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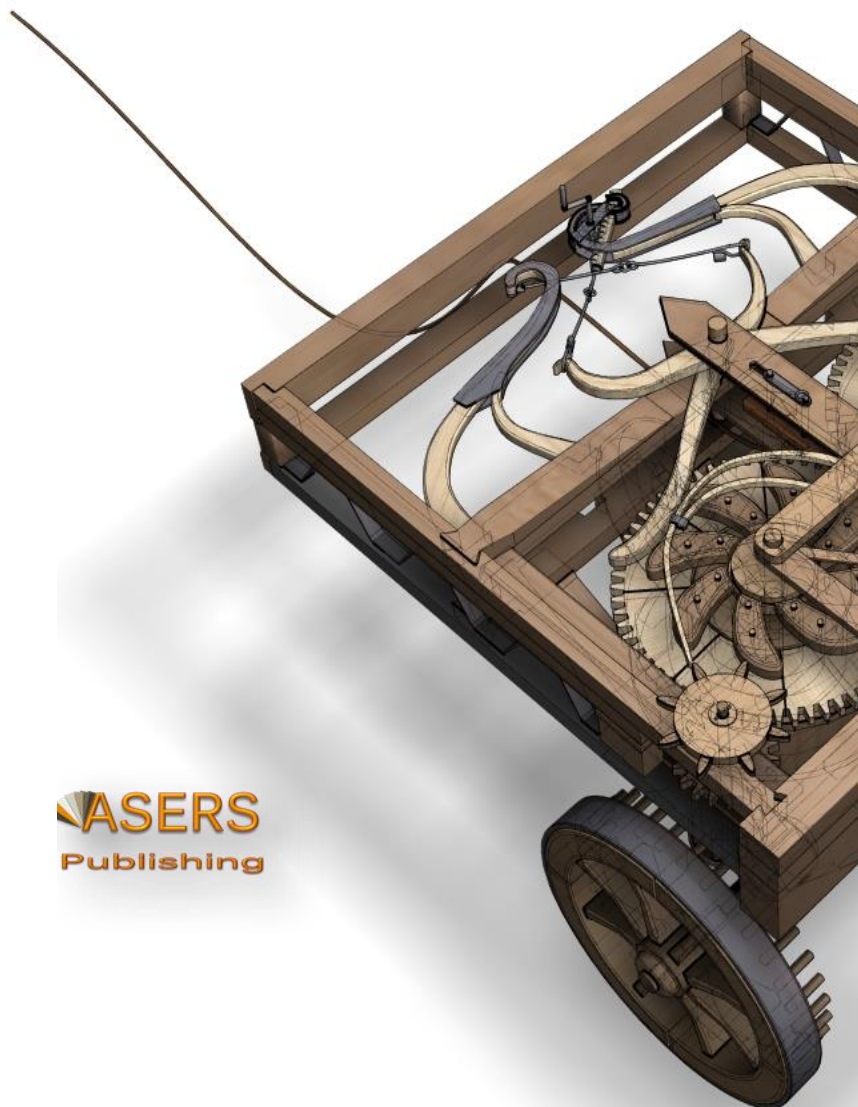
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A Basic Two-Sector New Keynesian DSGE Model of the Indian Economy

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Abstract: Indian economy is going through underlying changes in the post-pandemic recovery process. Effects of policies, monetary or fiscal, on macroeconomy need a thorough analysis in these recessionary times. In this context, this study develops a closed-economy DSGE model to see the impact of monetary policy on the Indian economy. The model includes price rigidities, and parameters are calibrated using the data on Indian economy. The model includes two sectors – intermediate goods and final goods producers, an inflation-targeting regime following the Taylor rule. Model is simulated for a positive productivity shock and an expansionary monetary policy shock. Results show that a positive productivity shock improves overall economic activity, and an expansionary monetary policy shock increases output for the short term only.

Keywords: DSGE models; monetary policy; general equilibrium; Indian economy; calibration.

JEL Classification: C32; E32; E37; E52; R11.

Introduction

One of the main objectives of macroeconomics is to learn how the overall economy works and to analyse how certain changes in one sector affect others and the economy as a whole. Like in natural sciences, economists are also interested in carrying out experiments to study the impacts of specific changes and disruptions on the economy. But unlike economics, researchers in other fields like Physics or Chemistry have the luxury of conducting experiments in laboratories where they can replicate real-world conditions and complete their experiments. The Dynamic Stochastic General Equilibrium or popular as DSGE models provide macroeconomists with such laboratories where they also conduct experiments to know in advance the effects of certain policy changes, disruptions and anticipated or unanticipated shocks at the aggregate level. We can call these models macroeconomic laboratories because they are grounded in microeconomic theory and construct a model economy in such a way that allows for more structural analysis and evolution of business cycles. Though prone to criticism, the DSGE approach is the core of present-day macroeconomic modelling.

The present study builds and calibrates a closed economy New-Keynesian DSGE model for the Indian economy. The Model presented in the later section is at an early stage and includes only two economic agents – households and firms along with a monetary authority which sets the interest rates. Model parameters are calibrated following the literature based on Indian quarterly data. Model is tested for productivity and monetary policy shocks. Results of our calibrated model are in line with the economic theory and existing literature on India. Impulse responses generated after productivity shock shows an increase in consumption and investment. An expansionary monetary shock increases output as well as inflation but decreases the demand for government bonds.

The paper is arranged in three sections. The following section gives a brief review of existing literature. Section two lays out the basic framework for the model with separate subsections dedicated to representative household, firm and monetary authority. Section 3 discusses the simulation results.

1. Literature Review

Kydland and Prescott (1982) were the first proponents of DSGE modelling. They originated out of the real business cycle (RBC) theory which argues that exogenous shocks can help explain economic fluctuations. RBC models held

unrealistic assumptions like perfect competition, absence of asymmetric assumptions etc. These assumptions have been relaxed in later New-Keynesian versions of DSGE models, which include nominal rigidities in pricing, investment adjustment costs and include different shocks to bring the models closer to the real economy as close as possible. More refined models by Christiano, Eichenbaum, and Evans (2005), Fernández-Villaverde and Rubio-Ramírez (2006), Smets and Wouters (2007) are some examples of DSGE models with New-Keynesian flavour.

