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Original Research Article

Optimal Monetary Policy Rules in Response to Oil Revenue and Liquidity Shocks: A DSGE Model for Iran

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This study analyzes the impact of oil revenue and liquidity shocks on optimal monetary policy in Iran using a Dynamic Stochastic General Equilibrium (DSGE) model calibrated to Iran's structural characteristics. The model incorporates the interactions among households, firms, the government, and the central bank, capturing both domestic and external disturbances. Using quarterly data from 2006 to 2023, the calibrated model simulates how oil-related fiscal shocks and liquidity fluctuations propagate through key macroeconomic channels. Simulation results show that both shocks significantly influence output, inflation, and asset prices. Strengthening the inflation stabilization component of the monetary policy rule mitigates the adverse effects of shocks on production and stock indices but increases interest rate volatility. The novelty of this study lies in jointly examining fiscal (oil revenue) and monetary (liquidity) shocks within a unified DSGE framework for an oil-dependent economy, an approach not previously applied to Iran. The findings provide new insights into policy trade-offs faced by the Central Bank of Iran, emphasizing that maintaining macroeconomic stability requires a careful balance between inflation control and growth objectives, particularly under exchange rate fluctuations.

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1 Introduction

Since the collapse of the Bretton Woods system in 1971, currency crises have periodically affected both advanced and emerging economies, including Latin America, Southeast Asia, Russia, and Iran. Currency crises, or speculative attacks, occur when a national currency comes under intense selling pressure, often leading to rapid depletion of foreign reserves and potential currency depreciation if the central bank cannot intervene successfully (Obstfeld, 1996; Reinhart & Rogoff, 2011).

The Iranian economy is particularly sensitive to such shocks due to its heavy reliance on oil revenues, managed exchange rate regimes, and structural financial market frictions. These characteristics amplify the effects of both domestic and external disturbances, making the design of optimal monetary policy crucial. Exchange rate movements in Iran are not only a reflection of macroeconomic conditions but also a central transmission mechanism through which shocks affect output, inflation, and asset prices (Hashemi et al., 2020). Unlike many small open economies, Iran's economy exhibits strong dependence on oil exports, volatile foreign inflows, and periodic liquidity fluctuations, which necessitate a tailored modeling approach.

Monetary policy in such an environment must balance multiple objectives, including price stability, output stabilization, and exchange rate management. Central banks typically implement policy rules, such as the Taylor rule, to guide nominal interest rate adjustments in response to deviations in inflation and output gaps (Taylor, 1993). However, in economies exposed to frequent external shocks, including oil price volatility, demand shocks, and global financial fluctuations, the standard implementation of these rules is challenging (Blanchard & Galí, 2010). For instance, an unexpected decline in oil revenues can simultaneously tighten fiscal space and exert upward pressure on inflation through exchange rate pass-through, complicating policy responses.

This study develops a Dynamic Stochastic General Equilibrium (DSGE) model specifically for the Iranian economy to examine how macroeconomic shocks influence optimal monetary policy. The model integrates households, firms, the government, and the central bank, and accounts for oil revenue fluctuations, liquidity shocks, and the structural constraints of the Iranian economy. While some model parameters are adopted from prior studies on open economies (e.g. Heydarian et al., 2025), this framework introduces novel features such as sector-specific fiscal ratios, explicit modeling of exchange rate regimes, and liquidity-dependent constraints, reflecting the unique structural characteristics of Iran.

The main objective of this research is to analyze the conditions under which different types of macroeconomic shocks—real, demand-side, and supply-side—affect optimal monetary policy, and to quantify how policy objectives such as output gap stabilization and inflation control are sensitive to these shocks. The study employs the Taylor rule as the baseline framework but allows for modifications in response to the identified shocks, providing a more realistic representation of policy implementation in an oil-dependent, small open economy.

Additionally, the study distinguishes between the contributions of previous literature and the innovations introduced in this work. While earlier DSGE applications focus primarily on generic open economies or on oil-exporting economies with simplified fiscal structures (e.g., Christiano et al., 2005; Celasun et al., 2006), this research explicitly models Iran-specific fiscal and monetary interactions, highlighting the role of exchange rate volatility, oil revenue dependence, and financial market frictions in shaping optimal policy responses. This approach allows for a deeper understanding of transmission mechanisms, policy trade-offs, and the calibration of DSGE models in economies with similar characteristics.

In conclusion, by incorporating domestic structural features and external shocks, this study offers a rigorous assessment of optimal monetary policy in Iran. The results provide policy-relevant guidance on the calibration of interest rate rules and enrich the literature on monetary policy under uncertainty in oil-dependent small open economies. The remainder of the paper is organized as follows: Section 2 reviews the literature and theoretical background; Section 3 presents the model structure and policy framework; Section 4 discusses calibration and model solution; and Section 5 concludes with policy implications.

2 Theoretical Foundations and Literature Review

Inflation in Iran is primarily driven by monetary expansion, oil revenue inflows, and exchange rate volatility (Tayebi et al., 2015). Exchange rate fluctuations, heavily influenced by central bank foreign reserves, directly affect price instability (Farrokhi Balajadeh et al., 2019). The monetary base, via the money multiplier, amplifies these effects. Fixed exchange rate regimes may help stabilize prices but reduce monetary policy independence and limit balance-of-payments adjustments.

Currency crises in emerging economies are classified into three generations: first-generation models focus on weak fundamentals (Krugman, 1979), second-generation models emphasize expectations and multiple equilibria (Obstfeld, 1996), and third-generation examine banking sector interactions and shock transmissions (Glick & Hutchison, 2011). Iran's experience shows that exchange rate volatility stems from chronic current account imbalances, sanctions, and inconsistent policies, while liquidity structure and political factors further complicate outcomes (Nematollahy et al., 2024).

Monetary policy effectiveness is limited by time lags, external shocks, and market imperfections, highlighting the need for forward-looking, adaptive frameworks (Sadeghi & Alavi, 2013; Adrian & Liang, 2018). Classical, neoclassical, and monetarist theories suggest money neutrality in the long run (Sadeghi & Alavi, 2013), whereas Keynesian and New Keynesian perspectives stress active stabilization (Keynes, 1936). This combination of structural shocks, oil dependency, and exchange rate regimes justifies using a tailored DSGE model for Iran.

Optimal monetary policy theory has evolved to address nonlinearities, zero-lower-bound constraints, and financial market interactions (Christiano et al., 2011; Rajan, 2010). Flexible inflation targeting remains central, but debates on price-level targeting and lean-versus-clean approaches highlight the importance of integrating financial stability considerations (Borio & Zhu, 2008; Mishkin, 2011). These insights inform the construction of an Iran-specific DSGE model incorporating oil revenues, liquidity, and exchange rate shocks.

Previous studies using DSGE models for optimal monetary policy have laid a foundational understanding of forward-looking and rule-based frameworks under macroeconomic shocks. Classic contributions include Gali and Monacelli (2005), who extended New Keynesian DSGE models to small open economies, Nisticò (2012), who modeled oil revenue shocks in emerging markets, Berg et al. (2010), who explored policy under fiscal-monetary interactions in developing countries. These studies primarily focus on general equilibrium responses to conventional monetary policy instruments, assuming either a single exchange rate or exogenous fiscal transfers.

Recent research has emphasized adaptive policy frameworks under structural uncertainty. Brandão Marques et al. (2024) and Dizioli (2025) investigate optimal policy in the presence of persistent shocks and stochastic volatility, showing that forward-looking rules need continuous updating to maintain stability. Similarly, studies such as Caporin et al. (2024) and Adrian et al. (2024) highlight the critical interaction between exchange rate volatility and financial markets, demonstrating that ignoring asset market feedback can lead to suboptimal policy outcomes.

Behavioral considerations, such as bounded rationality and limited information processing by agents, reduce the effectiveness of traditional forward guidance and standard policy tools. These findings are particularly relevant for emerging and oil-dependent economies where market frictions and incomplete financial markets are pronounced.

In the context of Iran, empirical evidence demonstrates that oil price and exchange rate shocks significantly affect capital market investment, output, and inflation dynamics. Moreover, money supply growth, credit expansion, and exchange rate dynamics are central to the monetary transmission mechanism (Heydarian et al., 2025). The presence of economic policy uncertainty further amplifies stock market vulnerability, increasing systemic risk (Moradi et al., 2021; Heydarian et al., 2025). Recent Iranian studies also underscore that structural factors—such as the dual exchange-rate system, oil-dollar fiscal flows, and liquidity-in-advance constraints imposed by Islamic banking—significantly alter the propagation of macroeconomic shocks (Boroumand et al., 2019).

Globally, newer DSGE approaches have incorporated financial frictions, heterogeneous agents, and multi-sectoral dynamics. For instance, Christiano et al. (2018) extend medium-scale DSGE models to account for non-linearities, zero-lower-bound constraints, and asset market feedbacks, providing a more realistic framework for policy evaluation in shock-prone economies. These studies provide methodological guidance for tailoring DSGE models to Iran, where oil dependence, parallel FX markets, and capital market imperfections coexist.

This literature demonstrates that standard DSGE models require customization for Iran to account for: Oil revenue shocks impacting liquidity and fiscal flows, Exchange rate regimes influencing inflation and output gaps, Financial frictions affecting stock market responses and monetary policy transmission.

Accordingly, this study constructs a multi-sector New Keynesian DSGE model with households, firms, government, and central bank, explicitly incorporating oil revenues and liquidity dynamics. The model extends previous frameworks (Gali & Monacelli, 2005; Nisticò, 2012) by allowing for simultaneous shocks in oil revenue, exchange rates, and stock market liquidity, providing insights that conventional models cannot capture. This approach highlights the policy trade-offs between inflation stabilization, output support, and financial stability in a small, open, oil-dependent economy.

In sum, the reviewed literature establishes both the relevance and limitations of prior models and motivates the tailored DSGE framework presented in the next section. This model enables a comprehensive analysis of optimal monetary policy in Iran under the dual influence of oil revenue and liquidity shocks, offering guidance for policy design beyond traditional approaches.

3 Research Methodology

Following the approaches of Gali and Monacelli (2005) and Nisticò (2012), this study constructs a multi-sector New Keynesian DSGE model incorporating physical capital, intermediate inputs, and government consumption expenditures. The economy consists of households, firms, the government, and the monetary authority (central bank). The model represents an open economy, including export, import, and exchange rate sectors. This design enables analysis of international interactions and their influence on macroeconomic dynamics. The model assumes that the effects of shocks on macroeconomic variables such as import prices, inflation, and domestic demand are gradually transmitted over time rather than immediately an assumption consistent with empirical evidence and suitable for describing the real behavior of Iran’s economy.

