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Inflation Reacts to Monetary Policy Tightening Using the Dsge Model

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Abstract

The cost channel is studied in monetary policies using the new Keynesian model of the business cycle. In this article, we explore when the model can produce a favorable inflation response during a situation of monetary tightening. This article utilizes stable price data sourced from the Central Bank of the Islamic Republic of Iran, spanning from 1982 to 2022. Initially, the model was linearized based on the stable growth trajectory, and its parameters were calculated using information and findings from DSGE literature. Next, they were evaluated using the Blanchard and Kun method in Matlab software by creating impulse response functions. The findings indicate that how inflation reacts to monetary policy tightening depends on the cost channel parameter's value. Following the implementation of monetary policy, inflation rates, and capital rent rates demonstrate opposite movements. Therefore, policymakers should not panic over the temporary increase in inflation after implementing stricter regulations.

Keywords: Price puzzle, New Keynesian model, Cost channel, Iran.

1 | Introduction

Inflation reacts differently to monetary policy tightening based on the DSGE model analysis presented in the sources. The New Keynesian small open economy model estimates the impact of unexpected interest rate tightening on inflation. The model suggests that, in some Emerging Market Economies (EMEs), an interest rate hike leads to a more significant response in the output gap and core CPI inflation than in Advanced Economies (AEs). This difference is attributed to exchange rate appreciation following policy tightening, especially in countries with shallow currency markets that rely on FX interventions to offset currency swings.

The traditional economic belief suggests that implementing stricter monetary policies results in a decrease in production and inflation. However, certain models have produced the most notable inconsistency in empirical

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studies on monetary policy shocks, commonly known as the "Price puzzle". By implementing a stricter monetary policy, prices can increase. Two explanations are provided to clarify this enigma. Vector Autoregression (VAR) models are unable to accurately capture the effects of future-oriented monetary policy, leading to inaccurate measurements of monetary policy shocks. The central bank foresees future high inflation caused by shocks in productivity, oil prices, and exchange rates, among other factors. An increase in the interest rates of the central bank may lead to economic shocks and higher prices. Therefore, the reason for the "Price puzzle" is the failure to recognize the unforeseen elements of monetary policy shocks. According to Sims [1], the VAR model does not exhibit a price puzzle when the prices of goods are included. Policymakers may focus on information sets with useful variables for predicting inflation rather than relying on conventional models. Research conducted by Romer and Romer [2] on monetary policy shocks determined that a price puzzle does not occur, as stated by Rabanal [3].

The impact of monetary policy on costs through the "Cost channel" should be considered. The monetary policy cost channel leads to changes in nominal interest rates and price levels following a monetary policy shock. Raising interest rates by the central bank will result in higher production costs and consequently cause an uptick in inflation. The impact of monetary policy's supply side can counteract the traditional impact of the demand side at the same time. Barth and Ramey [4] found a price puzzle when including commodity prices in the VAR model based on industry-level and overall US economy data.

This study attempts to clarify the two theories of the price puzzle by using a Dynamic Stochastic General Equilibrium (DSGE) model to analyze price stickiness and wage determination. In the writings of the Keynesian models implemented in Iran, there is no space for the cost-transmission mechanism of monetary policies. This study introduces a new Keynesian model that considers the cost channel hypothesis, where multiple companies must borrow money to cover payroll expenses before selling their goods. Therefore, the nominal interest rate plays a key role in establishing real expenses and consequently impacts "Inflation". This study proposes that the cost channel plays a role in transmitting monetary policy by permitting an inflation increase following the implementation of contractionary monetary measures.

Crump et al. [5] showed the New York Fed DSGE model simulates the lagged effect of monetary policy on interest rates, output, and inflation. This highlights the importance of sound and credible policy frameworks in stabilizing inflation expectations and ensuring a gradual return to target levels. The model emphasizes that a lack of reaction by central banks to higher inflation can de-anchor inflation expectations, underscoring the need for appropriate policy adjustments to maintain the credibility and stability of inflation rates.

Amatyakul et al. [6], in a study on the contribution of monetary policy to disinflation, indicate that the effectiveness of monetary policy in managing inflation depends on various factors, including the response of inflation to changes in the nominal interest rate. This study suggests that monetary policy tightening can increase the effective unit labor costs of production, potentially leading to an increase in inflation. However, the analysis shows that the elasticity of inflation to changes in the nominal interest rate is low, with limited evidence of a positive response of inflation to monetary policy contractions in the model.

Ravenna and Walsh [7] have explicitly examined the impact of monetary policy costs in a model featuring a new Phillips curve. They determined that inflation pressure was significantly elevated compared to nominal interest rates. The outcomes are influenced by the selection of the weight matrix in the GMM approach as well as by choosing auxiliary variables. Estimating single equations (Or limited information) is a highly effective method for mitigating incorrect outcomes by removing ambiguous connections. However, these techniques are not capable of capturing the connections between multiple variables in a complex model, resulting in low efficiency and identification issues.