There is a plethora of DSGE literature dedicated to explaining the business cycles in developed economies. But it is sparse in emerging market economies. These economies have different characteristics than developed ones. Developing nations economies face different frictions and distortions, which poses more challenges in developing such models. In the Indian context, DSGE literature is even sparser. In the first such attempts, Peiris, Saxegaard, and Anand (2010) estimate a small open economy DSGE model with macro-finance linkages for the Indian economy. They include a financial accelerator proposed by BGG (Bernanke, Gertler, and Gilchrist 1998) where firms can borrow in domestic as well as in foreign currency. They estimate the model using Bayesian for the post-1996 to 2008 data. V. J. Gabriel *et al.* (2011) build a more Indianised version of the DSGE model by including the informal sector and financial frictions due to the presence of credit-constrained consumers. They find that inclusion of financial friction and informal sector improves the model fit significantly. In later years, there have been efforts to develop DSGE models for specific objectives, such as to analyse monetary policy transmission, fiscal policy effects and impacts of financial intermediation on potential output growth. Banerjee, Basu, and Ghate (2020) try to understand weak aggregate demand channel of monetary policy transmission in India by building a New Keynesian monetary business cycle model. They calibrate the model using the quarterly data for 1996-2016 and find that informal sector hinders the monetary policy transmission in India. Sarkar (2020) calibrate the NK-DSGE model using Indian quarterly data to understand the short-run relationship between the stock market and economic growth. He incorporates the Lucas (1978) asset pricing framework within the general equilibrium model with two additional features of international borrowing and domestic shareholdings by foreign firms.

To trace the effects of COVID-19 pandemic, Sarkar (2022) builds a theoretical general equilibrium model to include three pandemic related shocks – obstruction of interregional migration, supply disruptions and reduced demand. He shows that supply shocks are contagious and create demand constraints in other sectors of the economy. He further finds that monetary transfers are helpful in mitigating unemployment and increasing output. Shah and Garg (2023) test the effectiveness of monetary and fiscal policy in the aftermath of COVID-19 in a New Keynesian DSGE framework. They find expansionary monetary policy to be more effective in growth revival from both demand and supply side, while expansionary fiscal policy to be effective from the demand side only. To trace the post-pandemic recovery, Sharma and Behera (2022) analyse the output gap using the DSGE model and find it to be superior to the traditional HP filter method.

Our paper contributes to this evolving DSGE literature for the Indian economy. We build a basic model to analyse different shocks, *i.e.*, productivity and monetary shocks. Our model can provide a basic structure to build upon and to include other economic agents, *i.e.*, government and the external sector.

2. Model

This section lays out the underlying DSGE model. We build a closed economy New-Keynesian DSGE model following Smets and Wouters (2007) and Costa (2018). Our model is in the early stage and consists of only two agents - households and firms. Model is discussed in the following subsections.

2.1 Households

There is a closed economy with no government sector. The economy is populated by a continuum of households indexed by $j \in [0, 1]$. The household maximises his utility function which is additively separable in consumption and labour. Household consumes goods and supply labour to the firms. Household maximises the following utility function:

$$\max_{C_{j,t}, L_{j,t}, B_t, K_{j,t+1}} u_t = E_t \sum_{t=0}^{\infty} \beta^t \left[\frac{C_{j,t}^{1-\sigma}}{1-\sigma} - \frac{L_{j,t}^{1+\psi}}{1+\psi} \right] \quad 2.1$$

where,

E_t – Expectation operator,

C – Consumption,

L – Labour supplied by household (in number of hours),

β – Discount Factor,

σ – Coefficient of relative risk-aversion (reciprocal to the elasticity of substitution of consumption),

ψ – Marginal disutility of labour (reciprocal to the elasticity of substitution of labour supply)

In line with the RBC models, the utility function chosen is a constant relative risk-aversion (CRRA)¹ utility function. CRRA utility functions are widely used in DSGE models because they are compatible with balanced growth² along with the optimal steady-state. It is a concave utility function with the properties of $u_C > 0, u_L < 0$ and $u_{CC}, u_{LL} < 0$. $u_L < 0$ means that labour has a negative effect on the utility *i.e.*, the more labour household supplies, less satisfaction he drives. Household maximises the utility function subject to the budget constraint:

$$P_t(C_{j,t} + I_{j,t}) + \frac{B_{j,t+1}}{r_t} = W_t L_{j,t} + R_t K_{j,t} + B_{j,t} + \Pi_t \quad 2.2$$

where,

P – General Price level

I – Investment

W – Wages

K – Capital Stock

B_t – One maturity bond issued by the government

R – Return on Capital

r – Interest rate set by the central bank

Π – dividends to households by firms

In budget constraint Equation 2.2, $\left(\frac{1}{r_t}\right)$ is the price of the government bond³. Our household derives his income from three sources - supplying labour, renting capital and holding the government bond. In the economy, capital is accumulated following the rule:

$$K_{j,t+1} = (1-\delta)K_{j,t} + I_{j,t} \quad 2.3$$

where δ is the depreciation rate of capital. Next, we form the Lagrangian to solve the above maximisation problem. After substituting $I_{j,t} = K_{j,t+1} - (1-\delta)K_{j,t}$ from Equation 2.3 in the budget constraint, Lagrangian is –

$$\mathcal{L} = E_t \sum_{t=0}^{\infty} \beta^t \left[\frac{C_{j,t}^{1-\sigma}}{1-\sigma} - \frac{L_{j,t}^{1+\psi}}{1+\psi} \right] - \lambda_{j,t} \left[P_t C_{j,t} + P_t K_{j,t+1} - P_t (1-\delta) K_{j,t} + \frac{B_{j,t+1}}{r_t} - W_t L_{j,t} - R_t K_{j,t} - B_{j,t} - \Pi_t \right] \quad 2.4$$

λ is the Lagrangian multiplier. First-order conditions for consumption, labour, capital and bond are:

$$\frac{\partial \mathcal{L}}{\partial C_{j,t}} = C_{j,t}^{-\sigma} - \lambda_{j,t} P_t = 0 \quad 2.5$$

$$\frac{\partial \mathcal{L}}{\partial L_{j,t}} = -L_{j,t}^{\psi} + \lambda_{j,t} W_t = 0 \quad 2.6$$

$$\frac{\partial \mathcal{L}}{\partial K_{j,t+1}} = -\lambda_{j,t} P_t + \beta E_t \lambda_{j,t+1} [(1-\delta)E_t P_{t+1} + E_t R_{t+1}] = 0 \quad 2.7$$

$$\frac{\partial \mathcal{L}}{\partial B_{j,t+1}} = -\frac{\lambda_{j,t}}{r_t} + \beta E_t \lambda_{j,t+1} = 0 \quad 2.8$$

from Equation 2.5 and 2.6, solving for λ gives the following equation:

$$C_{j,t}^{\sigma} L_{j,t}^{\psi} = \frac{W_t}{P_t} \quad 2.9$$

Equation 2.9 can be interpreted as the labour supply equation because it equates the marginal rate of substitution between consumption and leisure on the left-hand side to their relative prices on the right-hand side. In next step, we try to find the inter-temporal consumption/saving Euler equation. To get the Euler equation, we substitute the value of Lagrangian multiplier ($\lambda_{j,t}$) from Equation 2.5 in Equation 2.7. After some algebraic manipulation we get the Euler equation:

¹ Following (King, Plosser, and Rebelo 1988), (Gali and Monacelli 2008) and (Gertler and Karadi 2011) among others.

² In balanced growth, growth rate is constant at steady-state.