3.1 Households

The economy consists of a continuum of identical households indexed by i. Each household derives utility from consumption and real money balances, while disutility arises from labor supply due to reduced leisure. The household’s intertemporal utility function, which depends on total household consumption, real money balances, and labor supply, is defined as a function incorporating the time discount factor β:

$$E_0 \sum_{i=0}^{\infty} \beta^i = \left[\frac{1}{1-\sigma_c}\left(c_t^i - hc_{t-1}\right)^{1-\sigma_c} - \frac{1}{1+\sigma_l}\left(L_t^i\right)^{1+\sigma_l} + \frac{1}{1-\sigma_m}\left(\frac{M_t^{c,t}}{P_t^c}\right)^{1-\sigma_m}\right] \quad (1)$$

In Equation 1, consumption goods are composed of a composite of domestically produced and imported consumption goods, which are supplied by domestic producers and by imports. In the utility function in Equation 1, the parameter σ_c denotes the coefficient of relative risk aversion, which is the reciprocal of the intertemporal elasticity of substitution in consumption. The parameter σ_l denotes the inverse of the labor-supply elasticity with respect to the real wage, and the parameter σ_m denotes the inverse of the elasticity of real money balances ($m_t^{c,t} = \frac{M_t^{c,t}}{P_t^c}$) with respect to the interest rate. The utility function in Equation 1 embodies external ("keeping-up-with-the-Joneses") habits in consumer behavior, which depend on the economy's average per-capita consumption. Accordingly, a representative household at time t derives positive utility from higher consumption when its consumption exceeds h percent of the economy's average per-capita consumption in period t−1. Here h measures the extent to which the consumer prefers to smooth his/her consumption relative to last period's average per-capita consumption: the larger h is, the stronger the dependence on consumption habits.

Consumption Basket Choice and Derivation of Consumption Demand Functions

In Equation 1 it is assumed that aggregate consumption, measured at the real price(c_t^i), is a composite of consumption of domestic (c_t^d) and imported (c_t^m) goods, which are supplied, respectively, by domestic and foreign producing firms. These goods are aggregated using a Dixit–Stiglitz aggregator, namely:

$$c_t = \left[\xi_c^{\frac{1}{\mu_c}}\left(c_t^d\right)^{\frac{\mu_c - 1}{\mu_c}} + (1-\xi_c)^{\frac{1}{\mu_c}}\left(c_t^m\right)^{\frac{\mu_c - 1}{\mu_c}}\right]^{\frac{\mu_c}{\mu_c - 1}} \tag{2}$$

where ξ_c and $(1-\xi_c)$ respectively denote the shares of domestically-produced and imported goods in the household's total consumption bundle, and μ_c denotes the elasticity of substitution between domestic and imported consumption goods. In general, the household's decision problem can be analyzed in two stages. In the first stage, the household chooses the composition of consumption goods so that the cost of attaining a given level of the composite consumption good is minimized. In this stage households minimize the expenditure required to purchase the composite consumption (c_t). In the second stage, given the acquisition cost at each specified consumption level, the household selects optimal values of c_t so as to maximize its utility. To carry out the first stage, households minimize the cost $c_t, L_t, \frac{M_t^c}{P_t}$ of purchasing the composite consumption level c_t. With respect to the choice between domestically-produced and imported consumption goods, they solve the following problem:

$$\min_{C_t^i} P_t^d c_t^d + P_t^m c_t^m \quad s.t \quad c_t = \left[\xi_c^{\frac{1}{\mu_c}}\left(c_t^d\right)^{\frac{\mu_c-1}{\mu_c}} + (1-\xi_c)^{\frac{1}{\mu_c}}\left(c_t^m\right)^{\frac{\mu_c-1}{\mu_c}}\right]^{\frac{\mu_c}{\mu_c-1}} \tag{3}$$

where c_t^d and c_t^m denote, respectively, consumption of domestically produced goods and imported goods, and P_t^d and P_t^m denote, respectively, the price indices of domestic and imported goods. By solving the first-order conditions of Equation 3, the demand functions for domestic and imported consumption goods are obtained as follows:

$$c_t^m = (1-\xi_c)\left(\frac{P_t^m}{P_t^c}\right)^{-\mu_c} c_t \tag{4}$$

$$c_t^d = \xi_c\left(\frac{P_t^d}{P_t^c}\right)^{-\mu_c} c_t \tag{5}$$

By substituting Equation 4 and 5 into the household consumption bundle$P_t^d c_t^d + P_t^m c_t^m = P_t^c c_t$, the aggregate consumer price index P_t^c, is obtained, along with its components, that is,

$$P_t^c = \left[\xi_c\left(P_t^d\right)^{1-\eta_c} + (1-\xi_c)\left(P_t^m\right)^{1-\eta_c}\right]^{\frac{1}{1-\eta_c}} \tag{6}$$

where P_t^c denotes the aggregate consumer price index. After the optimal consumption bundle is determined in the first stage, households seek to maximize their expected utility function subject to the intertemporal budget constraint in the second stage. In the third stage, once the optimal composition of goods has been determined in the first stage, each household chooses the optimal levels of consumption c_t, labor L_t, and financial assets so as to maximize its utility. Households financial assets are composed of money, participation bonds, and shares. Money yields no return, whereas participation bonds pay an interest r_t^d at rate. Holders of shares are entitled to dividend payments (if any) and to capital gains. Households' financial assets at the end of period t comprise cash, participation bonds, and a portfolio of shares $N_t(j)$ issued by intermediary firms j .We denote the nominal price per share of firm j in period t by $P_t^s(j)$. Therefore, the equity wealth of household i consists of a portfolio of shares in intermediary firms, each of which pays a dividend with nominal value $DV_t(j)$. Consequently, at the beginning of each period a household's income sources include net rental income, wages, returns to capital, and a stock of financial wealth carried over from the previous period (including money, bonds and equities). To model equity holdings we follow

Nisticò (2012). The equity assets (wealth) of household i carried over from the previous period, ($\Omega^{*,i}_{t-1}$), can be written as:

$$\Omega^{*,i}_{t-1} = \int_0^1 (P^s_t(j) + DV_t(j))N_t(j)\,dj \tag{7}$$

The intertemporal budget constraint of households in terms of real prices can be expressed as follows:

$$c^i_t + I^i_t + b^i_t + \frac{1}{P^c_t}\int_0^1 P^s_t(j)\frac{N_t(j)}{\varepsilon^s_t}dj + m^{c,i}_t = \left(1 + r^d_{t-1}\right)\frac{b^i_{t-1}}{\pi^c_t} + \frac{m^{c,i}_{t-1}}{\pi^c_t} + \frac{1}{P^c_t}\Omega^{*,i}_{t-1} + TR^i_t - T^i_t + y^i_t \tag{8}$$

where I^i_t denotes investment, b^i_t represents bonds, r^d_{t-1} indicates the nominal interest rate on bonds, T^i_t refers to household taxes (including direct, indirect, and value-added taxes), TR^i_t denotes government subsidy payments, and P^I_t is the investment price index. Households hold their wealth in the form of real money balances $m^{c,i}_t$ and bonds b^i_t. Furthermore, π^c_t is the inflation rate based on the overall consumer price index, and ε^s_t represents the stock price shock, which effectively forms the price bubble. Other variables have been previously defined in the text. Finally, y^i_t denotes household income, which is defined as follows:

$$y^i_t = \frac{W^i_t}{P^c_t}L^i_t + R^k_t k^i_{t-1} - k^i_{t-1} + Div^i_t \tag{9}$$

Total household income is derived from labor wages ($\frac{W^i_t}{P^c_t}L^i_t$), capital rental income net of costs associated with changes in the utilization rate of capital, and dividends of firms producing intermediate goods Div^i_t. In Equation 9, W^i_t denotes the nominal wage, and R^k_t represents the real return on capital. The capital stock is owned by households and is employed as a homogeneous factor of production in the production process. Households rent their capital stock to intermediate goods-producing firms at the rate R^k_t. It is assumed that the capital accumulation process follows the Equation:

$$k^i_t = (1-\delta)k^i_{t-1} + \left[1 - S\left(\frac{I^i_t}{I^i_{t-1}}\right)\right]I^i_t \tag{10}$$

Let δdenote the depreciation rate of capital, I^i_t the gross private investment, and $S(0)$ the investment adjustment cost function, which is positively related to changes in investment. $S(0)$ captures the resources lost in converting new investment into the capital stock. In static equilibrium, $S'(1) = S(1) = 0$ and $S'' > 0$, indicating that the adjustment cost depends solely on its second derivative.

By combining Equations 43 and 45, the intertemporal consumption equilibrium can be expressed as follows:

$$\beta E_t \lambda_{t+1}\left(1 + r_t^d\right)\frac{1}{\pi_{t+1}^c} = E_t \frac{(c_t)^{-\sigma_c}}{(c_{t+1})^{-\sigma_c}} \tag{11}$$

Equation 12 represents the optimal intertemporal allocation of household consumption, which households determine based on the discount rate and interest rate. By combining Equations 43, 46, and 48, the household money demand Equation can be derived as follows:

$$(m_t^c)^{-\sigma_m} = (c_t)^{-\sigma_c} \times \frac{r_t^d}{1r_t^d} \tag{12}$$

The real money balance has a positive relationship with consumption, with an elasticity equal to $\frac{\sigma_c}{\sigma_m}$, but it has a negative relationship with the interest rate on deposits. By combining Equations 43 and 45, the final Tobin's Q relationship can be expressed, which is obtained from the ratio $q_t = \frac{Q_t}{\lambda_t}$ and represents the value of the investment level in terms of the replacement cost of capital. After performing the necessary algebraic operations, it can be written sequentially as follows.

$$1 = q_t\left[1 - S\left(\frac{I_t}{I_{t-1}}\right) - S'\left(\frac{I_t}{I_{t-1}}\right).\frac{I_t}{I_{t-1}}\right] + \beta E_t q_{t+1}\frac{\lambda_{t+1}}{\lambda_t}S'\left(\frac{I_{t+1}}{I_t}\right)\left(\frac{I_{t+1}}{I_t}\right)^2 \tag{13}$$

$$q_t = \beta E_t \frac{\lambda_{t+1}}{\lambda_t}\left[q_{t+1}(1-\delta) + R_{t+1}^k\right] \tag{14}$$

Equation 13 can be interpreted as the Euler Equation for investment, representing the optimal investment path. It should be noted that when there are no investment adjustment costs, i.e., $S\left(\frac{I_t}{I_{t-1}}\right)$, the Equation simplifies accordingly. Equation (14) represents the discounted value of the expected future return on capital, after accounting for the necessary adjustments for depreciation and the capital utilization rate. Although in New Keynesian economics wages exhibit stickiness for various reasons and are typically determined through labor unions, in this study the stickiness process is applied solely to prices. To characterize household labor supply behavior, the first-order conditions, namely equations (44) and (48), are used. This implies that households supply their labor in a perfectly competitive wage setting. Accordingly, the household labor supply relationship is expressed as follows:

$$-L_t^{\sigma_l} + (c_t - hc_{t-1})^{-\sigma_c} \frac{W_t}{P_t^c} = 0 \tag{15}$$