Christiano et al. [8] estimated parameters by minimizing the difference between VAR-based estimates and the immediate responses of the base model variables to monetary policy shocks. Their findings demonstrate that following a tighter monetary policy, there has been an increase in inflation, with their estimated parameters indicating that their model accurately captures these trends.

This paper is divided into five sections. A dynamic random general equilibrium model is introduced, following the literature review and research background. The third section covers the simulation, initialization, and estimation of the model, and the fourth section discusses the presentation of response functions. The fifth section presents the conclusions, followed by a list of relevant references. This part introduces a fresh Keynesian model that is fairly typical with nominal and real rigidity. This model explains how production behavior, inflation, interest rates on bank deposits, and real wage dynamics in the Iranian economy are connected through the use of a cost channel in monetary policy.

Similar to Blanchard and Kiyotaki's model from [9], this paper examines the configuration of goods and labor markets in a situation of monopolistic competition. This model contains: 1) a continuous sequence of comparable households represented by the index $j \in [0,1]$, each providing different types of labor power that are imperfect replacements for other workforces, 2) a continuous sequence of commodity producers represented by the index $i \in [0,1]$, each offering a type of commodity that is an imperfect substitute for other commodities; and 3) a continuous series of identical marginal goods producers.

2 | Intermediate Goods Producers and Cost Channels

The key advancement in this model is the inclusion of a monetary policy cost channel, where some intermediate goods manufacturing firms with an index of $i \in [0, \gamma]$ must cover workers' wages before selling their products in each period. These companies take on debt with a nominal risk-free interest rate. Considering the impact of labor cost units, this channel can be viewed as the supply side of the channel, according to Barth and Ramey [4].

Eq. (1) creates the intermediate products.

$$Y_t^i = A_t\left(u_t K_{i,t}\right)^{\alpha} {N_{i,t}}^{1-\alpha}. \tag{1}$$

In *Eq. (1)*, A_t is the technology factor, $K_{i,t}$ is capital stock used by firm i, $N_{i,t}$ is labor force used by firm i. $\alpha \in [0, 1]$ is capital share of production, and firms define the rate of utilization of Household capital (u_t). In order to obtain an effective labor force unit, firms employ $N_{i,t}^j$ representing labor force of jth household; and $N_{i,t}$ is the combination of labor supply and φ is wage markup, which is as *Eq. (2)*.

$$N_{i,t} = \left[\int_0^1 \left(N_{i,t}^j\right)^{(\phi-1)/\phi} dj\right]^{\phi/(\phi-1)}. \tag{2}$$

After solving the problem, the demand function for the jth Household labor force is obtained from the sum of the workforce, as shown in *Eq. (3)*.

$$N_t^j = (W_t^i/W_t)^{-\phi} N_t.$$
$$W_t = [\int_0^1 (w_t^j)^{1-\phi} d_j]^{1/(1-\phi)}. \tag{3}$$

In *Eq. (3)*, N_t and W_t are the total labor and wage indices, respectively. The workforce aggregator offers intermediate firms a homogeneous workforce in a fully competitive environment. For a part of the firm's γ, the nominal payroll is equal to $1 + R_t^l \int_0^1 W_t^j N_{i,t}^{\,j} dj$ while for other firms (1-γ), the nominal payroll is equal to $R_t^l \int_0^1 W_t^j N_{i,t}^{\,j} dj$, so for firms that need to borrow to pay the payroll bill, borrowing interest rates work as a pressure shock.

2.1 | Sample Producer of Marginal Goods

It is assumed that there is a firm that buys distinct goods produced by the intermediate goods producer, produces the marginal product and sells to marginal buyers by combining them[1]. The producer of the marginal product combines intermediate goods that are distinct and substitutable to each other based on the Dixit-Stiglitz aggregator defined in *Eq. (4).*

$$\left[\int_0^1 {Y_t^i}^{(\lambda-1)/\lambda} dj\right]^{\lambda/(\lambda-1)} = Y_t, \tag{4}$$

where Y_t is a marginal product, the intermediary goods Y_t^i, are distinct and incomplete substitutions, and there is a static substitution elongation $\lambda_t > 1$ between them.

The profit maximization of the marginal products after the demand for the various types of intermediate goods is in the form of *Eq. (5).*

$$Y_t^i = \left[\frac{P_t^i}{P_t}\right]^{-\lambda_t} Y_t, \tag{5}$$

where $P_t = \left[\int_0^1 \left(P_t^i\right)^{1-\lambda_t} di\right]^{\frac{1}{(1-\lambda_t)}}$ price index of marginal products of zero profit condition is obtained in the marginal goods sector and P_t^i is the price of all intermediate goods.