³ Bond price is inversely related to the interest paid on holding the bond.

$$\left(\frac{E_t C_{j,t+1}}{C_{j,t}}\right)^\sigma = \beta \left[(1-\delta) + E_t \left(\frac{R_{t+1}}{P_{t+1}}\right) \right] \quad 2.10$$

As we see, the above equation is an inter-temporal condition which can be interpreted that households must be indifferent between consuming one more unit today (in period t) and saving that unit, earning some interest on it, and then consuming it in the next period ($t+1$). From Equation 2.8, we can get the Euler equation for government bond:

$$\frac{\lambda_{j,t}}{r_t} = \beta E_t \lambda_{j,t+1} \quad 2.11$$

2.2 Firms

The proposed model is a New-Keynesian model. It features imperfect competition in the production sector. In NK models, prices are temporarily rigid and adjusts with a lag. We assume price stickiness in the model. There are two types of firms - final goods producing firms and intermediate goods producing firms. We discuss both types of firms as follows:

2.2.1 Final Goods Firms

Final goods producing firms operate in a perfectly competitive market. Firms follow Dixit-Stiglitz (Dixit and Stiglitz 1977) aggregator function:

$$Y_t = \left(\int_0^1 Y_{j,t}^{\frac{\xi-1}{\xi}} dj \right)^{\frac{\xi}{\xi-1}} \quad 2.12$$

where, $Y_{j,t}$ is intermediate good and Y_t is the final good after aggregating goods. $\xi > 1$ is the elasticity of substitution between intermediate goods. If P_t is the nominal price of final goods and $P_{j,t}$ is the price of intermediate goods, then the profit maximising problem of the final goods firm is:

$$\max_{Y_{j,t}} P_t Y_t - \int_0^1 P_{j,t} Y_{j,t} dj \quad 1.13$$

substituting the expression for Y_t from Equation 2.12 yields:

$$\max_{Y_{j,t}} P_t \left(\int_0^1 Y_{j,t}^{\frac{\xi-1}{\xi}} dj \right)^{\frac{\xi}{\xi-1}} - P_{j,t} \int_0^1 Y_{j,t} dj \quad 2.14$$

first order condition for the above problem leads to:

$$P_t \left(\int_0^1 Y_{j,t}^{\frac{\xi-1}{\xi}} dj \right)^{\frac{1}{\xi-1}} Y_{j,t}^{-\frac{1}{\xi}} - P_{j,t} = 0 \quad 2.15$$

rearranging the aggregator function in Equation 2.12 gives the following expression for Y_t :

$$Y_t^{\frac{1}{\xi}} = \left(\int_0^1 Y_{j,t}^{\frac{\xi-1}{\xi}} dj \right)^{\frac{1}{\xi-1}} \quad 2.16$$

substituting the R.H.S. of this equation in Equation 2.15 and after doing some algebraic manipulation gives the demand function for intermediate goods:

$$Y_{j,t} = Y_t \left(\frac{P_t}{P_{j,t}} \right)^\xi \quad 2.17$$

This demand function is directly proportional to aggregate demand Y_t and indirectly proportional to the relative price level. Now, substituting this expression for $Y_{j,t}$ back in the aggregator in Equation 2.12:

$$Y_t = \left[\int_0^1 \left\{ Y_t \left(\frac{P_t}{P_{j,t}} \right)^\xi \right\}^{\frac{\xi-1}{\xi}} dj \right]^{\frac{\xi}{\xi-1}} \quad 2.18$$

again, after some algebraic manipulation,

$$P_t = \left[\int_0^1 P_{j,t}^{1-\xi} dj \right]^{\frac{1}{1-\xi}} \quad 2.19$$

2.2.2 Intermediate Goods Firms

Firms in this sector produce differentiated intermediate goods and sell them to final goods producing firms. Due to the differentiated nature of their products, they enjoy some degree of market power. Therefore, there is monopolistic competition in this market structure. In first stage, intermediate firm determines the amount of labour and capital to minimise its production cost. Firms use both labour and physical capital and follow the Cobb-Douglas production function:

$$Y_{j,t} = A_t K_{j,t}^\alpha L_{j,t}^{1-\alpha} \quad 2.20$$

where, A_t is the technology and follows an AR(1) process:

$$\log A_t = (1-\phi_A) \log \bar{A} + \phi_A \log A_{t-1} + \epsilon_t \quad 2.21$$

where, \bar{A} is the productivity at steady-state, ϕ_A is the autoregressive parameter ϵ_t is the productivity shock with $\epsilon_t \sim N(0, \sigma_a)$. Cobb-Douglas production function has some properties - It is strictly increasing and concave function, which means $F_L, F_K > 0$ and $F_{LL}, F_{KK} < 0$. Production function gives constant returns to scale and follows Inada⁴ conditions. The problem of the firm is to minimise the production cost subject to the production function in Equation 2.20:

$$\min_{L_{j,t}, K_{j,t}} W_t L_{j,t} + R_t K_{j,t} \quad 2.22$$

subject to,

$$Y_{j,t} = A_t K_{j,t}^\alpha L_{j,t}^{1-\alpha} \quad 2.23$$

The Lagrangian for this problem is:

$$\mathcal{L} = W_t L_{j,t} + R_t K_{j,t} + v_{j,t} (Y_{j,t} - A_t K_{j,t}^\alpha L_{j,t}^{1-\alpha}) \quad 2.24$$

where, $v_{j,t}$ is the Lagrangian multiplier. First-order conditions for labour and capital are:

$$\frac{\partial \mathcal{L}}{\partial L_{j,t}} = W_t - (1-\alpha) v_{j,t} A_t K_{j,t}^\alpha L_{j,t}^{-\alpha} = 0 \quad 2.25$$

$$\frac{\partial \mathcal{L}}{\partial K_{j,t}} = R_t - \alpha v_{j,t} A_t K_{j,t}^{\alpha-1} L_{j,t}^{1-\alpha} = 0 \quad 2.26$$

Here, the Lagrange multiplier $v_{j,t}$ shows the shadow prices of change in the ratio of capital and labour used. Therefore, we can consider the Lagrangian multiplier as the marginal cost ($mc_{j,t}$). Now the above equations are:

$$L_{j,t} = (1-\alpha) mc_{j,t} \frac{Y_{j,t}}{W_t} \quad 2.27$$

and

⁴ $\lim_{L \rightarrow 0} F_L = \infty$; $\lim_{L \rightarrow \infty} F_L = 0$ and $\lim_{K \rightarrow 0} F_K = \infty$; $\lim_{K \rightarrow \infty} F_K = 0$ conditions.

$$K_{j,t} = \alpha mc_{j,t} \frac{Y_{j,t}}{R_t} \quad 2.28$$

Since total cost for the firm j is:

$$TC_{j,t} = W_t L_{j,t} + R_t K_{j,t} \quad 2.29$$

substituting Equation 2.27 and 2.28 in total cost function and dividing by output, we get the expression for the marginal cost:

$$mc_{j,t} = \frac{1}{A_t} \left(\frac{W_t}{1-\alpha} \right)^{1-\alpha} \left(\frac{R_t}{\alpha} \right)^\alpha \quad 2.30$$

2.2.3 Calvo Pricing

In the next stage, firm defines the prices of intermediate goods. In our model, we assume that firm decides the prices following the Calvo rule (Calvo 1983). Under this rule, in a period, only a fraction of total firms selected are allowed to change the prices when they receive the random signal. Remaining firms define their prices following the stickiness rule, like maintaining the previous period's price or updating the price based on previous period's inflation rate. We follow the previous period's price rule $P_{j,t} = P_{j,t-1}$ to introduce price stickiness.