3.2 Stock Price Dynamics

Equation (49) represents the dynamics of stock returns. By combining Equations (43) and (49), the dynamics of stock returns (including dividends and capital gains) can be expressed as follows:

$$\mathrm{P}_{\mathrm{t}}^{s}(j) = \varepsilon_t^s E\left\{\beta \frac{\varepsilon_{t+1}^s (c_{t+1} - hc_t)^{-\sigma_c}}{\varepsilon_t^s (c_t - hc_{t-1})^{-\sigma_c}} \left(P_{t+1}^s(j) + DV_{t+1}(j)\right) \frac{P_t^c}{P_{t+1}^c}\right\} \tag{16}$$

Alternatively, using Equation (11), the above relationship can be expressed as follows:

$$P_t^s(j) = \varepsilon_t^s E\left\{\beta \frac{\pi_{t+1}^c}{(1+r_t^d)} \left(P_{t+1}^s(j) + DV_{t+1}(j)\right) \frac{P_t^c}{P_{t+1}^c}\right\} \tag{17}$$

Alternatively, in terms of real prices, it can be expressed as follows:

$$\gamma_t^{sc}(j) = \varepsilon_t^s E\left\{\beta \frac{\pi_{t+1}^c}{(1+r_t^d)} \left(\gamma_{t+1}^{sc}(j) + dv_{t+1}(j)\right)\right\} \tag{18}$$

where $\gamma_t^{sc}(j) = \frac{\pi_t^s(j)}{P_t^c}$ represents the ratio of the return on firm j's stock to the consumer price index. According to Equation (18), the return of each share of firm j is equal to the present value of all its future payoffs, including both dividends and capital gains. It is assumed that the demand for stocks in period t is influenced by a stochastic shock ε_t^s, which in fact constitutes the price bubble. This shock is uncorrelated with the fundamental economic variables that determine the stock's fundamental value. The stock price shock is defined by the following equation:

$$\log \hat{\varepsilon}_{\mathrm{t}}^{\mathrm{s}} = \rho_S \log \hat{\varepsilon}_{\mathrm{t}-1}^{\mathrm{s}} + \varepsilon_t^s \qquad \varepsilon_t^s \sim N(0, \sigma_S^2) \tag{19}$$

3.3 Producers (Firms)

In this model, domestic firms are divided into two main groups: intermediate goods producing firms and final goods producing firms. The first group, intermediate goods producing firms, produces intermediate goods using inputs such as homogeneous labor, capital, and other production factors. The second group, final goods producing firms, is responsible for combining intermediate goods and transforming them into homogeneous final goods.

3.3.1 Behavior of Final Goods Producing Firms

It is assumed that there exists a firm that purchases the differentiated intermediate goods produced by the intermediate goods producing firms and combines them to produce a final good, which is then sold to final consumers. The final goods producer combines the differentiated intermediate goods, which are imperfect substitutes for each other, using a Dixit-Stiglitz aggregator, defined as follows:

$$y_t = \left[\int_0^1 y_t^{j\frac{\epsilon-1}{\epsilon}} dj\right]^{\frac{\epsilon}{\epsilon-1}} \tag{20}$$

In this expression, the parameter ε denotes the elasticity of substitution among differentiated intermediate goods. Under monopolistic competition with flexible prices, the steady-state markup is given by $\mu = \frac{\epsilon}{\epsilon-1}$. The final goods producing firm, operating under perfect competition, chooses its purchases of differentiated intermediate goods to maximize profit or minimize cost, given the prices of these intermediate goods.

Therefore, the profit maximization problem of the final goods producing firm can be formulated as follows:

$$\max_{y_t^j} \quad P_t^d y_t - \int_0^1 P_t^j y_t^j dj \quad s.t \quad y_t = \left[\int_0^1 y_t^{j\frac{\epsilon-1}{\epsilon}} dj\right]^{\frac{\epsilon}{\epsilon-1}} \tag{21}$$

By solving the first-order conditions of Equation (21), the demand function for each differentiated intermediate good produced by the intermediate goods firms can be expressed as follows, depending on the ratio of its price to the price of the domestic final good:

$$y_t^j = \left(\frac{P_t^j}{P_t^d}\right)^{-\epsilon} y_t \quad j \in [0,1] \tag{22}$$

where P_t^j is the price of intermediate good j and P_t^d is the domestic output price index. By substituting equation (22) into equation (20), the relationship between the domestic final goods price index and the prices of intermediate goods can be obtained as follows:

$$P_t^d = \left[\int_0^1 P_t^{j^{1-\epsilon}} dj\right]^{\frac{1}{1-\epsilon}} \tag{23}$$

3.3.2 Behavior of Intermediate Goods Producing Firms

The economy consists of a continuum of monopolistically competitive firms in the intermediate goods sector, indexed over the interval $[0,1]$, i.e $j \in [0,1]$. Each firm produces a differentiated good. These firms employ labor, capital, and other inputs to produce intermediate goods j. Labor and capital are used as inputs in the production process. Given the dominant role of the government in the economy, and the fact that public investment significantly affects the productivity of the private sector, it is necessary to incorporate government capital formation into the production function of intermediate goods firms. Accordingly, the production function of intermediate goods firms is specified as a Cobb-Douglas function as follows:

$$y_t^j = A_t L_t^{j^{1-\alpha}} K_t^{j^{\alpha}} \tag{24}$$

where y_t^j denotes the gross output of firm j, L_t^j represents labor employed by firm j, and K_t^j denotes the capital stock of firm j. α indicates the share of capital in the production function, while 1-α represents the labor share. A_t denotes productivity, which is common across all firms and follows the process below

$$logA_t = \rho_a logA_{t-1} + u_t^a \quad , \quad u_t^a \sim N(0, \sigma_a^2) \tag{25}$$

The firm producing good j in sector j seeks to minimize its costs given a specified level of output. Therefore, the objective function of firm j can be expressed as follows:

$$\min_{K_t^j, L_t^j} \frac{W_t}{P_t^d} L_t^j + R_t^k K_t^j \quad \text{s.t.} \quad y_t^j = A_t L_t^{j^{1-\alpha}} K_t^{j^{\alpha}} \tag{26}$$

where W_t denotes the nominal partial wage, R_t^k is the return on capital, and y_t^j represents the demand for good j. If we derive the first-order condition associated with the firms' optimization problem, the marginal cost of the firm in terms of real prices can be expressed as follows:

$$\frac{W_t}{P_t^d} = A_t \mu_t (1-\alpha) {L_t^j}^{-\alpha} {K_t^j}^{\alpha} \left({L_t^j}^{1-\alpha} {K_t^j}^{\alpha}\right)^{-1} = \mu_t (1-\alpha) \frac{y_t}{L_t^j} \tag{27}$$

$$R_t^k = A_t \mu_t (\alpha) {L_t^j}^{1-\alpha} {K_t^j}^{\alpha-1} = \mu_t \alpha \frac{y_t}{K_t^j} \tag{28}$$

where μ_t is the Lagrange multiplier, representing the marginal cost in terms of real prices. By combining equations (27) and (28), the capital-to-labor ratio is obtained as follows:

$$\frac{\alpha W_t}{(1-\alpha) R_t^k P_t^d} = \frac{K_t^j}{L_t^j} \tag{29}$$

The marginal cost of domestic firms is given by $MC_t = \frac{W_t}{MP_L}$. Therefore, the marginal cost of the firm in terms of real prices can be expressed as follows:

$$mc_t = \frac{W_t}{(1-\alpha) P_t^d \frac{y_t}{L_t^j}} \tag{30}$$

Another issue faced by firms producing intermediate goods is price adjustment. In this study, we adopt the Calvo (1983) approach to price adjustment. That is, in each period, only $(1-\theta_P)$ percent of firms are able to optimally adjust the price of their product, while the remaining θ_P percent of firms, which cannot set prices optimally in the current period, partially index their prices based on past prices using the following formula.

$$P_{t+1}^i = \left(\pi_t^i\right)^{\tau_p} P_t^i \tag{31}$$

where $\pi_t^i = \frac{P_t^i}{P_{t-1}^i}$ represents the inflation rate of sector i's output, and τ_p is a parameter that indicates the degree of price indexation. Given that in each period only a fraction $(1-\theta_P)$ of firms can optimally reoptimize their prices while the remaining firms index their prices to past-period values, the aggregate price index at time t evolves, using Equation 52, according to the following weighted-average formula.

$$\left[P_t^d\right]^{1-\zeta} = \theta_P \left[\left(\pi_{t-1}^d\right)^{\tau_p} P_{t-1}^d\right]^{1-\zeta} + (1-\theta_P)[\bar{P}_t]^{1-\zeta} \tag{32}$$

3.4 Government and Central Bank

Similar to Berg et al. (2010) for low-income, oil-producing developing countries and Dagher et al. (2010) for Ghana, the government budget constraint in real terms is expressed by the following equation:

$$g_t + \frac{(1+r_{t-1}^d)b_{t-1}}{\pi_t^c} = \frac{\omega EX_t o_t}{P_t^c} + T_t + TR_t + other_t + fa_t + \frac{GBD_t}{P_t^c} \tag{33}$$

where g_t denotes total government expenditures, EX_t the nominal exchange rate, $o_t$oil-related foreign revenues, b_t bonds, T_t tax revenues, $other_t$ other revenues, and fa_t privatization of state-owned enterprises, while GBD_t represents the government budget deficit. As is evident, the government spends a fraction ω of oil revenues through the budget.

Since oil production is largely determined by the country's natural reserves and its variation is constrained by increases in capital or labor, this study abstracts from modeling oil production by firms. Instead, oil output is treated as exogenous. Similarly, foreign exchange revenues from oil exports are also considered exogenous. To model these revenues, it is assumed that they follow a first-order autoregressive process, which can be represented in log-linear form as follows:

$$\hat{o}_t=\rho_o \hat{o}_{t-1} + \varepsilon_t^o \qquad \varepsilon_t^o \sim N(0,\sigma_o^2) \tag{34}$$

where $\hat{o}_t$ denotes the deviation of the logarithm of oil export revenue (in dollars) in period t.