2.2 | Households

It is assumed that the economy consists of a large number of households that we show with i and that all of them are homogeneous. Households benefit from the use of goods, maintaining real balances of money, and by providing more work, their desirability decreases because their leisure will be reduced. The present value of desirability represented by a household during its lifetime is in the form of *Eq. (6).*

Households have the desirability of using marginal goods, C_t^j, a and they have inadequacy due to the supply of work hours N_t^j. They are the owners of capital, capital creation, and decision-makers of capital utilization. The form of the household utility function, which is a function of total household consumption, real money balance, and workforce supply, is given by *Eq. (6).*

$$\max \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{\left(C_t^j - bC_{t-1}\right)^{1-\sigma}}{1-\sigma} - \frac{\left(N_t^j\right)^{1+\eta}}{1+\eta} + \frac{\left(\frac{M_t^{c,t}}{P_t^c}\right)^{1-\sigma_m}}{1-\sigma_m}\right]. \tag{6}$$

In which $\beta \in (0, 1)$ is the factor of discount, E_0 represents the rational expectation factors using full information up to time $t = 0, C_t^j$ is the amount of marginal goods consumption. The parameters σ and η are positive; σ is the substitution pull reverse between consumption time. Parameter $\eta > 0$ is workforce supply relative to the actual wage in the utility function, and b_ε (0, 1) indicates the importance of consumption habits, which is the total consumption of the previous period. These habits depend on average economy per capita consumption. Therefore, every household is representative of the economy at time t when its consumption is larger; it receives more positive utility from more consumption, where b indicates how much the consumer

[1] There are two methods for introducing monopoly competition using the Dixit-Stiglitz index. First, we assume that producers of distinctive goods directly sell their products to consumers, and consumers combine these commodities based on the Dixit-Stiglitz index. Another way is to assume that chains of intermediate goods producers sell their distinctive goods to a competitive manufacturer of the marginal product, whose production function is a CES summation of these distinct goods. In this study, we chose the second method, but the choice of either of the two methods of analysis does not affect the outcome of the analyses.

tends to smooth its level of consumption compared with the average per capita consumption of the past period. A higher b represents a higher degree of dependence on consumption habits.

Households maximize their utility according to the budget:

$$c_t^i + I_t^i + b_t^i + m_t^{c,i} = \left(1 + r_{t-1}^d\right)\frac{b_{t-1}^i}{\pi_t^c} + \frac{m_{t-1}^{c,i}}{\pi_t^c} + \frac{W_t^j N_t^j}{P_t} + \left[R_t^k u_t - \Psi(u_t)\right]K_{t-1}^j + TR_t^i - T_t^i + Div_t^i, \quad (7)$$

where sample household expenses for purchases of marginal consumer goods are (C_t^j), I_t^ii is the amount of investment, b_t^i is government bonds, r_{t-1}^d epresents the nominal interest rate of government bonds, T_t^i is household taxes (direct, indirect, and value-added taxes), TR_t^i government subsidies and households hold their wealth as $m_t^{c,i}$of the real balance of money and government bonds. Total income of households from wages ($\frac{W_t^i}{P_t^c}N_t^i$), is obtained by the lease of capital minus the cost of changes in the rate of utilization of capital capacity and dividends distributed by enterprises producing intermediate goods and banks Div_t^i. In *Eq. (7)*, W_t^i is the nominal wage, $R_t^k$is the actual return rate of capital and u_t is the intensity of use (Operating rate) of capital capacity and $\Psi(u_t)$ is the cost of capital utilization.

The cost of using capital capacity $\Psi(u_t)$ represents the cost per unit of physical capital. In long-term equilibrium, relations are established. $\Psi'' > 0, \Psi' > 0, \Psi(1) = 0, u = 1$.

Capital stock is the ownership of households and is used as a homogeneous factor in the production process. Households lease their capital stock at the R_t^k rate to intermediate goods producers. Households can raise capital in two ways.

- *Through increasing investment, I_t, which leads to an increase in capital stock.*
- *Changes in the amount of capital utilization.*

We assume that the process of capital accumulation is carried out using *Eq. (8)*.

$$k_t = (1-\delta)k_{t-1} + \left[1 - s\left(\frac{I_t}{I_{t-1}}\right)\right]I_t, \quad (8)$$

where δ is the depreciation rate of investment, I_t^i is the gross investment of the private sector, and S(0) is the investment cost adjustment function, which is a positive function of investment changes. S(0) represents the resources lost to transform the new investment into capital stock.