Following the Calvo pricing rule, we assume that there is a φ probability that a firm keeps its price fixed in the next period and a $1-\varphi$ probability that it receives the random signal and resets the prices. For the firm which reset its prices, there is φ probability that the price remains fixed in time $t+1$ and φ^2 probability to remain fixed in $t+2$ and so on. The maximisation problem of the firm which reset its prices can be defined by subtracting total costs from the total revenue in the following way:

$$\max_{P_{j,t}^*} E_t \sum_{i=0}^{\infty} (\beta\varphi)^i (P_{j,t}^* Y_{j,t+i} - TC_{j,t+i}) \quad 2.31$$

where $P_{j,t}^*$ is the optimal price. Substituting the expression for $Y_{j,t}$ from Equation 2.17 in Equation 2.31 and replacing the $TC_{j,t+i} = mc_{j,t+i} \times Y_{j,t+i}$ gives:

$$\max_{P_{j,t}^*} E_t \sum_{i=0}^{\infty} (\beta\varphi)^i \left[P_{j,t}^* Y_{t+i} \left(\frac{P_{t+i}}{P_{j,t}^*} \right)^\xi - Y_{t+i} \left(\frac{P_{t+i}}{P_{j,t}^*} \right)^\xi mc_{j,t+i} \right] \quad 2.32$$

taking the first derivative and solving for $P_{j,t}^*$ gives:

$$P_{j,t}^* = \left(\frac{\xi}{\xi-1} \right) E_t \sum_{i=0}^{\infty} (\beta\varphi)^i mc_{j,t+i} \quad 2.33$$

Since all the firms which reset the prices face the same marginal cost. Therefore, $P_{j,t}^*$ is the same price for all $(1-\varphi)$ price resetting firms. Now, from Equation 2.19, the expression can also be written as: $P_t^{1-\xi} = \left[\int_0^1 P_{j,t}^{1-\xi} dj \right]$ and the equation for the aggregate price level can be solved in the following way:

$$P_t^{1-\xi} = \int_0^\varphi P_{t-1}^{1-\xi} dj + \int_\varphi^1 P_t^{*1-\xi} dj \quad 2.34$$

solving the equation gives the expression for general price level:

$$P_t = \left[\varphi P_{t-1}^{1-\xi} + (1-\varphi) P_t^{*1-\xi} \right]^{\frac{1}{1-\xi}} \quad 2.35$$

2.3 Central Bank

Now, we introduce a monetary policy authority, typically a central bank in any economy which sets the interest rates. We assume that central bank follows a simple Taylor rule (Taylor 1993) and sets the interest rate keeping in mind two broad objectives - price stability and economic growth. We follow the Taylor rule defined in (Costa 2018) and (Banerjee, Basu, and Ghate 2020) as:

$$\frac{r_t}{\bar{r}} = \left(\frac{r_{t-1}}{\bar{r}}\right)^{\gamma_r} \left[\left(\frac{\pi_t}{\bar{\pi}}\right)^{\gamma_\pi} \left(\frac{Y_t}{\bar{Y}}\right)^{\gamma_Y} \right]^{(1-\gamma_r)} s_t^m \quad 2.36$$

where, γ_r is the smoothing parameter, γ_Y is the interest rate sensitivity of output, γ_π is the interest rate sensitivity of inflation. s_t^m monetary policy shock which follows AR(1) process:

$$\log s_t^m = (1-\rho_m) \log \bar{s}^m + \rho_m \log \bar{s}^{m,t-1} + \epsilon_{m,t} \quad 2.37$$

Since there is symmetry in the preferences of both households and firms, so they are represented by representative agents. So, we can remove the j subscript from the equations. Model equations removing the j subscript can be written as:

$C_{j,t}^\sigma L_{j,t}^\psi = \frac{W_t}{P_t}$	Labour Supply
$\left(\frac{E_t C_{t+1}}{C_t}\right)^\sigma = \beta \left[(1-\delta) + E_t \left(\frac{R_{t+1}}{P_{t+1}}\right) \right]$	Euler Equation
$K_{t+1} = (1-\delta)K_t + I_t$	Law of Capital Accumulation
$Y_t = A_t K_t^{\alpha_1} L_t^{1-\alpha}$	Production function
$mc_t = \frac{1}{A_t} \left(\frac{W_t}{1-\alpha}\right)^{1-\alpha} \left(\frac{R_t}{\alpha}\right)^\alpha$	Marginal Cost
$L_t = (1-\alpha) mc_t \frac{Y_t}{W_t}$	Labour Demand
$K_t = \alpha mc_t \frac{Y_t}{R_t}$	Capital Demand
$P_t^* = \left(\frac{\xi}{\xi-1}\right) E_t \sum_{i=0}^{\infty} (\beta\phi)^i mc_{t+i}$	Optimal Price level
$\pi_t = \frac{P_t}{P_{t-1}}$	Inflation Rate
$K_t = \alpha mc_t \frac{Y_t}{R_t}$	Capital Demand
$P_t^* = \left(\frac{\xi}{\xi-1}\right) E_t \sum_{i=0}^{\infty} (\beta\phi)^i mc_{t+i}$	Optimal Price level

$$\pi_t = \frac{P_t}{P_{t-1}} \quad \text{Inflation Rate}$$

$$Y_t = C_t + I_t \quad \text{Equilibrium Condition}$$

$$\log A_t = (1 - \phi_A) \log \bar{A} + \phi_A \log A_{t-1} + \epsilon_t \quad \text{Productivity Shock}$$

2.4 Steady State

Next step in solving the model is to define the steady-state⁵ values. We remove time subscript and solve above equations for steady-state for households:

$$\bar{C}^\sigma \bar{L}^\psi = \frac{\bar{W}}{\bar{P}} \quad 2.38$$

$$1 = \beta \left[(1 - \delta) + \left(\frac{\bar{R}}{\bar{P}} \right) \right] \quad 2.39$$

$$\delta \bar{K} = \bar{I} \quad 2.40$$

For firms:

$$\bar{Y} = \bar{K}^\alpha \bar{L}^{1-\alpha} \quad 2.41$$

$$\bar{L} = (1 - \alpha) \bar{m}c \frac{\bar{Y}}{\bar{W}} \quad 2.42$$

$$\bar{K} = \alpha \bar{m}c \frac{\bar{Y}}{\bar{R}} \quad 2.43$$

$$\bar{m}c = \left(\frac{\bar{W}}{1 - \alpha} \right)^{1-\alpha} \left(\frac{\bar{R}}{\alpha} \right)^\alpha \quad 2.44$$

