may be used on deciding possible functional forms of policy rules.

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Appendix 1: Impulse response functions

Figure 1: Impulse responses to a 1 percent productivity shock (Cashless Economy)
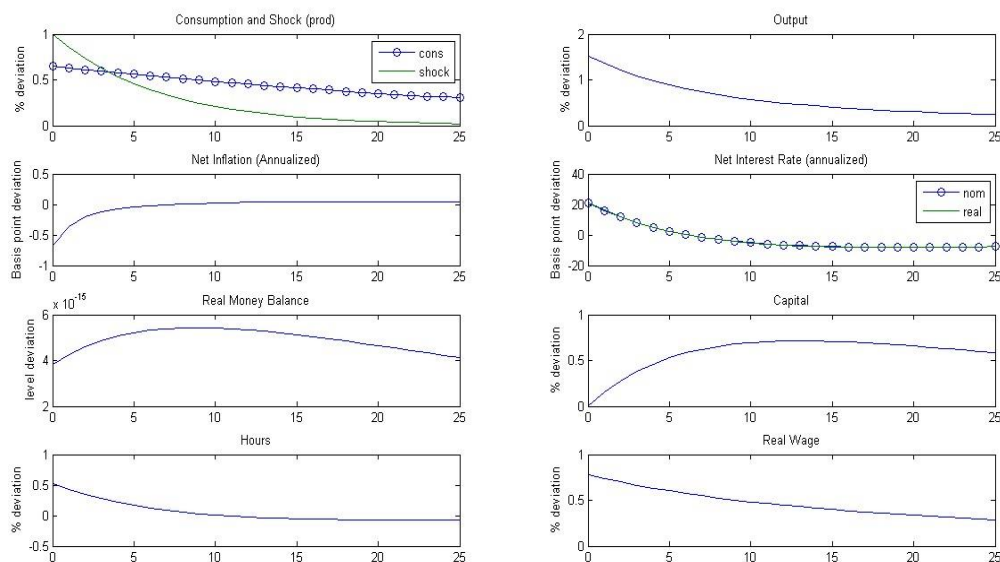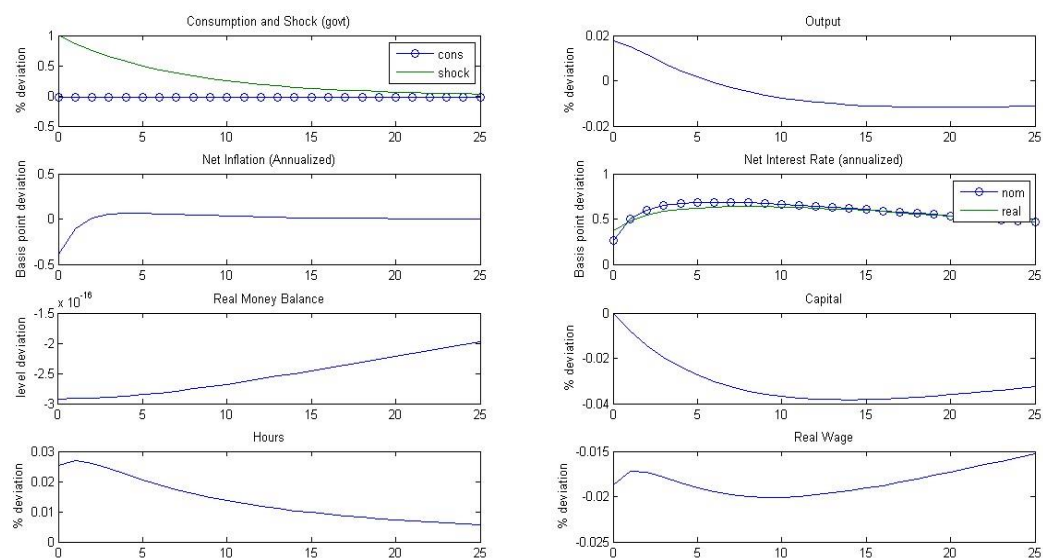

Figure 2: Impulse responses to a 1 percent government purchase shock (Cashless Economy)

Appendix 2: The Recursive Augmented Lagrangian

The recursive augmented Lagrangian for the optimal policy problem is as follows. In this Lagrangian, d_t is a vector of endogenous variables at time t while Λ_t is the vector of Lagrange multipliers chosen at time t. Here I am using the standard approach used by others, including Khan et al. (2003) and Schmitt-Groh´e and Uribe (2007).