In the case of a static equilibrium where z = 1, $S'(1) = S(1) = 0$ and $S'' > 0$, so the adjustment cost depends only on the second derivative.

According to the above, the household problem is maximizing the utility function relative to the budget. In the optimization process, households choose the amount of consumption, deposit, labor supply, capital stock, investment, and utilization of capital in a way that maximizes their objective function relative to the budget:

$$\text{Max}\, E_t \sum_{t=0}^{\infty}\left\{\left[\frac{\left(C_t^j - bC_{t-1}\right)^{1-\sigma}}{1-\sigma} - \frac{\left(N_t^j\right)^{1+\eta}}{1+\eta} + \frac{\left(\frac{M_t^{c,t}}{P_t^c}\right)^{1-\sigma_m}}{1-\sigma_m}\right] + \lambda_t\left[\left(1 + r_{t-1}^d\right)\frac{b_{t-1}^i}{\pi_t^c} + \frac{m_{t-1}^{c,i}}{\pi_t^c} + + \frac{W_t^j N_t^j}{P_t} + \left[R_t^k u_t - \Psi(u_t)\right]K_{t-1}^j + TR_t^i - T_t^i + Div_t^i - c_t^i - I_t^i - b_t^i - m_t^{c,i}\right] + Q_t\left[(1-\delta)k_{t-1} + \left[1 - S\left(\frac{I_t}{I_{t-1}}\right)\right]I_t - k_t\right]\right\}, \quad (9)$$

where λ_t is the coefficient of the process related to the budget constraint, and Q_t is the coefficient of the process related to capital stock. The first-order condition for each period t≥0 is as follows[1]:

$$(\partial c_t)(c_t - bc_{t-1})^{-\sigma} = \lambda_t. \tag{10}$$

$$(\partial I_t)Q_t\left[1 - S\left(\frac{I_t}{I_{t-1}}\right) - S'\left(\frac{I_t}{I_{t-1}}\right).\frac{I_t}{I_{t-1}}\right] + \beta E_t Q_{t+1} S'\left(\frac{I_{t+1}}{I_t}\right)\left(\frac{I_{t+1}}{I_t}\right)^2 = \lambda_t. \tag{11}$$

$$(\partial z_t)R_t^k = \Psi'(u_t). \tag{12}$$

$$(\partial K_t)Q_t = \beta E_t \lambda_{t+1}\left[u_{t+1}R_{t+1}^k - \Psi(u_{t+1})\right] + \beta(1-\delta)E_t Q_{t+1}. \tag{13}$$

$$(\partial b_t)Q_t = \beta E_t \lambda_{t+1}\left(1 + r_t^d\right)\frac{1}{\pi_{t+1}^c} = \lambda_t. \tag{14}$$

$$(\partial m_t^c)(m_t^c)^{-\sigma_m} = \lambda_t - \beta E_t \lambda_{t+1}\frac{1}{\pi_{t+1}^c}. \tag{15}$$

$$(\partial N_t)\quad -N_t^{\eta} + \lambda_t \frac{W_t}{P_t^c} = 0. \tag{16}$$

2.2.1 | Saving and consumption behavior of households

Eq. (10) represents the consumption Euler equation, which is obtained through two Euler equations at times t and t+1 in the below equation:

$$E_t\frac{\lambda_t}{\lambda_{t+1}} = E_t\frac{(c_t - bc_{t-1})^{-\sigma}}{(c_{t+1} - bc_t)^{-\sigma}}. \tag{17}$$

Using *Eq.(14)* for time periods of t and t+1, below relation is reached:

$$E_t\frac{\lambda_t}{\lambda_{t+1}} = \beta E_t\left(1 + r_t^d\right)\frac{1}{\pi_{t+1}^c}. \tag{18}$$

By combining *Eqs. (17)* and *(18)*, the equilibrium relation between the consumption times is obtained:

$$\beta E_t\left(1 + r_t^d\right)\frac{1}{\pi_{t+1}^c} = E_t\frac{(c_t - bc_{t-1})^{-\sigma}}{(c_{t+1} - bc_t)^{-\sigma}}. \tag{19}$$

Eq. (19) shows the consumption optimum dedication inter-period of households; this is done by households because of the discount rate and interest rate of this dedication.

2.2.2 | Money demand

The combination of *Eqs. (10), (14),* and *(15)* can be used to obtain the equation for the demand for household money, which is in the form of *Relation (20)* as follows:

$$(m_t^c)^{-\sigma_m} = (c_t - bc_{t-1})^{-\sigma} \times \frac{r_t^d}{1 + r_t^d}. \tag{20}$$

The true balance of money has a positive relationship with consumption, and its traction is $\frac{\sigma}{\sigma_m}$, but it has a negative relationship with the interest rate on deposits.