Solving from Equation 2.33, $E_t \sum_{i=0}^{\infty} (\beta\phi)^i = \frac{1}{1-\beta\phi}$. Substituting this value in the optimal pricing equation and defining steady-state:

$$\bar{P} = \left(\frac{\xi}{\xi - 1} \right) \left(\frac{1}{1 - \beta\phi} \right) \bar{m}c \quad 2.45$$

and equilibrium condition

$$\bar{Y} = \bar{C} + \bar{I} \quad 2.46$$

where, a bar over a variable shows it's steady-state. For some variables, it is easy to get the steady state values analytically, but for most variables, it's not possible. The standard practice is to solve for steady states numerically for such variables. For e.g. in equation 2.21, it's difficult to solve for steady state value of productivity. In literature, \bar{A} is given the value 1. Following the literature, we also assign unit value to the productivity steady state. We also normalise general price level to 1 ($\bar{P} = 1$) which is again a standard practice in literature to simplify the model.

With these equations ready, we try to solve for steady states for our variables of interest. From Equation 2.11, steady -state value for interest rate simply is:

$$\bar{r} = \frac{1}{\beta} \quad 2.47$$

Next, we start with \bar{R} , as in Equation 2.39, \bar{R} depends only on parameter values and $\bar{P} = 1$. Rearranging Equation 2.39:

$$\bar{R} = \bar{P} \left[\left(\frac{1}{\beta} \right) - (1 - \delta) \right] \quad 2.48$$

⁵ A variable is said to be in steady-state, if it's value doesn't change over time, i.e., $E_t z_{t+1} = z_t = z_{t-1} = \bar{z}$.

It's easy to find steady-state values for \bar{R} by putting calibrated values of parameters. Next, we can find the steady-state values for $\bar{m}\bar{c}$ with the help of \bar{R} . So, from Equation 2.45:

$$\bar{m}\bar{c} = \left(\frac{\xi-1}{\xi}\right) (1-\beta\varphi)\bar{P} \tag{2.49}$$

Next, we solve for \bar{W} , from Equation 2.44, the expression for \bar{W} can be written as:

$$\bar{W} = (1-\alpha)\bar{m}\bar{c}^{1-\alpha} \left(\frac{\alpha}{\bar{R}}\right)^{\frac{\alpha}{1-\alpha}} \tag{2.50}$$

So far, we get the steady-state values for the capital, labour and general prices. Now, we can aim for consumption and investment demands. \bar{I} can be obtained by substituting Equation 2.43 into Equation 2.40:

$$\bar{I} = \left(\frac{\delta\alpha\bar{m}\bar{c}}{\bar{R}}\right) \bar{Y} \tag{2.51}$$

and solving for \bar{C} and \bar{Y} , we get:

$$\bar{C} = \frac{1}{\bar{Y}^{\frac{\psi}{\sigma}}} \left[\frac{\bar{W}}{\bar{P}} \left(\frac{\bar{W}}{(1-\alpha)\bar{m}\bar{c}} \right)^{\psi} \right]^{\frac{1}{\sigma}} \tag{2.52}$$

$$\bar{Y} = \left(\frac{\bar{R}}{\bar{R}-\alpha\delta\bar{m}\bar{c}} \right)^{\frac{\sigma}{\sigma+\psi}} \left[\frac{\bar{W}}{\bar{P}} \left(\frac{\bar{W}}{(1-\alpha)\bar{m}\bar{c}} \right)^{\psi} \right]^{\frac{1}{\sigma+\psi}} \tag{2.53}$$

2.4 Calibration

To get the variables' steady-state values and solve model numerically, we need to assign values to the parameters. There are two methods in the literature - calibration and estimation of the parameters. Though estimation is the most recommended method, we restrict to the calibration method for the study. Calibration is a popular method in DSGE literature. In this method, parameters are given values based on the standard literature which are observed from the data. We also follow the existing literature in assigning the parameter values.

Table 1. Calibration of Parameters

Parameter	Meaning	Value	Source
σ	Coefficient of Relative Risk Aversion	1.50	(V. J. Gabriel <i>et al.</i> 2011; Das and Nath 2019)
ψ	Inverse of Frisch elasticity of labour supply	2.7	(Anand and Prasad 2010; Sharma and Behera 2022)
β	Discount Factor	0.98	(V. Gabriel <i>et al.</i> 2012)
δ	Depreciation rate	0.025	(Banerjee, Basu, and Ghatge 2020)
α	Share of capital	0.30	(Banerjee, Basu, and Ghatge 2020)
ξ	Elasticity of substitution between intermediate goods	7.02	(V. Gabriel <i>et al.</i> 2012)
φ	Price stickiness parameter	0.75	(Smets and Wouters 2003)
γ_r	Interest rate smoothing parameter	0.80	(Banerjee, Basu, and Ghatge 2020)
γ_Y	Interest rate sensitivity of output	0.50	(Banerjee, Basu, and Ghatge 2020)
γ_π	Interest rate sensitivity of inflation	1.20	(V. Gabriel <i>et al.</i> 2012)
ρ_A	Productivity shock autoregressive parameter	0.95	
ρ_m	MP shock autoregressive parameter	0.95	

Value of depreciation rate for capital (δ) is taken as 0.025 which means around 10% capital depreciation per annum is broadly in line with literature (V. J. Gabriel *et al.* 2011; Das and Nath 2019). Discount factor (β) is set to 0.98 following V. J. Gabriel *et al.* (2011) (literature broadly defines the value of discount factor between 0.97 to 0.99). Share of capital in production (α) is 0.30 taken from Banerjee, Basu, and Ghatge (2020). Value of coefficient of relative risk-aversion (σ) is again in line with Indian case from V. J. Gabriel *et al.* (2011). Smets and Wouters

(2007) take the price stickiness parameter (φ) value 0.75 which is around the estimated value using Indian data by V. J. Gabriel *et al.* (2011). The value of Frisch elasticity of labour supply (inverse of ψ) is contested in literature and is in the range between 0.25 to 1.28⁶. We take the value 2.7 following Indian studies (Anand and Prasad 2010; Sharma and Behera 2022). Table 1 below gives the description of calibration of the structural parameters.