3.4.1 Central Bank

According to the study by Manzoor and Taghipour (2015), the exchange rate policy rule can be expressed as follows:

$$\frac{\Delta EX_t}{\Delta EX} = \frac{\Delta EX_{t-1}}{\Delta EX}^{k_\circ} \left(\frac{\pi_t^c}{\pi_t^T}\right)^{k_1} \left(\frac{\frac{FR_t}{MB_t}}{\frac{FR}{MB}}\right)^{k_2} u_t^{EX} \tag{35}$$

Where $\Delta \mathrm{EX_t}$ denotes the growth rate of the nominal exchange rate, π_t^c represents the CPI-based inflation rate π_t^T is the targeted inflation rate, $\frac{FR_t}{MB_t}$ indicates the ratio of the central bank's net foreign reserves to the monetary base, and u_t^{EX} is a disturbance term assumed to follow a normal distribution with zero mean and standard deviation σ_{ER}.Furthermore, to complete the model, it is assumed that the monetary policy instrument available to the central bank is the growth rate of the money supply. In the context of Iran, due to the central bank's non-adherence to specific targeting policies (such as inflation targeting or exchange rate targeting) and the absence of the necessary infrastructure and economic environment for implementing such policies, there is no explicit target regarding inflation or economic growth. Nevertheless, it is observed that monetary policymakers implicitly maintain a reference inflation target and respond to deviations of actual inflation from this implicit target. Accordingly, in response to inflation deviations from the target level, policymakers adjust the growth rate of the monetary base either upward or downward. Based on this framework, it is assumed that the central bank's policy reaction function is designed so that, by setting the growth rate of the money supply, the policymaker pursues two primary objectives: (a) Reducing the deviation of output from potential output (i.e., stabilizing economic activity). (b) Minimizing the deviation of inflation from the target rate (i.e., controlling inflation and maintaining price stability).

In this study, following the approach of Bayat et al. (2016), the monetary policy is adjusted by explicitly considering the dynamics of the aggregate stock price index. Accordingly, the monetary policymaker responds to deviations of key variables such as inflation, output (production), and the aggregate stock price index from their respective equilibrium levels by adjusting the money supply (or its growth rate) to stabilize the economy. Considering these aspects, the monetary policy reaction function (in a log-linear form) can be expressed as follows:

$$\widehat{\Theta}_t = \rho_\Theta \widehat{\Theta}_{t-1} + \theta_\pi \hat{\pi}_t^c + \theta_y \hat{y}_t + \theta_{rer} \widehat{rer}_t + \varepsilon_t^\Theta \tag{36}$$

$$\widehat{\Theta}_t = \widehat{m}_t^c - \widehat{m}_{t-1}^c \hat{\pi}_t^c \tag{37}$$

$$\hat{\varepsilon}_t^\Theta = \rho_\Theta \hat{\varepsilon}_{t-1}^\Theta u_t^\Theta \qquad u_t^\Theta \sim N(0, \sigma_\Theta^2) \tag{38}$$

Where $\hat{\theta}_t$ denotes the nominal growth rate of the monetary base , an $\hat{\pi}_t^c$ ، $\hat{y}_t$, ،$\widehat{rer}_t$ represent the deviations of CPI inflation, the logarithm of output, and the real exchange rate from their respective steady-state values. θ_π ،θ_y , and θ_{rer} are the weights that the monetary policy assigns to the inflation gap, output gap, and real exchange rate deviations, respectively. ε_t^Θ is the monetary policy shock, which follows an AR(1) stochastic process.

3.5 Aggregate Market Equilibrium

The final goods market is in equilibrium when production equals the demand from households for consumption and investment, government expenditures, and net exports (exports minus imports):

$$y_t = c_t + c_t^g + I_t^T + \frac{EX_t o_t}{P_t^c} - \frac{P_t^{mc} c_t^m + P_t^{mc} I_t^m}{P_t^c} \tag{39}$$

Where $I_t I_t^g = I_t^T$ equals the total of private investment and public investment, hence

$$y_t = c_t + c_t^g + I_t + I_t^T + rer_t \times o_t - \gamma_t^{mc}(c_t^m + I_t^m) \tag{40}$$

3.6 Determination of the Optimal Monetary Policy

Optimal monetary policy is based on mathematical functions that link the central bank's objectives to policy instruments. These functions are typically formulated within the framework of stochastic dynamic general equilibrium (DSGE) models and consist of three main components: the loss function, the optimal reaction function, and the model constraints.

3.6.1 Objective Function

The central bank minimizes a quadratic loss function that penalizes deviations of key macroeconomic variables from their target levels. The general form of the loss function is as follows:

$$\min_{\gamma} \mathbb{E}(y_t' W y_t) \tag{41}$$

where y_t is the vector of endogenous variables, $(y_t = [\pi_c, y, rer]')$, comprising inflation π_c, the output gap (y), and the real exchange rate (rer). W: denotes a weighting matrix that reflects the relative importance attached to stabilising each variable. $\mathbb{E}$:denotes the unconditional mathematical expectation operator.

For this problem, the optimization problem can be rewritten as follows:

$$\min_{\gamma} \mathbb{E}(y_t' W y_t) = (\pi_c - \pi_{tar})^2 + (y - y^*)^2 + (rer - rer^*)^2 \tag{42}$$

This function corresponds to the following weighting matrix:

$$W = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

The term$(\pi_c - \pi_{tar})^2$ penalizes the deviation of inflation from its target (π_{tar}). The term$(y - y^*)^2$ penalizes the deviation of output from its potential level (y^*). The term $(rer - rer^*)^2$: penalizes the deviation of the real exchange rate from its equilibrium level (rer^*).

3.6.2 Dynamic Constraint

The dynamics of the model are described by the following equation:

$$A_1\mathbb{E}_t[y_{t+1}]+A_2y_t+A_3y_{t-1}+Ce_t=0$$

Where A1, A2, A3 are matrices that encode the dynamic structure of the model, representing forward-looking, contemporaneous, and lagged relationships, respectively. C: The matrix that links exogenous shocks $\mathrm{e_t}$ to the model. $\mathrm{e_t}$ Exogenous stochastic shocks (e.g., demand or supply shocks). These parameters (θ_π, θ_y and θ_{rer}), which determine the response to deviations in inflation, output gap, and the real exchange rate (Equation 36), are embedded in the matrices A1, A2, A3, defining the dynamic structure of the model.

The solution of the problem involves solving a quadratic-linear optimization problem, which can be divided into the following steps:

Step 1: State-Space Representation

The model is expressed in state-space form as follows:

$$\mathbb{E}_t[y_{t+1}]=Fy_t+Gu_t$$

Where: F: The transition matrix, derived from A1, A2, A3, representing the evolution of the state variables over time. G: The matrix that links the control variables (u_t) to the system, where u_t denotes the central bank's policy instruments (e.g., money growth adjustments).

Step 2: Riccati Equation

To determine the optimal feedback rule, the Riccati equation is solved in its standard LQR form as [P = W + F'PF - F'PG(R + G'PG)^{-1}G'PF]

Where :P: Positive semi-definite solution matrix.R: Penalty matrix for the control variables (usually zero in simple rules).

W: Weighting matrix from the loss function.

Step 3: Optimal Feedback Rule

The optimal feedback rule is given as follows:

$$u_t=-Ky_t$$

$K=(RG'PG)^{-1}(G'PF)$is the feedback gain matrix, which determines how the central bank adjusts its policy instruments in response to deviations in the state variables.

Step 4: Minimization

Minimize the loss function with respect to the policy parameters (θ_{π}, θ_{y}, θ_{rer}) using numerical optimization techniques. This involves solving the following equations:

$$\frac{\partial Loss}{\partial \phi_i} = 0 \ \ for\ i \in \{\pi, y, rer\}$$

3.7 Model Equations for the Linearized Model

Linear DSGE models are typically employed for reasons of computational efficiency. In other words, solving linear models is computationally faster and more efficient than solving nonlinear ones, which enables researchers to estimate and simulate larger-scale models. Moreover, linear models facilitate the application of estimation techniques such as the Kalman filter and Bayesian methods. To facilitate numerical simulation and estimation, the system of nonlinear equilibrium equations is log-linearized around the steady state. Following the standard Taylor first-order approximation, each variable is expressed as a percentage deviation from its steady-state value. Specifically, if X_t denotes the vector of endogenous variables and $\bar{X}$ its steady-state value, then the log-linearized variable is defined as $\hat{X}_t = \log(X_t) - \log(\bar{X})$, which represents the deviation of X_t from the steady state in percentage terms.

Under these conditions, the steady-state relationships $E_t[X_{t+1}] = X_t = \bar{X}$ are imposed. Applying a first-order Taylor expansion around $\hat{X}_t$ yields a linear system of equations that can be expressed in terms of current and expected future deviations of the variables. Accordingly, the model is represented as a linear dynamic system in the form of:

$$A.\hat{X}_t = B.E_t\left[\hat{X}_{t+1}\right] + C.\hat{X}_{t-1} + D.\hat{\varepsilon}_t$$

where $\hat{\varepsilon}_t$ denotes exogenous shocks.

This approach follows the methodology of Uhlig (1999), who formalized a general procedure for log-linearizing dynamic stochastic general equilibrium (DSGE) models. In this framework, both determinate (current-period) and expectational (forward-looking) equations are linearized consistently to obtain a solvable rational expectations system.

4 Model Solution

In this section, the results obtained from the parameterization of the structural model and the computation of the steady-state values of the model variables are presented. Some of the coefficients were adopted from previous studies, while others such as certain ratios in the steady-state were calculated using seasonal data from the Statistical Center of Iran for the period Spring 2006 (1385:1) to Spring 2023 (1402:1), based on the base year 2016 (1395). Furthermore, the variables used in this study are expressed in billion Rials, and the exchange rate variable is in Rials. To detrend the variables, the Hodrick-Prescott filter was applied. The remaining coefficients were calibrated using the algorithm introduced by Canova (2011) to achieve the best fit between the model-generated moments and the real-world data.

To ensure transparency in the calibration process, all real variables were expressed at constant 2016 prices, and the detrending was conducted with the standard HP smoothing parameter ($\lambda = 1600$) suitable for quarterly data. The parameters drawn from previous DSGE studies (e.g., Manzoor & Taghipour, 2015; Rahbar & Salimi, 2015) correspond to economies with similar structural characteristics. The parameters obtained from data, including key steady-state ratios such as c/y, i/y, and the oil revenue share in the government budget, were calculated directly from national accounts and fiscal statistics. The calibration ensures that the model replicates the main macroeconomic ratios observed in the Iranian economy, confirming the empirical consistency of the parameterization.

The results of the model parameterization are presented in Table 1.

Table 1
Results of model parameterization and ratios.