[1] In the first-order conditions, the indexes i are deleted. That is, the first-order conditions are the same for all households in the economy (Symmetric equilibrium).

2.2.3 | Accumulation of capital and investment

The combination of *Eqs. (11)* and *(13)* can be used to write the marginal Tobin Q relation, which derives from the ratio $q_t = \frac{Q_t}{\lambda_t}$, and represents the value of the investment in terms of the replacement cost of capital. Given the definition of the marginal Tobin-Q relation, *Eqs. (11)* and *(13)* can be written after the required algebraic operations, respectively, as *Eqs. (21)* and *(22).*

$$1 = q_t\left[1 - S\left(\frac{I_t}{I_{t-1}}\right) - S'\left(\frac{I_t}{I_{t-1}}\right).\frac{I_t}{I_{t-1}}\right] + \beta E_t q_{t+1}\frac{\lambda_{t+1}}{\lambda_t}S'\left(\frac{I_{t+1}}{I_t}\right)\left(\frac{I_{t+1}}{I_t}\right)^2. \tag{21}$$

$$q_t = \beta E_t\frac{\lambda_{t+1}}{\lambda_t}\left[q_{t+1}(1-\delta) + u_{t+1}R^k_{t+1} - \Psi(u_{t+1})\right]. \tag{22}$$

Eq. (21) can be interpreted as Euler's equation of investment, which represents an optimal investment path. In the case of *Eq. (21),* it should be said that when there is no investment adjustment cost, that is, $S\left(\frac{I_t}{I_{t-1}}\right)$ and *Eq. (22),* the depreciated value of the expected future return of capital is expressed after adjusting for the depreciation rate and the rate of capital utilization. The operating rate of capital is equal to *Relation (23)*:

$$R^k_t = \Psi'(u_t). \tag{23}$$

2.3 | Price and Wages under a Sticky Contract

For modeling the wage adjustment process, similar to the studies conducted by Kollman [10] and Erceg et al. [11], it is assumed that households in the labor market determine their wages because they offer their labor force under exclusive competition conditions. However, it is not always possible for them to adjust their wages optimally at any given time. The probability that a representative household can adjust its nominal wage optimally is equal to 1-θw. On the other hand, households who do not have the opportunity to adjust their wages accordingly are expected to index their wages relative to past prices based on *Relation 24*:

$$W^j_{t+1} = (\Delta p_t)^{\omega_w} W^j_t, \tag{24}$$

where ω_w is the degree of wage indexation. When $\omega_w = 0$, there is no wage indexation. However, in the case of $\omega_w = 1$, complete indexation is performed. The percentage of households who do not have the opportunity to adjust their wages, according to *Relation (24)*, will measure their wages so that in the future, an opportunity will be found to adjust optimally. Given this limitation, when households adjust their wages optimally, they are not likely to adjust them for many future periods for θw.

The problem that households are looking for is actually solving a part of the Lagrange equation *Function (9)* with respect to the implications in the demand equation for labor *Eq. (3)* and it is wage indexation relation *Eq. (24)*, that is, *Eq. (25).* can be used to write the marginal Tobin Q relation, which derives from the ratio can be used to write the marginal Tobin Q relation, which derives from the ratio:

$$\begin{aligned} &\max_{W^j_t} E\sum_{k=0}^{\infty}(\beta\theta_w)^k\left[-\frac{\left(N^j_t\right)^{1+\eta}}{1+\eta} + \lambda_{t+k}\prod_{s=1}^{k}\frac{(\Delta p_{t+s-1})^{\omega_w}}{(\Delta p_{t+s})}\frac{W^j_t N^j_t}{P_t}\right], \\ &\text{s.t:} \quad N^j_{t+k} = \left[\prod_{s=1}^{k}(\Delta p_{t+s-1})^{\omega_w}\frac{W^j_t}{W_{t+k}}\right]^{-\phi} N_{t+k} \quad \text{for all } k \geq 0. \end{aligned} \tag{25}$$

By replacing the demand curve for labor in the target function and after performing the required algebra operation, the first-order condition of the nominal wage would be equal to *Eq. (26).*

$$\frac{\overline{W}_t}{P_t}E\sum_{k=0}^{\infty}\beta^k\theta^k_w\left(\frac{\Delta p_t}{\Delta p_{t+k}}\right)^{\omega_w}\frac{(1+\phi)\left(N^j_{t+k}U^c_{t+k}\right)}{\phi} = E\sum_{k=0}^{\infty}\beta^k\theta^k_w N^j_{t+k}U^N_{t+k}, \tag{26}$$

where, U_{t+k}^{N} is the ultimate cost (Non-utility) caused by labor supply and $U_{t+k}^{c}U$ is the marginal utility of consumption. *Eq. (25)* suggests that the nominal wage at time t for the ith household, which provides the adjustment opportunity, will adjust it so that the present value of the resulting return on labor is equal to a markup value on the present value of the marginal cost arising from work (Ultimate inappropriateness)[1].