2.5 Log-linearisation of the Model

After getting the steady-states, next step is to log-linearise the model around the steady-state. Solving the linear model is relatively simple compared to non-linear models. To get the intuition of linear model is often easier than the non-linear version of the model. Therefore, it is a standard practice in literature to solve the model with log-linear approximations⁷. In the log-linearisation process, we replace all the necessary equations in the model by approximations, which are linear in the log-deviation form. We use Uhlig's method (Uhlig 1999) for our log-linearisation. In this method, a variable is replaced in this way: a variable Z_t is replaced by $\bar{Z}e^{\tilde{Z}_t}$, where $\tilde{Z} = \log Z - \log \bar{Z}$. Uhlig method gives the following set of tools to solve for more than one variable:

$$e^{(\tilde{Y}_t + b\tilde{Z}_t)} \approx 1 + \tilde{Y}_t + b\tilde{Z} \quad 2.54$$

$$\tilde{Y}_t \tilde{Z}_t \approx 0 \quad 2.55$$

$$E_t[be^{\tilde{Z}_{t+1}}] \approx b + bE_t[\tilde{Z}_{t+1}] \quad 2.56$$

We log-linearise our model equations using the Uhlig method and apply these tools. First solving for the labour supply equation

$$C_{j,t}^\sigma L_{j,t}^\psi = \frac{W_t}{P_t}$$

replacing C_t by $\bar{C}e^{\tilde{C}_t}$ and following the same for other variables, we get

$$\bar{C}^\sigma \bar{L}^\psi e^{(\sigma\tilde{C}_t + \psi\tilde{L}_t)} = \frac{\bar{W}}{\bar{P}} e^{(\tilde{W}_t - \tilde{P}_t)}$$

using the rule in Equation 2.54, above equation can be transformed into

$$\bar{C}^\sigma \bar{L}^\psi (1 + \sigma\tilde{C}_t + \psi\tilde{L}_t) = \frac{\bar{W}}{\bar{P}} (1 + \tilde{W}_t - \tilde{P}_t)$$

since at steady-state, $\bar{C}^\sigma \bar{L}^\psi = \frac{\bar{W}}{\bar{P}}$ (Equation 2.38), we get the final log-linearised form of the labour supply equation:

$$\sigma\tilde{C} + \psi\tilde{L} = \tilde{W} - \tilde{P} \quad 2.57$$

Calculating in similar ways, we can get the log-linearised form of other model equations in the following way: Euler equation:

$$\frac{\sigma}{\beta} (E_t \tilde{C}_{t+1} - \tilde{C}_t) = \frac{\bar{R}}{\bar{P}} E_t (\tilde{R}_{t+1} - \tilde{P}_{t+1}) \quad 2.58$$

Euler equation for government bonds:

$$\tilde{\lambda}_t - \tilde{r}_t = \tilde{\lambda}_{t+1} \quad 2.59$$

Marginal cost:

$$\tilde{m}\tilde{c}_t = (1-\alpha)\tilde{W}_t + \alpha\tilde{R}_t - \tilde{A}_t \quad 2.60$$

Capital demand:

$$\tilde{K}_t = \tilde{m}\tilde{c}_t + \tilde{Y}_t - \tilde{R}_t \quad 2.61$$

⁶ (Christiano, Eichenbaum, and Evans 1996; Rotemberg and Woodford 1997)

⁷ (King, Plosser, and Rebelo 1988; Campbell 1994) are among the firsts to solve RBC models through log-linearisation.

Labour demand:

$$\tilde{L}_t = \tilde{m}c_t + \tilde{Y}_t - \tilde{W}_t \quad 2.62$$

Production function:

$$\tilde{Y}_t = \tilde{A}_t + \alpha \tilde{K}_t + (1-\alpha)\tilde{L}_t \quad 2.63$$

Law of capital motion:

$$\tilde{K}_{t+1} = (1-\delta)\tilde{K}_t + \delta \tilde{I}_t \quad 2.64$$

Optimal price level:

$$\tilde{P}_t^* = (1-\beta\varphi)E_t \sum_{i=0}^{\infty} (\beta\varphi)^i \tilde{m}c_{t+i} \quad 2.65$$

General price level:

$$\tilde{P}_t = \varphi \tilde{P}_{t-1} + (1-\varphi)(1-\beta\varphi)E_t \sum_{i=0}^{\infty} (\beta\varphi)^i \tilde{m}c_{t+i} \quad 2.66$$

Monetary policy rule:

$$\tilde{r}_t = \gamma_r \tilde{r}_{t-1} + (1-\gamma_r)(\gamma_\pi \tilde{\pi} + \gamma_Y \tilde{Y}_t) + \tilde{s}_t^m \quad 2.67$$

Inflation rate:

$$\tilde{\pi} = \tilde{P}_t - \tilde{P}_{t-1} \quad 2.68$$

Equilibrium condition:

$$\tilde{Y}\tilde{Y}_t = \tilde{C}\tilde{C}_t + \tilde{\Pi}_t \quad 2.69$$

Productivity Shock:

$$\tilde{A}_t = \rho_A \tilde{A}_{t-1} + \epsilon_t \quad 2.70$$

Monetary policy shock:

$$\tilde{s}_t^m = \rho_m \tilde{s}_{t-1}^m + \epsilon_{m,t} \quad 2.71$$

3. Results and Discussions

After transforming the model equations in log-linearisation form, we simulate the model for monetary policy and productivity shocks. Model is simulated using Dynare 5.1 in Matlab. This section discusses the results of impulse response functions to one std. deviation to the productivity shock and monetary policy shock. Impulse responses are simulated for 40 periods.

3.1 Productivity Shock

Figure 1. Impulse response function (IRF) of a positive productivity shock (part 1)