$$U^*(\tilde{s}_t, \zeta_t) = \min_{\{\Lambda_t\}_{t=0}^{\infty}}, \max_{\{d_t\}_{t=0}^{\infty}} \left\{ \left[\frac{(c_t(1-h_t)^\gamma)^{1-\sigma}-1}{1-\sigma} \right] + \beta E_t U^*(\tilde{s}_{t+1}, \zeta_{t+1}) \right.$$

$$+\Omega_{1,t}\left(\frac{\lambda_t}{R_t}\right) - \Omega_{1,t-1}\left(\frac{\lambda_t}{\pi_t}\right)$$

$$+\Omega_{2,t}\left(-x_t^1 + \tilde{p}_t^{-1-\eta} y_t mc_t\right) + \Omega_{2,t-1}\left(\alpha\frac{\lambda_t}{\lambda_{t-1}}\pi_t^\eta \left(\frac{\tilde{p}_{t-1}}{\tilde{p}_t}\right)^{-1-\eta} x_t^1\right)$$

$$+\Omega_{3,t}\left(-x_t^2 + \tilde{p}_t^{-\eta} y_t\right) + \Omega_{3,t-1}\left(\alpha\frac{\lambda_t}{\lambda_{t-1}}\pi_t^{\eta-1} \left(\frac{\tilde{p}_{t-1}}{\tilde{p}_t}\right)^{-\eta} x_t^2\right)$$

$$+\Omega_{4,t}\left(-\lambda_t + \lambda_t q_t \left(\left(1 - \frac{\psi}{2}\left(\frac{i_t}{i_{t-1}}-1\right)^2\right) + \left(\frac{i_t}{i_{t-1}}\right)\psi\left(1 - \frac{i_t}{i_{t-1}}\right)\right)\right)$$

$$+\Omega_{4,t-1}\left(-\lambda_t q_t \left(\frac{i_t}{i_{t-1}}\right)^2 \psi\left(1 - \frac{i_t}{i_{t-1}}\right)\right)$$

$$+\Omega_{5,t}\left(\lambda_t q_t\right) + \Omega_{5,t-1}\left(\lambda_t \left((1 - \tau_t^D) u_t + q_t(1-\delta) + q_t\delta\tau_t^D\right)\right)$$

$$+\Omega_{6,t}\left(k_{t+1} - (1-\delta) k_t - i_t\left(1 - \frac{\psi}{2}\left(\frac{i_t}{i_{t-1}}-1\right)^2\right)\right)$$

$$+\Omega_{7,t}\left((c_t(1-h_t)^\gamma)^{-\sigma}(1-h_t)^\gamma - \lambda_t\left(1 + \nu^h\left(1 - R_t^{-1}\right)\right)\right)$$

$$+\Omega_{8,t}\left(-\gamma c_t^{1-\sigma}(1-h_t)^{\gamma-1-\gamma\sigma} + w_t\left(1 - \tau_t^D\right)\lambda_t\right)$$

$$+\Omega_{9,t}\left(l_t - \frac{R_t}{\pi_t}l_{t-1} - R_t(g_t - \tau_t) + m_t(R_t - 1)\right)$$

$$+\Omega_{10,t}\left(\tau_t - \tau_t^L - \tau_t^D y_t\right)$$

$$+\Omega_{11,t}\left(mc_t z_t(1-\theta)\left(\frac{k_t}{h_t}\right)^\theta - w_t\left(1 + \nu^f\left(1 - R_t^{-1}\right)\right)\right)$$

$$+\Omega_{12,t}\left(mc_t z_t\theta\left(\frac{k_t}{h_t}\right)^{\theta-1} - u_t\right)$$

$$+\Omega_{13,t}\left(m_t - \nu^h c_t - \nu^f w_t h_t\right)$$

$$+\Omega_{14,t}\left(\alpha\pi_t^{-1-\eta} + (1-\alpha)\tilde{p}_t^{1-\eta} - 1\right)$$

$$+\Omega_{15,t}\left(\frac{\eta}{\eta-1}x_t^1 - x_t^2\right)$$

$$+\Omega_{16,t}\left(y_t - \frac{1}{s_t}\left(z_t k_t^\theta h_t^{1-\theta} - \chi\right)\right)$$

$$+\Omega_{17,t}\left(y_t - c_t - i_t - g_t\right)$$

$$+\Omega_{18,t}\left(s_t - (1-\alpha)\tilde{p}_t^{-\eta} - \alpha\pi_t^\eta s_{t-1}\right)$$

$$\left. +\Omega_{19,t}\left(\tau_t^L - 0\right) \right\}$$