When wages are quite flexible (i.e., $\theta w = 0$), the real wage is equal to the markup value $(1+\varphi)/\varphi$ of the marginal labor cost ratio (the lack of marginal labor utilization) to the marginal utilization of consumption in the current time. Under these conditions, the real wage dynamics are determined using the process presented in *Eq. (16)*. This means that households supply their labor force in perfectly competitive conditions, and wages are flexibly adjusted in a fully competitive market.

But in monopolistic competition conditions, as stated, in each period, 1-θw% of households succeed in adjusting their wages at an optimal level $\overline{W_t}$, and θw of the remaining percent partially index their wages with the inflation rate; thus, using *Eq. (3)*, the total wage index can be written as *Eq. (27)*.

$$W_t^{1-\phi} = \theta_w[W_{t-1}(\Delta p_{t-1})^{\omega_w}]^{1-\phi} + (1-\theta_w)(\overline{W}_t)^{1-\phi}. \tag{27}$$

Another issue faced by Intermediate goods producers is price adjustments. In this study, the Calvo method [12] was used to adjust the prices. That is, in each period, only (1-θp)% of them will be able to optimize their product prices optimally; other firms (θp%) that cannot determine prices optimally in the current period, based on past prices using *Eq. (28)* partially indexes prices.

$$P_{t+1}^{i} = (\Delta p_t)^{\omega_P} P_t^{i}, \tag{28}$$

where Δpt represents the inflation rate, and ωp∈(0.1) is the parameter that shows the degree of price indexation. In each period, the goal of domestic production companies is to maximize the present value of the expected future profit for future periods in terms of the demand function for the product made by the marginal producers, that is, *Relation (29)*.

$$\begin{aligned} &\max_{P_t^i} E\textstyle\sum_{k=0}^{\infty}(\beta\theta_P)^k \frac{\lambda_{t+k}}{\lambda_t}\left[\prod_{s=1}^{k}(\Delta p_{t+s-1})^{\omega_P}\frac{P_t^i}{P_{t+k}} - mc_{t+k}\right]Y_{t+k}^{i}. \\ &\text{s.t:}\quad Y_{t+k}^{i} = \left[\prod_{s=1}^{k}(\Delta p_{t+s-1})^{\omega_P}\frac{P_t^i}{P_{t+k}}\right]^{-\lambda_t} Y_{t+k} \quad \text{for all } k \geq 0. \end{aligned} \tag{29}$$

By replacing the demand curve in the objective function and deriving from the recent relation concerning the firm's optimum price ($\overline{P}_t$), the first-order condition for the firm's problem will be as *Eq. (30)*.

$$\begin{aligned} &E\textstyle\sum_{k=0}^{\infty}(\beta\theta_P)^k\lambda_{t+k}.\lambda_t\left[\prod_{s=1}^{k}(\Delta p_{t+s-1})^{\omega_P}\right]^{\lambda_t}\frac{\overline{P}_t}{P_t}Y_{t+k} = E\textstyle\sum_{k=0}^{\infty}(\beta\theta_P)^k\lambda_{t+k}.(1- \\ &\lambda_t)\left[\prod_{s=1}^{k}(\Delta p_{t+s-1})^{\omega_P}\right]^{\lambda_t} mc_{t+k}Y_{t+k}. \end{aligned} \tag{30}$$

All firms use a production technology function in which the ratio of optimal production factors is the same among all firms, and this leads to the fact that price $\overline{P}$ i is equal for all firms (Symmetric equilibrium, $\overline{P}_t = P_t^i$).

Eq. (30) shows that the price determined by the ith firm at time t is a function of the expected marginal costs in the future and is equal to a markup over the marginal rationale cost. If prices are quite flexible ($\theta_P = 0$), it is similar to the exclusive competition condition in perfect price flexibility, in which the price is equal to the markup amount in addition to the nominal marginal cost.

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[1] In the business cycle model, it is usually assumed that the stretch of labor supply is infinite; as a result of this assumption, the increase in costs and prices as a result of increased production (In the case of price stickiness) is limited, which contributes to the sustainability of monetary policy effects.