Variable	**Title**	**Value**	**Source**
β	Time Preference Rate of the Representative Consumer	0.97	Manzoor and Taghipour, 2015
h	Degree of Habit Persistence	0.3	Fakhrhosseini, 2014
σ_c	relative risk aversion	0.8	Kavand, 2009
σ_l	Inverse of the Labor Supply Elasticity with respect to the Real Wage	2.92	Manzoor and Taghipour, 2015
σ_m	Inverse of the Interest Elasticity of Real Money Balances	1.315	Manzoor and Taghipour, 2015
η_c	Intertemporal Elasticity of Substitution in Consumption	1.6	Research Calculations
α	Capital Share in the Production Function	0.21	Research Calculations
χ_S	Share of Goods from Other Sectors	0.79	Research Calculations
τ_p	Degree of Price Indexation	0.511	Rahbar & Salimi, 2015
θ_p	Fraction of Firms Unable to Adjust Their Prices	0.2	Parsa et al., 2015
ψ_c	Elasticity of Substitution between Domestic and Imported Goods	1.05	Parsa et al., 2015
ρ_g	Autoregressive Coefficient of the Government Spending Shock	0.66	Manzoor and Taghipour, 2015

ρ_M	Autoregressive Coefficient of the Productivity Shock	0.42	Research Calculations
δ	Capital Depreciation Rate	0.042	Fakhrhosseini et al., 2010
θ_π	Inflation Weight in the Monetary Policy Reaction Function	-1.54	Manzoor and Taghipour, 2015
θ_y	Output Weight in the Monetary Policy Reaction Function	-1.7	Manzoor and Taghipour, 2015
θ_{rer}	Real Exchange Rate Weight in the Monetary Policy Reaction Function	0.8	Manzoor and Taghipour, 2015
ρ_Θ	First-Order Autoregressive Coefficient of the Monetary Shock	0.37	Manzoor and Taghipour, 2015
ρ_o	First-Order Autoregressive Coefficient of the Oil Revenue Shock	0.25	Parsa et al., 2015
o_gbar	Share of Oil Revenues in the Government Budget	0.394	Research Calculations
obar_i_Tbar	Ratio of Private Investment to Total Investment	0.728	Research Calculations
i_gbar_i_Tbar	Ratio of Public Investment to Total Investment	0.272	Research Calculations
obar_frbar	Ratio of Oil Exports to Net Foreign Assets of the Central Bank	1.68	Research Calculations
pe_xx_frbar	Ratio of Non-oil Exports to Net Foreign Assets of the Central Bank	0.512	Research Calculations
gama_mc_cm	Ratio of Total Imports to Net Foreign Assets of the Central Bank	0.287	Research Calculations
c_gbar_gbar	Ratio of Government Current Expenditures to Total Government Expenditures	0.731	Research Calculations
i_gbar_gbar	Ratio of Development Expenditures to Total Government Expenditures	0.268	Research Calculations
ibar_i_Tbar	Oil Revenue Share in Government Budget	0.394	Research Calculations
R_kbar	Real Rate of Return on Capital	0.046	Research Calculations
c_ybar	Ratio of Consumption to Output	0.51	Research Calculations
i_ybar	Ratio of Total Investment to Output	0.321	Research Calculations

Source: Compiled by the authors based on the cited literature and authors' calculations

5 Model Validation

To assess the performance and validity of the proposed model, we use the consistency and closeness of the moments generated by the model calibration compared with the moments observed in the real-world data. In other words, by using the estimated parameters and calculated ratios, we can simulate the time series of the variables in the model. The closer the moments of these simulated series are to the moments of the corresponding real-world time series, the more successful the model is considered in replicating real-world dynamics.

Table 2
Comparison of moments generated by the model with the moments from real-world data.

Variable	**Volatility (Standard Deviation)**		**Relative Volatility (Ratio of Variable's SD to Output SD)**	
	Observed Value in Real Data	Calibrated Value in the Model	Observed Relative Value in Real Data	Calibrated Relative Value in the Model
Inflation	0.018	0.025	0.62	0.96
Consumption	0.032	0.021	1.1	0.84
Production	0.029	0.026	1	1
Investment	0.044	0.043	1.5	1.65

The sample under study contains seasonal data from Spring 2006 (1385:1) to Spring 2023(1402:1)
Source: Research Findings

6 Analysis of Impulse Response Functions and Research Findings

In this section, using estimated parameters as well as some parameters calculated based on Iranian economic data, the log-linear system of equations has been simulated using DYNARE software. In the following sections, the effects of productivity shocks, liquidity shocks, and government oil revenue shocks on macroeconomic variables, as well as the impact of exchange rate shocks on stock market volatility and optimal monetary policy on selected macroeconomic variables, are analyzed and presented.

6.1 Effects of a Liquidity Growth Shock (monetary base)

To analyze the effects of monetary shocks on key macroeconomic variables, we introduce a liquidity shock equivalent to one standard deviation (2%) in the nominal money growth rate, consistent with empirical estimates of Iran's monetary volatility. The impulse response functions (IRFs) are computed over a 20-quarter horizon. The 90% confidence bands, obtained from 1000 Monte Carlo simulations, are shown in the revised figure to assess statistical significance.

Figure 1 presents the impulse response functions (IRFs) of key macroeconomic variables, YNO (non-oil output), π_c (CPI inflation rate), γ_sc (stock price index), w (wages), q (Tobins Q), Δ_ex (exchange rate growth), RER (real exchange rate), and C (consumption), to a positive 2% liquidity growth shock in the nominal money supply. The liquidity shock leads to heterogeneous effects across the economy, reflecting the complex transmission mechanisms in Iran's oil-dependent and partially segmented financial markets.

Following the shock, non-oil output (YNO) rises by approximately 3%, driven by higher domestic demand and increased access to financial resources for both households and firms. Consumption (C) also increases by roughly 2.5%, as households respond to the higher liquidity by raising expenditures. However, investment declines slightly, by about 1%, due to a temporary rise in borrowing costs caused by higher short-term interest rates. This result illustrates the classical crowding-out effect, where increased liquidity can initially raise overall demand but dampen investment through higher financing costs.

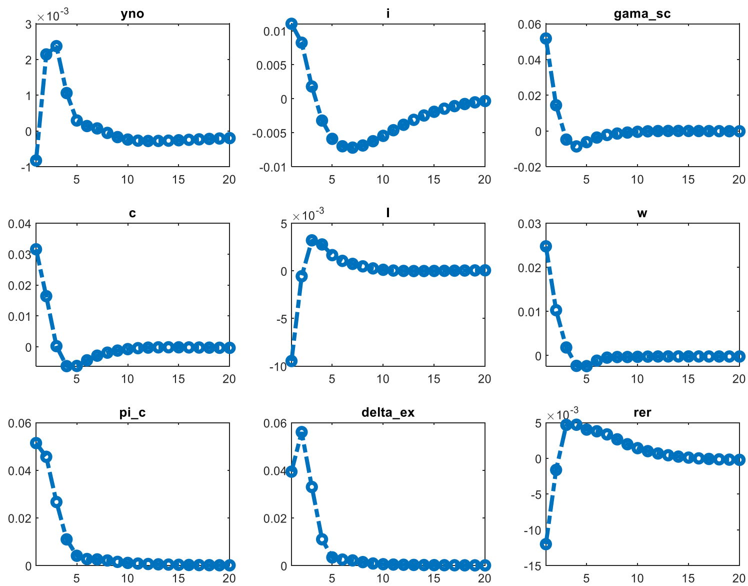

Figure 1. Impulse response functions of variables to a 2% liquidity growth shock.
Source: Research Findings
YNO: Non-oil output: pi_c: Inflation rate; gama_sc: Stock price index, w: Wage, q: Capital stock, delta_ex: Exchange rate growth, rer: Real exchange rate, C: Consumption

The stock price index (γ_sc) rises by nearly 2%, reflecting improved investor expectations and stronger demand for equities as liquidity supports corporate profitability. Wages (w) increase by around 2%, consistent with heightened labor demand resulting from the expansionary effects on production. On the inflation side, π_c rises by about 4%, reflecting increased aggregate demand and cost pressures, signaling the trade-off between output stabilization and price stability under liquidity shocks.

Regarding the exchange rate, nominal exchange rate growth (Δ_ex) decreases by roughly 10%, as heightened domestic interest rates and foreign currency demand reduce the pace of nominal depreciation. Consequently, the real exchange rate (RER) appreciates by approximately 15%, reflecting both nominal exchange rate dynamics and domestic price increases. Capital stock (q) exhibits a modest rise due to the interaction of past investment and Tobin's Q effects, which adjust gradually given investment adjustment costs.

Overall, the 2% liquidity growth shock generates diverse and economically intuitive effects: it stimulates non-oil output, consumption, wages, stock prices, and the real exchange rate, while slightly reducing investment and nominal exchange rate growth, and elevating inflation. These results highlight the importance of carefully calibrating monetary expansion to balance output support with inflation control. Sensitivity analysis confirms that varying the shock magnitude between 1% and 3% produces qualitatively similar responses, while changes in the liquidity-interest rate elasticity mainly affect the magnitude of the responses of investment and the exchange rate. The detailed results are reported in Section 6.1, following Figure 1.

6.2 Effects of Government Oil Revenue Shocks

In this section, the effects of shocks to the government's foreign exchange revenues from oil exports on macroeconomic variables are examined. Figure 2 presents the impulse response functions (IRFs) of YNO (non-oil output), π_c (CPI inflation rate), γ_sc (stock price index), L (employment), i (investment), Δ_ex (exchange rate growth), RER (real exchange rate), liqu (liquidity growth), C_p (private consumption), MB (monetary base), FR (net foreign reserves of the Central Bank), k (capital stock), I_g (government infrastructure investment), I_m (imported capital goods), and C_m (imported consumer goods) to a 2% positive government oil revenue shock.

Following the shock, the Central Bank's net foreign reserves (FR) increase by approximately 3%, reflecting higher inflows of foreign currency from oil exports. This increase expands the monetary base (MB) by around 1.5%, which in turn raises liquidity growth (liqu) by roughly 1.5%, providing additional financial resources to households and investors. Higher oil revenues enable the government to increase infrastructure investment (I_g) by about 2%, while the capital stock (k) grows by approximately 2% as a result of higher public investment and expanded monetary resources.

The nominal exchange rate growth (Δ_ex) rises by nearly 3%, driven by stronger demand for domestic currency through increased exports. Consequently, the real exchange rate (RER) appreciates by roughly 2%, reflecting the combined effects of nominal exchange rate growth and slightly lower inflation, which enhances the purchasing power of the domestic currency. Private consumption (C_p) increases by around 2%, as households benefit from higher income and liquidity. Total investment (i) rises by about 2%, supported by capital accumulation and improved investor confidence. The stock price index (γ_sc) grows by approximately 2%, reflecting positive expectations regarding corporate profitability. Employment (L) increases by roughly 1.5%, consistent with the expansion of oil-related production and investment.

On the other hand, demand for imported consumer goods (C_m) declines only slightly, consistent with the [10^{-3}] scale of the IRF, as higher nominal and real exchange rates make imports more expensive. Similarly, demand for imported capital goods (I_m) decreases marginally, limiting investment in imported machinery and equipment. Non-oil output (YNO) contracts modestly, reflecting reduced access to imported inputs and capital. Inflation (π_c) also moves only slightly, indicating that the price effect of the shock is small relative to the scale shown in Figure 2.