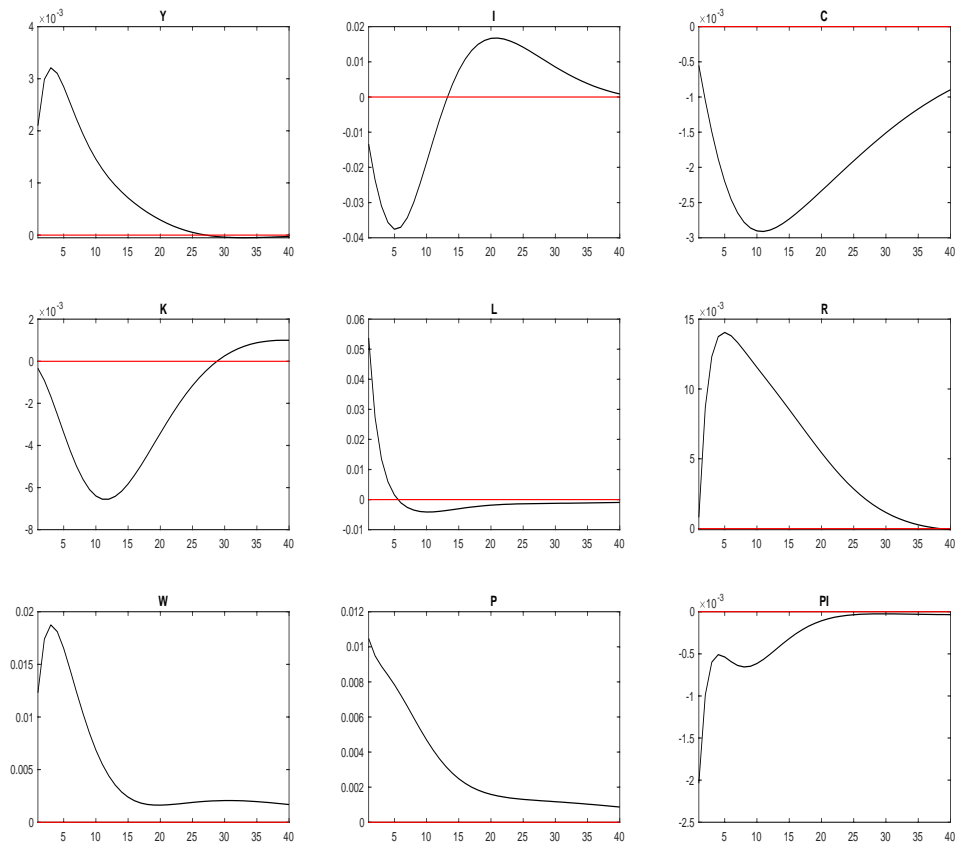
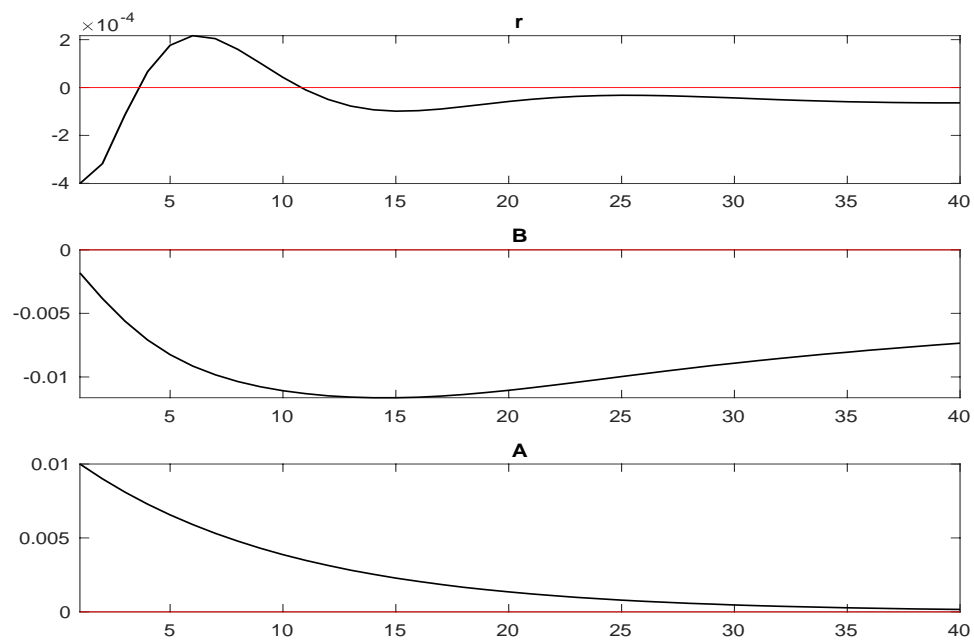


Figure 2. Impulse response function (IRF) of a positive productivity shock (part 2)



Response of macro variables to the exogenous productivity shock ϵ_t are shown in Figure 1 and Figure 2. A positive productive shock makes means of production more efficient, *i.e.*, increases marginal productivities of labour

and capital. This leads to an increase in the demand of labour and capital by firms, leading to a spike in the prices of labour and capital *i.e.*, wages and rent. Higher wages and rent on capital increase household income resulting in higher inflation. Higher inflation binds the central bank to increase the interest rate. Increased wage rates induce households to consume more leisure due to the income effect, thereby supplying less labour. Higher aggregate supply in the economy due to productivity growth increases investment. In summary, we see that a positive productivity shock increases spending variables like investment and consumption as well as input prices.

3.2 Monetary Policy Shock

Figure 3. Impulse response function (IRF) of an expansionary monetary policy shock (part 1)

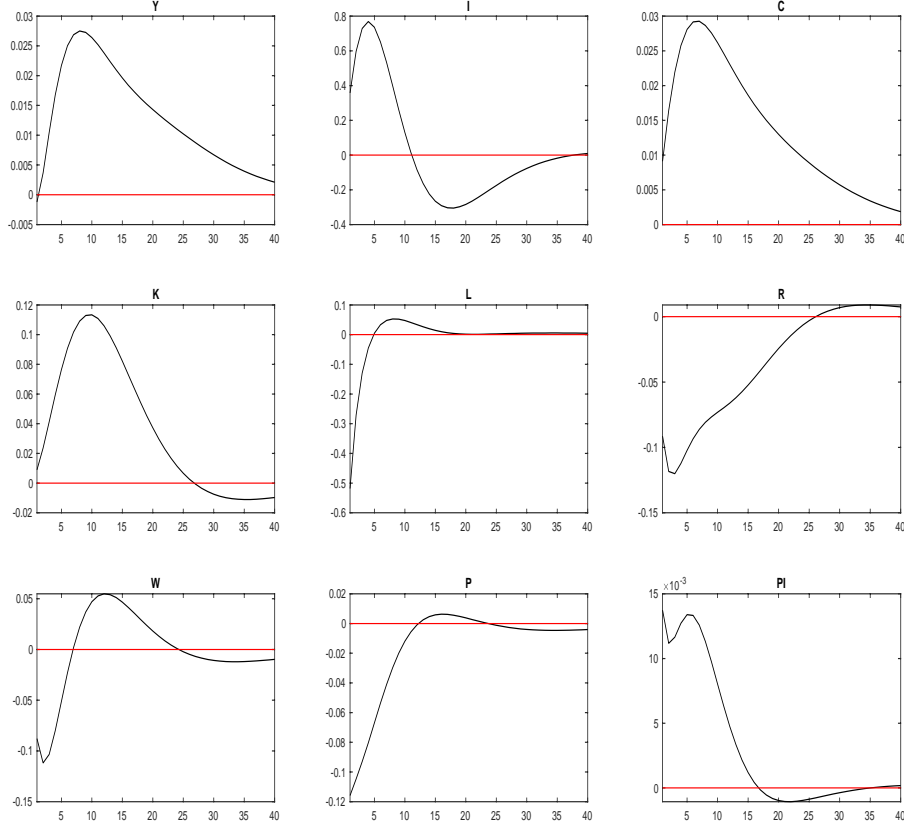


Figure 4. Impulse response function (IRF) of an expansionary monetary policy shock (part 2)