Given that in each period, $1-\theta_P$% of firms can adjust their price at an optimal level $\overline{P}_t$, and another θ_P% determines the prices based on the price of the previous periods, so using the marginal production goods price index equation, the total price index at time t is based on the average weight formula, *Eq. (31)*.

$$P_t = \left[\int_0^{\theta_P}((\Delta p_t)^{\omega_P}P_{t-1})^{1-\lambda_t}di + \int_{\theta_P}^{1}(\overline{P}_t)^{1-\lambda_t}di\right]^{\frac{1}{(1-\lambda_t)}}.$$
$$(P_t)^{(1-\lambda_t)} = \theta_P[(\Delta p_t)^{\omega_P}P_{t-1}]^{1-\lambda_t} + (1-\theta_P)[\overline{P}_t]^{1-\lambda_t}. \quad (31)$$

2.4 | Monetary Authority and Market Liquidation

As a monetary authority, the central bank can set the rate of bank deposition r_t^d. Accordingly, in modeling the behavior of the central bank, it is assumed that the monetary authority in setting the policy rate follows the Taylor rule. In this rule, monetary policy is determined through the interest rate reflection law, and in fact, it is a response to the deviation from the rate of bank deposits and some economic indicators in a stable situation.

$$r_t^d = \rho_r r_t^d + (1-\rho_r)\gamma_p\Delta p_t + (1-\rho_r)\gamma_y y_t + (1-\rho_r)\gamma_\mu\mu_t + \varepsilon_t^z \quad (32)$$

In *Eq. (32)*, μ_t is the rate of money growth in the economy.

Now, the growth rate of money in period t is defined as *Eq. (33)*:

$$\mu_t = \frac{M_t}{M_{t-1}} = \frac{m_t\Delta p_t}{m_{t-1}}. \quad (33)$$

$\gamma_p > 1$ and $\gamma_y > 0$, $\gamma_\mu > 0$ are shown as the weighted parameters of inflation, the rate of growth of money and production variables in the monetary policy, and also the long-term response of the bank deposits to these variables. The shock ε_t^z is due to the central bank's policymaker's mistake in determining the interest rate (Profit) of the target. As can be seen, this type of shock directly enters the monetary policy principle and, as an exogenous and random variable, affects the variable of interest rate on the investment deposit.

According to Saxegaard et al. [13] and Agénor and Montiel [14], it is assumed that the interest rates on loans granted by banks to firms (r_t^l) are equal to markup (μ), as well as the interest rate on bank deposits (r_t^d).

$$\mu_t = \frac{M_t}{M_{t-1}} = \frac{m_t\Delta p_t}{m_{t-1}}. \quad (34)$$

In *Eq. (34)*, u_t^l is the momentum of the interest rate (Interest) of the bank loans and as $u_t^l \sim N(0, \sigma_l^2)$.

Market liquidation conditions require that in all inputs, intermediate and marginal goods are equal to demand. The economic resource constraint is in the form of *Eq. (35)*.

$$Y = C_t + I_t + G_t + \Psi(u_t)k_{t-1}. \quad (35)$$

3 | Linear Model

Setting sticky prices with backward-looking leads to the following equations for the dynamics of price inflation, in which Et represents the operator's expectations with information up to time t, and Δ indicates that the operator is the first difference $(x_t - x_{t-1})$:

$$\Delta P_t = \gamma_b\Delta P_{t-1} + \gamma_f E_t\Delta P_{t+1} + \kappa_p mc_t + \kappa_p\varepsilon_t^p \quad (36)$$

In *Eq. (36)*, $\gamma_b = \frac{\omega_p}{1+\beta\omega_p}$ and $\gamma_f = \frac{\beta}{1+\beta\omega_p}$ and $\kappa_p = (1-\theta_p\beta)(1-\theta_p)/[(1+\beta\omega_p)\theta_p]$, price markup shock is equal to $\varepsilon_t^p = \log[\lambda_t/(\lambda_t - 1)] - \log[\bar{\lambda}/(\bar{\lambda}-1)]$, where $\bar{\lambda}$ is the long-term value of λ_t.

A high degree of ω_p given to any shock in reply to inflation will be increased. A high degree of nominal adhesion, which reflects a high probability, that is, prices are not able to be optimized over a period of time, meaning small responses of inflation to actual marginal production cost, because there is a negative relationship between the slope of Phillips curve parameters, κ_p, and θp. Two parameters, ω_p and θp, are not effective on the sign of the inflation response to monetary shocks, but they affect the range (Value) and durability.

According to Gali and Gertler [15] and Svensson and Woodford [16], the ultimate cost of production is the main factor driving inflation in the model. In the absence of the cost channel in the standard model, the total actual cost is determined by the current wage and the capital rental rate, as both labor and capital play a role in the production function and technology shock. When the model includes the cost channel, the interest rate directly influences both the marginal cost and inflation. *Eq. (37)* represents the actual ultimate expense.

$$mc_t = \alpha r_t^k + (1-\alpha)\left(\omega_t + \gamma r_t^l\right) - a_t. \tag{37}$$

In a cost channel-free model, as described by Smets and Wouters [17], γ = 0. After a rise in interest rates from a monetary policy shock, the actual production costs decrease because of the reduced demand for labor and lower rental rates caused by decreased investment. This may be attributed to the traditional impact of monetary policy, as well as to the impact of demand, according to Barth and Ramey [4]. Alternatively, with a cost channel present (γ > 0), the impact is on the supply side of the monetary policy, as the nominal interest rate serves as a cost shock. The current total production cost is increasing because of interest expenses. To accurately assess total expenses and increase inflation following a strict monetary policy, it is crucial to ensure that any supply-side impact is not offset by demand-side effects.