Overall, a positive government oil revenue shock produces broadly expansionary effects on the economy, including higher public investment, private consumption, employment, capital stock, and stock prices. Nevertheless, the negative effects on non-oil output and imported goods highlight the need for careful policy management to ensure balanced growth across sectors.

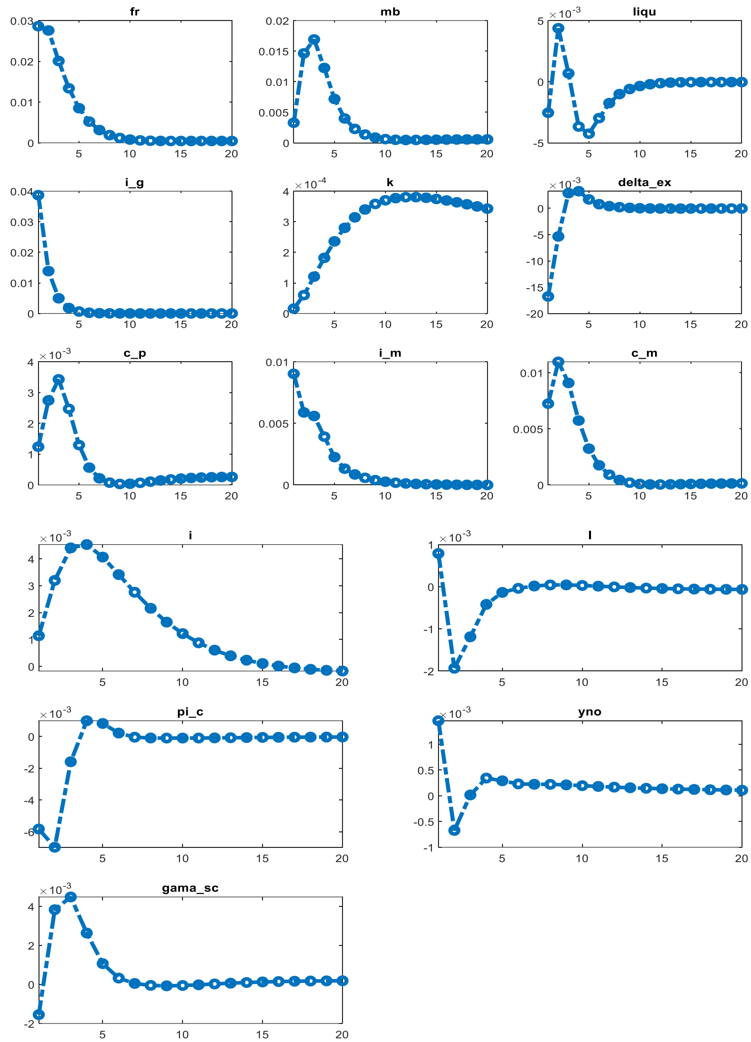

Figure 2. Impulse response functions of variables to a 2% government oil Revenue shock.
Source: Research Findings
YNO: Non-oil output: pi_c Inflation rate; gama_sc: Stock price index, L: Employment, i: Investment, delta_ex: Exchange rate growth, rer: Real exchange rate, liqu: Liquidity growth, c_p: Private consumption,mb, Monetary base, fr: Net foreign

reserves of the Central Bank, k: Capital stock, i_g: Government investment (public infrastructure investment), i_m: Imported capital goods c_m: Imported consumer goods

6.3 Effects of a Total Factor Productivity Shock

This section examines the effects of a total factor productivity (TFP) shock equal to one standard deviation (2%) on key macroeconomic variables. Figure 3 presents the impulse response functions (IRFs) of YNO (non-oil output), π_c (CPI inflation rate), γ_sc (stock price index), w (wages), q (capital stock), Δ_ex (exchange rate growth), RER (real exchange rate), C_p (private consumption), and i (investment) to the 2% TFP shock.

The shock leads to a gradual increase in non-oil output (YNO) by approximately 2%, reflecting improvements in the economy's productive capacity. Investment (i) rises from about 1% initially to over 2% in subsequent periods, while Tobin's Q (q) grows by roughly 15%, as higher productivity enhances returns on investment and encourages capital accumulation. The productivity shock also raises labor demand, leading to an increase in wages (w) of around 15%, which gradually moderates as the labor market adjusts to the new equilibrium.

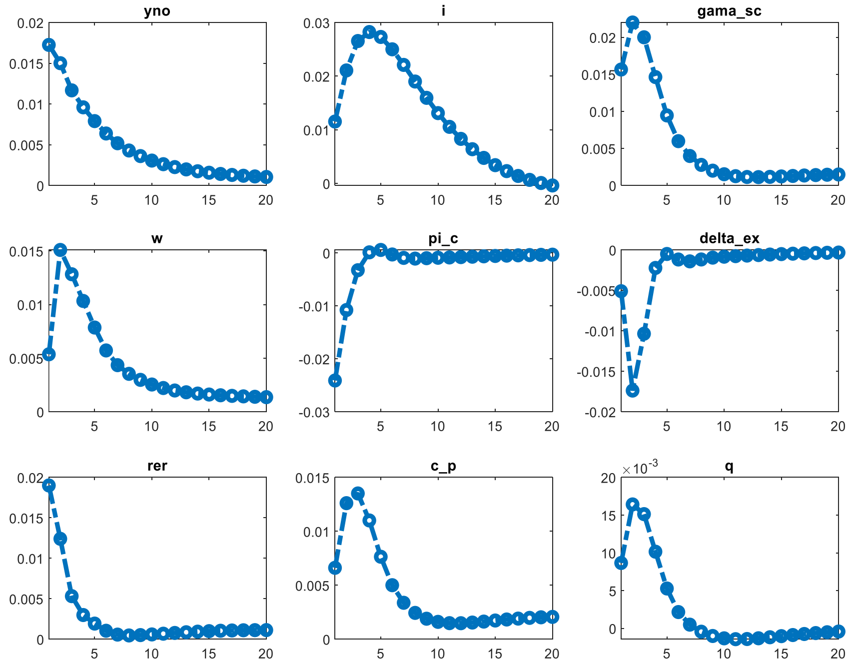

Figure 3. Impulse response functions of variables to a 2% total factor productivity shock.
Source: Research Findings
YNO: Non-oil output: pi_c: Inflation rate; gama_sc: Stock price index, w: Wage, q: Capital stock, delta_ex: Exchange rate growth, rer: Real exchange rate, c_p: Private consumption i: Investment

Private consumption (C_p) increases by about 3%, reflecting higher household income from increased wages and employment opportunities. The stock price index (γ_sc) rises by approximately 2%, as higher productivity improves expectations regarding corporate profitability, stimulating demand for equities. However, this effect diminishes gradually as the stock market reaches its new equilibrium.

The TFP shock exerts downward pressure on the inflation rate (π_c), which falls by roughly 1%, due to lower production costs and improved efficiency. Exchange rate growth (Δ_ex) decreases by about 2%, as improved domestic productivity reduces the demand for foreign currency, while the real exchange rate (RER) appreciates by approximately 2%, reflecting enhanced competitiveness and higher output.

Overall, a positive TFP shock strengthens the economy by increasing output, investment, capital stock, wages, private consumption, and the real exchange rate, while reducing inflation and exchange rate growth. These effects occur gradually, stabilizing at a new equilibrium over several periods, and highlight the role of productivity improvements in promoting sustainable economic growth.

6.4 Effects of Exchange Rate Shocks on the Optimal Monetary Policy

This section examines the effects of exchange rate shocks on macroeconomic variables using the Optimal Simple Rule (OSR) approach. Table 3 presents the calibrated and optimal values of the parameters in the central bank's monetary policy reaction function. The objective function value, close to zero, indicates that the model is well-optimized.

Table 3 presents the calibrated and optimal values of the parameters in the monetary policy reaction function. The objective function value is very close to zero ($-6^{3.13872}$) was a formatting error and has been corrected in the revised manuscript. The table highlights the optimal weights assigned to inflation (θ_π), output (θ_y), and the real exchange rate (θ_{rer}), as well as the autoregressive coefficient of the monetary shock (ρ_Θ).

Table 3

Results of comparing the calibrated and optimal values of the monetary policy rule.

Optimal Value	**Calibrated Value**	**Description**	**Parameter**
-1.6377	-1.54	Inflation Weight in the Monetary Policy Reaction Function	θ_π
-1.2856	-1.70	Output (or Production) Weight in the Monetary Policy Reaction Function	θ_y
0.5799	0.80	Real Exchange Rate Weight in the Monetary Policy Reaction Function	θ_{rer}
0.3816	0.37	First-Order Autoregressive Coefficient of the Monetary Shock	ρ_Θ
$-6^{3.13872}$		Objective Function	

Source: Research Findings

Adjusting these weights provides actionable guidance for policymakers. For instance, increasing the inflation weight in the reaction function reduces the sensitivity of output and the stock price index to exchange rate shocks, but this comes at the cost of higher interest rates, which may negatively affect the stock market. Conversely, placing greater weight on output or the real exchange rate allows monetary policy to stabilize production and currency fluctuations, while moderating the negative impact on the stock market. These results suggest that an optimal monetary policy should balance the trade-offs between inflation control, output stabilization, and exchange rate management, rather than focusing solely on one target.

By quantifying the impact of each parameter on key macroeconomic variables, Table 3 and the associated impulse response analyses provide practical guidance: policymakers can select ranges for (θ_{π}), (θ_{y}), and (θ_{rer}) that minimize volatility in output, inflation, and financial markets under exchange rate shocks, thereby improving overall macroeconomic stability.

In this section, the effects of exchange rate growth shocks on key macroeconomic variables are analyzed by varying the weights of monetary policy parameters. Figure (4) illustrates the impulse response functions (IRFs) for non-oil total output (YNO), inflation (pi_c), and the stock price index (gama_sc) when the weight of inflation in the monetary policy rule changes. The black line represents the baseline scenario in which inflation, output, and the exchange rate each have equal weights of one. The orange and blue lines show cases where the inflation weight is increased to five and ten, respectively.

– Inflation-Focused Policy and Exchange Rate Shocks

As shown in Figure (4), when all policy weights are equal, an exchange rate growth shock leads to a temporary decline in non-oil output, a short-term rise in inflation, and a decrease in the stock price index. When the inflation weight (θ_{π}) is increased to five and ten, the magnitude of these fluctuations declines notably. This occurs because a higher inflation weight causes the monetary authority to respond more aggressively to price instability by tightening monetary conditions, and the inflation response is lower than in the baseline scenario.