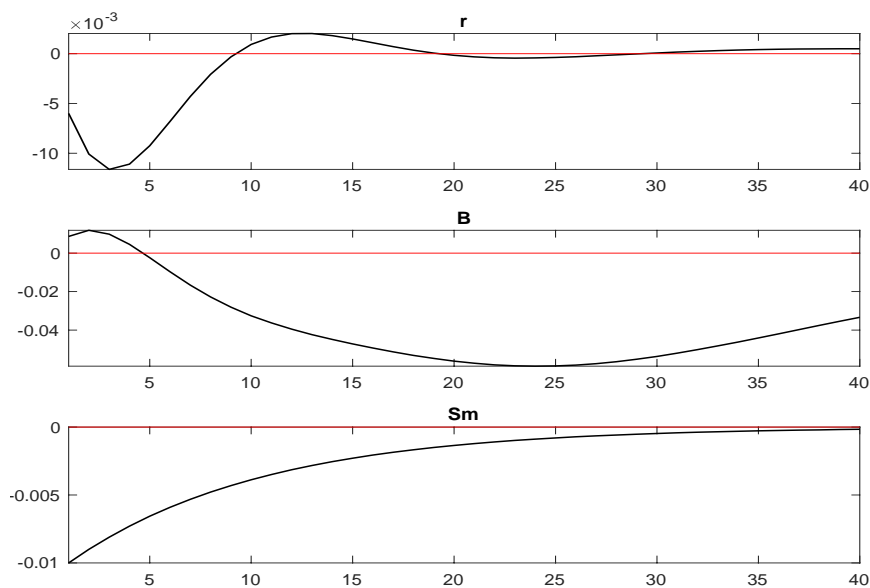


Figure 3 and Figure 4 plot the simulated impulse responses of an expansionary monetary policy shock s_t^m . An expansionary monetary policy increases the money supply base and lowers the short-term interest rates. As the graphs show, expansionary shock triggers a positive response to output and prices, so high inflation. Taylor rule specified in the model works as an automatic stabiliser because higher inflation increases the policy rates via the Taylor rule, keeping the inflation in a defined band. The lower short-term interest rate increases the price of the government bonds $(P_t^B = \frac{1}{r_t})$, which decreases household demand for these bonds. Now, households purchase less bonds and save more by investing in physical capital. While a lower interest rate incentivises more private investment, on the other hand, it lowers the opportunity for government bonds. We see a positive response of majority of endogenous variables. Not only consumption and investment, but also capital accumulation and employment respond positively.

Conclusions and Further Research

This study presents a basic set-up of a New-Keynesian dynamic stochastic general equilibrium (DSGE) model. DSGE models are state-of-the-art models in macroeconomic analysis. These models are based on theoretical foundations, hence more capable of providing structural analysis than their counterpart reduced form vector autoregressive (VAR) models. The present study builds a two-sector closed economy DSGE model with nominal price rigidities. In the model, two economic agents, households and firms interact with each other, and a monetary authority sets the interest rate. The model features imperfect competition in intermediate firms' production sector where firms follow the Calvo rule to set their prices. To make model equations more intuitive and to take the model to computational techniques, it is transformed in the log-linearised form. Model is solved numerically by assigning parameter values. Simulation of the model presents interesting results which are in line with the economic theory. A positive productivity shock improves overall economic activity, however, putting upward inflationary pressure. An expansionary monetary policy seems most appropriate option to revive growth for the short-term. But it discourages households to invest in government bonds due to lower interest rates, hence leaving little room for fiscal expansion from the government side.

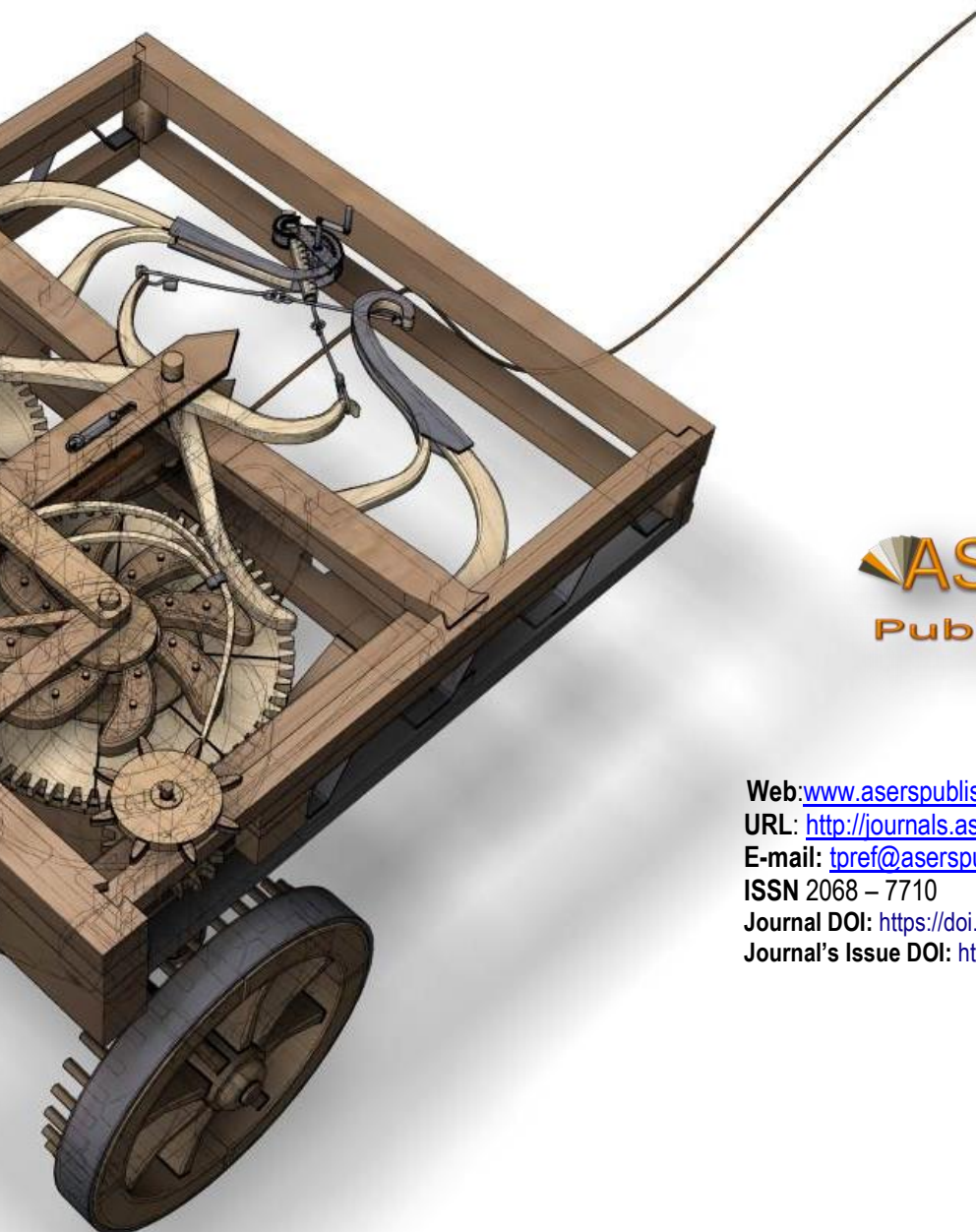
The current model can be extended by including the government sector which will enable to analyse fiscal policy shocks along with monetary shocks. Certain improvements, like habit persistence in the utility function and integration of term-structure dynamics, can improve the model's performance by making it more competitive for policy analysis and forecasting.

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