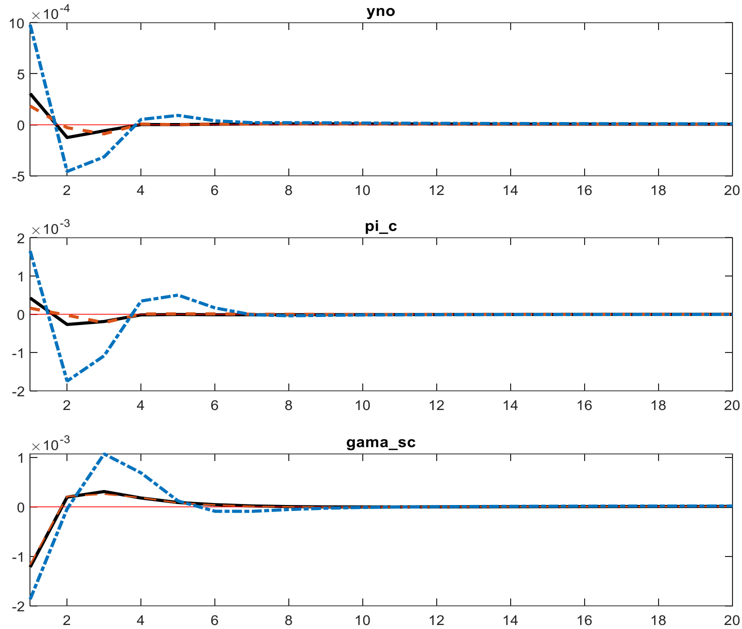

Figure 4. Response of variables to an exchange rate growth shock under different weights of inflation in the monetary policy rule.
Source: Research Findings
YNO: Non-oil total output; pi_c: Inflation rate; gama_sc: Stock price index

The black line represents the case where inflation, output, and the exchange rate each have a weight of one in the monetary policy rule; the orange line corresponds to a scenario where the weight of inflation is set to five; and the blue line reflects a case where the inflation weight is increased to ten.

However, stronger anti-inflationary responses also produce trade-offs. As monetary tightening becomes more pronounced, short-term borrowing costs rise, which can dampen investment and exert downward pressure on stock prices. The sharper fall in the stock price index under higher inflation weights reflects this tighter policy stance. Meanwhile, the reduction in output volatility suggests that a more inflation-focused policy helps shield the real economy from exchange rate–induced inflationary shocks.

The results highlight the importance of selecting balanced policy weights in the central bank's reaction function. Assigning an excessively high weight to inflation control may succeed in stabilizing prices but at the cost of financial market performance and investment growth. A moderate inflation weight, such as between five and ten, appears optimal for maintaining price stability without generating excessive contractionary effects. Central banks in oil-dependent economies like Iran should therefore calibrate inflation targets flexibly, coordinating monetary actions with exchange rate management to limit volatility while preserving output and market stability.

– Output-Oriented Monetary Response to Exchange Rate Shocks

In this section, the effects of exchange rate growth shocks are examined when the weight of output in the monetary policy reaction function is altered. Figure (5) presents the impulse response functions (IRFs) of key variables, including non-oil total output (YNO), inflation rate (pi_c), and the stock price index (gama_sc), in response to an exchange rate shock. The black line represents the baseline scenario in which the weights of inflation, output, and the exchange rate are all equal to one, while the orange and blue lines correspond to cases where the output weight is increased to five and ten, respectively.

As illustrated in Figure (5), when the policy weights are equal, an exchange rate shock leads to a temporary decline in non-oil output, a short-term increase in inflation, and a fall in the stock price index. As the weight assigned to output increases, monetary policy becomes more oriented toward stabilizing real activity rather than strictly targeting inflation. This adjustment moderates the decline in non-oil output and allows the economy to return to equilibrium more rapidly.

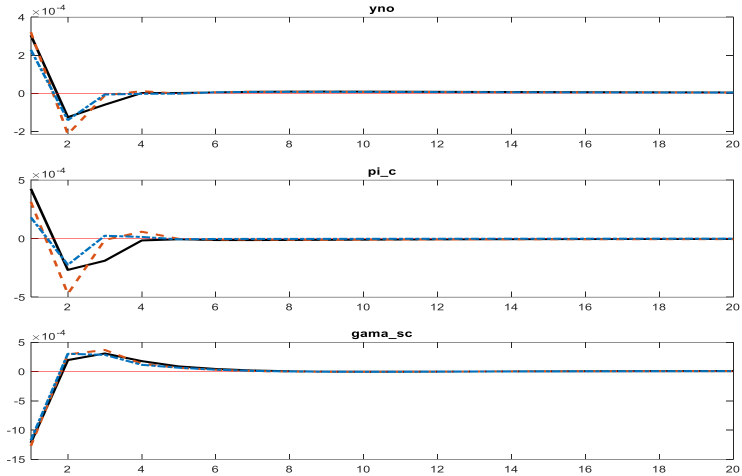

Figure 5. Response of macroeconomic variables to an exchange rate growth shock under different weights of output in the monetary policy rule
Source: Research Findings
YNO: Non-oil total output, pi_c: Inflation rate; gama_sc: Stock price index
The black line represents the case where inflation, output, and the exchange rate each have a weight of one in the monetary policy rule; the orange line corresponds to a scenario where the weight of output is set to five; and the blue line reflects a case where the output weight is increased to ten.

Regarding inflation, increasing the output weight leads the central bank to place greater emphasis on supporting economic activity, often by maintaining lower interest rates. Consequently, inflationary pressures are mitigated, and the inflation rate declines more smoothly after the shock. For the stock price index, higher output weights reduce the contractionary impact of monetary tightening, easing financial conditions and resulting in a smaller decline in asset prices.

Overall, assigning a higher weight to output in the monetary policy rule helps cushion the negative effects of exchange rate shocks on real activity and financial markets. However, this comes at the cost of a less aggressive response to inflationary pressures, which may temporarily weaken the central bank's ability to anchor inflation expectations.

These results suggest that a more output-oriented monetary policy framework enhances economic stability following external shocks, particularly in oil-dependent and exchange-rate-sensitive economies. Nonetheless, policymakers must strike a balance between output stabilization and inflation control. Excessive emphasis on output could reduce the credibility of anti-inflation policy, while moderate output weighting, combined with prudent exchange rate management, appears to yield the most favorable macroeconomic outcomes.

– Exchange Rate Stabilization and Monetary Policy Trade-offs

Figure (6) illustrates the impulse response functions (IRFs) of key macroeconomic variables,including non-oil total output (YNO), inflation rate (pi_c), and the stock price index (gama_sc), in response to an exchange rate growth shock, when the weight of the real exchange rate in the monetary policy rule changes. The black line represents the baseline case where inflation, output, and the real exchange rate each have an equal weight of one in the monetary policy function. The orange and blue lines correspond to cases where the real exchange rate weight is increased to five and ten, respectively.

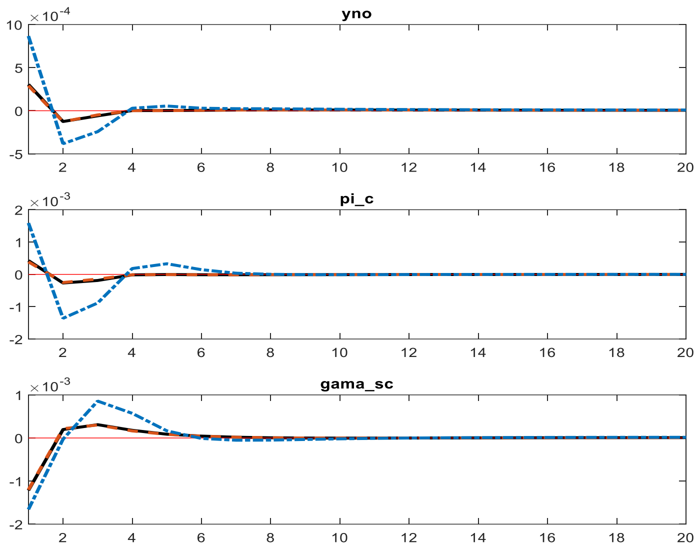

Figure 6. Response of macroeconomic variables to an exchange rate growth shock under different weights of the real exchange rate in the monetary
Source: Research Findings
YNO: Non-oil total output, pi_c: Inflation rate; gama_sc: Stock price index

The black line represents the case where inflation, output, and the real exchange rate each have a weight of one in the monetary policy rule; the orange line corresponds to a scenario where the weight of the real exchange rate is set to five; and the blue line reflects a case where the real exchange rate weight is increased to ten.

When all policy weights are equal, the exchange rate shock causes a temporary decline in non-oil total output, a short-term increase in inflation, and a decrease in the stock price index. However, as the weight of the real exchange rate increases, monetary policy places greater emphasis on exchange rate stabilization rather than aggressive inflation targeting. This adjustment leads to a more stable output trajectory and a faster return to equilibrium.

Regarding inflation, increasing the real exchange rate weight moderates monetary tightening by keeping interest rates relatively lower. This indirectly reduces inflationary volatility and allows prices to stabilize more smoothly. Similarly, the stock price index experiences a smaller decline as financial conditions remain more accommodative under a policy stance focused on real exchange rate stability.

Overall, assigning a higher weight to the real exchange rate in the monetary policy function helps reduce the adverse effects of exchange rate shocks on output and the stock market, while also lowering inflationary pressures. Nevertheless, this comes with a trade-off: a less aggressive anti-inflation stance may slightly weaken the central bank’s short-term control over price dynamics.

The results suggest that giving more importance to the real exchange rate within the monetary policy rule can enhance macroeconomic stability in economies vulnerable to external shocks—especially those with open capital accounts or high import dependency. However, policymakers must maintain a careful balance between exchange rate stabilization and inflation control to ensure sustainable economic performance.

7 Summary, Conclusions, and Policy Recommendations

This study develops and estimates a multi-sector New Keynesian DSGE model tailored to the structural and institutional features of the Iranian economy, an oil-dependent, small open economy with a managed exchange rate and strong fiscal–monetary linkages. The model integrates nominal and real rigidities, including price stickiness, investment adjustment costs, and financial market imperfections, allowing for a realistic assessment of monetary transmission in an oil-based context. Using quarterly data from 2006Q1 to 2023Q1, the model is calibrated and validated through moment-matching, showing high consistency with observed macroeconomic dynamics. The main findings of the study can be summarized as follows:

Liquidity Shocks: A 2% increase in money growth temporarily stimulates output, wages, and consumption but triggers a disproportionate inflationary response (≈4%), underscoring the inflation–growth trade-off inherent in liquidity-based policy channels.

Oil Revenue Shocks: Positive oil windfalls expand liquidity and public investment but appreciate the real exchange rate, crowding out non-oil production, evidence of a moderate “Dutch disease” effect.

Productivity Shocks: A 2% TFP shock delivers the most favorable outcome, increasing output, investment, and wages while lowering inflation, highlighting productivity enhancement as a non-inflationary path to growth.

Exchange Rate Shocks and OSR Analysis: The Optimal Simple Rule estimation indicates that moderate inflation targeting (θ_{π} between –1.6 and –1.8), output responsiveness (θ_{y} around –1.7), and a smaller but positive real exchange rate weight (θ_{rer} around 0.8) yield the lowest joint volatility in inflation, output, and financial variables.

These results confirm that Iran's macroeconomic structure requires a multidimensional policy framework rather than a single-target inflation focus. A coordinated monetary–fiscal approach, complemented by flexible exchange rate management, is crucial to achieve stability in the face of external and domestic shocks.

8 Policy Implications and Recommendations

1) **Adopt a Structured Multi-Target Monetary Framework:** The Central Bank should formalize a rule-based policy reaction function incorporating inflation, output, and real exchange rate stabilization. The estimated optimal ranges (θ_π ≈ –1.6 to –1.8; θ_y ≈ –1.7; θ_{rer} ≈ 0.8) can guide calibration of policy instruments. Periodic re-estimation of these coefficients will maintain relevance under evolving macro conditions.
2) **Sequence Policy Actions in Response to Shocks:**
    - For inflationary shocks: prioritize tightening liquidity and managing expectations through higher θ_π.
    - For output or employment downturns: temporarily raise θ_y and allow moderate liquidity expansion.
    - For exchange rate shocks: apply a balanced response—tightening monetary policy while coordinating with fiscal sterilization to avoid excessive appreciation.
3) **Coordinate Fiscal and Monetary Policies to Manage Oil Revenues**: Establish a sovereign stabilization fund to sterilize oil inflows, using part of the surplus for productivity-enhancing infrastructure. This limits liquidity surges and exchange rate appreciation while sustaining investment in tradable sectors.
4) **Strengthen Financial Market Resilience**: Given the sensitivity of stock prices to monetary tightening, macroprudential buffers, such as countercyclical capital requirements and liquidity coverage ratios, should accompany interest rate adjustments to prevent destabilizing capital outflows.
5) **Prioritize Structural Reforms and Productivity Growth**: Reducing oil dependency through diversification, innovation, and labor market flexibility enhances the long-term growth potential identified in the TFP simulations. Productivity-driven growth offers a sustainable, non-inflationary route to stability.
6) **Institutionalize Model-Based Forecasting and Communication**: The Central Bank should publish quarterly DSGE-based forecasts and shock

decompositions to anchor expectations and increase policy transparency. A "policy dashboard" integrating OSR indicators can strengthen forward guidance and accountability.

9 Limitations and Future Research

While the model captures Iran's main macroeconomic mechanisms, it abstracts from political uncertainty, fiscal inefficiency, and informal credit markets. Future research should integrate heterogeneous agents, fiscal rules, and global oil price volatility to examine multi-sectoral spillovers and the effectiveness of coordinated stabilization under uncertainty.

10 Overall Conclusion

Sustainable macroeconomic stability in oil-dependent economies like Iran cannot be achieved through inflation targeting alone. An adaptive, multi-target monetary strategy, supported by credible communication and synchronized fiscal policy, offers a pragmatic roadmap for balancing inflation control, output stabilization, and exchange rate management in a volatile global environment.

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Appendix

Given the above, households aim to maximize their utility function subject to a budget constraint. In this optimization process, they optimally choose consumption, money holdings, stock investments, deposits, labor supply, capital stock, investment, and the rate of capital utilization, so as to maximize their objective function while satisfying the budget constraint.

$$\max \mathrm{E}_t \sum_{t=0}^{\infty} \beta^t \Bigg\{ \Bigg[\frac{1}{1-\sigma_c} \left(c_t^i - hc_{t-1}\right)^{1-\sigma_c} - \frac{1}{1+\sigma_l} \left(L_t^i\right)^{1+\sigma_l} + \frac{1}{1-\sigma_m} \left(\frac{M_t^{c,t}}{P_t^c}\right)^{1-\sigma_m} \Bigg] + \lambda_t \Bigg[\left(1 + r_{t-1}^d\right) \frac{b_{t-1}^i}{\pi_t^c} + \frac{m_{t-1}^{c,i}}{\pi_t^c} + \frac{1}{P_t^c} \Omega_{t-1}^{*,i} + TR_t^i - T_t^i + \frac{W_t^i}{P_t^c} L_t^i + R_t^k k_{t-1}^i - k_{t-1}^i + Div_t^i - c_t^i - I_t^i - b_t^i - m_t^{c,i} - \frac{1}{P_t^c} \int_0^1 P_t^s(j) \frac{N_t(j)}{\varepsilon_t^s} dj \Bigg] + Q_t \Bigg[(1-\delta) k_{t-1}^i + \left[1 - S\left(\frac{I_t^i}{I_{t-1}^i}\right) \right] I_t^i - k_t^i \Bigg] \Bigg\}$$

whereλ_t is the multiplier associated with the budget constraint, and Q_t is the multiplier associated with the capital stock. The first-order conditions for each period $t \geq 0$ are given as follows[1]:

[1] In first-order conditions, the indices iii are omitted. That is, the first-order conditions are identical across all households in the economy (symmetric equilibrium).

$$(\partial c_t) \qquad (c_t - hc_{t-1})^{-\sigma_c} = \lambda_t \tag{43}$$

$$(\partial I_t) \quad \mathrm{Q_t}\left[1 - \mathrm{S}\left(\frac{\mathrm{I_t}}{\mathrm{I_{t-1}}}\right) - \mathrm{S'}\left(\frac{\mathrm{I_t}}{\mathrm{I_{t-1}}}\right).\frac{\mathrm{I_t}}{\mathrm{I_{t-1}}}\right] + \beta \mathrm{E_t Q_{t+1} S'}\left(\frac{\mathrm{I_{t+1}}}{\mathrm{I_t}}\right)\left(\frac{\mathrm{I_{t+1}}}{\mathrm{I_t}}\right)^2 = \lambda_t \tag{44}$$

$$(\partial K_t) \quad \mathrm{Q_t} = \beta \mathrm{E_t} \lambda_{t+1} \mathrm{R^k_{t+1}} + \beta(1-\delta)\mathrm{E_t Q_{t+1}} \tag{45}$$

$$(\partial b_t) \quad \lambda_t = \beta \mathrm{E_t} \lambda_{t+1}\left(1 + \mathrm{r^d_t}\right)\frac{1}{\pi^{c}_{t+1}} \tag{46}$$

$$(\partial m^c_t) \quad \varepsilon^{\mathrm{M}}_t (\mathrm{m^c_t})^{-\sigma_m} = \lambda_t - \beta \mathrm{E_t} \lambda_{t+1}\frac{1}{\pi^{c}_{t+1}} \tag{47}$$

$$(\partial L_t) \quad - L_t^{\sigma_l} + \lambda_t \frac{W_t}{P^c_t} = 0 \tag{48}$$

$$(\partial N_t) \quad \frac{1}{\mathrm{P^c_t}\varepsilon^{\mathrm{s}}_t}\lambda_t \mathrm{P^s_t(j)} + \mathrm{E}\left\{\beta\frac{1}{\mathrm{P^c_{t+1}}}\lambda_{t+1}(\mathrm{P^s_{t+1}(j)} + \mathrm{DV_{t+1}(j)})\right\} = 0 \tag{49}$$

In each period $t \geq 0$, the objective of the production firms in the three domestic sectors is to maximize the present value of expected future profits, taking into account the demand function for their products as determined by the final goods producers, that is,

$$\underset{P^i_t}{Max}\ \mathbb{E}_t \sum_{k=0}^{\infty}(\beta\theta_P)^k \frac{\lambda_{t+k}}{\lambda_t}\left\{\prod_{s=1}^{k}\left(\pi^i_{t+s-1}\right)^{\tau_p}\frac{P^i_t}{P^d_{t+k}} - mc^i_{t+k}\right\} y^i_{t+k}$$
$$s.t \tag{50}$$
$$y^i_{t+k} = \left[\prod_{s=1}^{k}\left(\pi^i_{t+s-1}\right)^{\tau_p}\frac{P^i_t}{P^{\mathrm{d}}_{t+k}}\right]^{-\zeta} y_{t+k} \qquad \forall k \geq 0$$

The concept of $\frac{\lambda_{t+k}}{\lambda_t}$ represents how much one unit of consumption good in period tk is valued by households in period t. Here, λ_{tk} is, in fact, the marginal utility of nominal income in period tk, which is exogenous to intermediary firms. Since households own these firms, the firm's profit is expressed in period t using a discounting factor based on the marginal utility of period tk. After performing further algebraic manipulations on the previous equation, we obtain the following relation:

$$\underset{P^i_t}{Max}\mathbb{E}_t \sum_{k=0}^{\infty}(\beta\theta_P)^k \frac{\lambda_{t+k}}{\lambda_t}\left\{\left[\prod_{s=1}^{k}\frac{\left(\pi^i_{t+s-1}\right)^{\tau_p}}{\pi^i_{t+s}}\frac{P^i_t}{P^d_t}\right]^{1-\zeta} - \right.$$
$$\left.\left[\prod_{s=1}^{k}\frac{\left(\pi^i_{t+s-1}\right)^{\tau_p}}{\pi^i_{t+s}}\frac{P^i_t}{P^d_t}\right]^{-\zeta} mc^i_{t+k}\right\} y_{t+k} \tag{51}$$

By differentiating the last equation with respect to the firm's optimal price $(\bar{P}_t)$, the first-order condition can be expressed as follows:

After simplification (removing constant terms from both sides) and applying symmetric equilibrium, the firm's optimization problem can be summarized as follows:

$$\mathbb{E}_t \sum_{k=0}^{\infty}(\beta\theta_P)^k \lambda_{t+k}(\zeta-1)\left[\prod_{s=1}^{k}\frac{(\pi_{t+s-1}^i)^{\tau p}}{\pi_{t+s}^i}\right]^{1-\zeta}\frac{\bar{P}_t}{P_t^d}y_{t+k} = \mathbb{E}_t \sum_{k=0}^{\infty}(\beta\theta_P)^k \lambda_{t+k}\zeta\left[\prod_{s=1}^{k}\frac{(\pi_{t+s-1}^i)^{\tau p}}{\pi_{t+s}^i}\frac{\bar{P}_t}{P_t^d}\right]^{-\zeta}\bar{P}_t^{-1} mc_{t+k}^i y_{t+k} \quad (52)$$

As stated above, because all firms employ a production-function technology in which the optimal ratios of inputs are identical across firms, it follows that the price is identical for all firms.(symmetric equilibrium $\bar{P}_t = P_t^i$) Equation (52) shows that the price set by firm i at time t is a function of the expected future marginal costs, and equals an added amount (a markup) over the weighted marginal costs. If prices are fully flexible ($\theta_P = 0$), the markup at time t equals ($\frac{\zeta}{\zeta-1}$); consequently, ($\bar{P} = \left(\frac{\zeta}{\zeta-1}\right) mc_t^i$),which is the monopolistic-competition condition under full price flexibility i.e. the price equals a markup. But when prices are sticky ($\theta_P > 0$), the markup varies over time when the economy is hit by an exogenous shock.