Eq. (38) represents the connection between the capital rental rate and capital utilization rate.

$$u_t = \psi r_t^k. \tag{38}$$

$\Psi = \frac{\Psi}{\Psi''}$ It is assumed that the user rate in the long-run equilibrium is one. Thus, high values of ψ indicate oscillating efficiency and a smooth capital rental rate. Conversely, if the user's rate is not variable (Fixed), then ψ=0, and the rental rate of capital will be very volatile. Hereafter, these two terms will be used interchangeably.

The high stickiness of the wage, which is in the form of high probabilities, will not be able to be re-optimized in each period θw, and a high wage index ωw will pave the way for a real wage response. Setting sticky wages with a predetermined indexation leads to real wage dynamics in the form of *Eq. (39)*.

$$(1+\beta)\omega_t = \omega_{t-1} + \beta E_t \omega_{t+1} + \omega_w \Delta p_{t-1} - (1+\beta\omega_w)\Delta p_t + \beta E_t \Delta p_{t+1} - \kappa_w \left(\omega_t - \frac{\sigma}{(1-b)}(c_t - bc_{t-1}) - \eta n_t\right). \tag{39}$$

In *Eq. (39)*, $\kappa_w = \frac{(1-\theta_w\beta)(1-\theta_w)}{\{[1+\emptyset(\eta-1)]\theta_w\}}$ if wages are completely flexible, the marginal sentence is nonexistent. Firms understand that, by committing to contracts, they restrict their ability to adjust wages soon, leading them to weigh the expected differences between desired and actual wages using the likelihood of being connected as a factor. The marginal equation affected by the cost channel is the optimal capital ratio for employment. To make optimal decisions, companies ensure that the cost of using one more unit of capital or labor is the same when in balance. Because of the cost channel, the nominal interest rate affects the total cost of employing one extra unit of labor.

$$l_t - u_t - k_{t-1} = r_t^k - \left(\omega_t + \gamma r_t^l\right). \tag{40}$$

This equation clearly illustrates how the monetary policy cost channel affects output. Since share capital remains steady, households determine the user rate. An increase in nominal rates impacts labor expenses, resulting in decreased demand for both labor and products when all other variables remain constant.

In models that belong to this category, the remaining equations are typically typical. Therefore, we simply present them at this point. The standard form of Euler's consumption equation is given by;

$$(1+b)c_t = bc_{t-1} + E_t c_{t+1} - (1-b)\sigma^{-1}(r_t - E_t \Delta p_{t+1}). \quad \textbf{(41)}$$

The development of investment shadow prices for consumer goods (Tobin's Q) depends on the rental rate of capital and real interest rates, as follows:

$$q_t = \beta(1-\delta)E_t q_{t+1} + [1-\beta(1-\delta)]E_t r^k_{t+1} - (r_t - E_t \Delta p_{t+1}). \quad \textbf{(42)}$$

The linear equation of developing capital and investment is in the form of *Eq. (43)*.

$$k_t = (1-\delta)k_{t-1} + \delta i_t, \text{و}\ i_t = \frac{1}{1+\beta}(\beta E_t i_{t+1} + i_{t-1} + \varphi q_t). \quad \textbf{(43)}$$

$\varphi = 1/\bar{s}''$ Note that although the capital movement rule is standard, the investment equation with a predetermined and forward-looking composition is obtained from a definite form that is selected from the capital adjustment cost function for generating concave responses from investment to different shocks. The production function is in the form of *Eq. (44)*.

$$y_t = a_t + \alpha(u_t + k_{t-1}) + (1-\alpha)n_t. \quad \textbf{(44)}$$

The resource constraint is according to *Eq. (45)*.

$$y_t = (1 - \bar{I} - \bar{G})c_t + \bar{I}i_t + \bar{G}g_t + \alpha\bar{\lambda}/(\bar{\lambda}-1)u_t. \quad \textbf{(45)}$$

The investment-to-product ratio is in steady state $\bar{I} = \frac{\delta\alpha\bar{\lambda}}{\{(\bar{\lambda}-1)[\frac{1}{\beta}-(1-\delta)]\}}$, and G^{-} is the ratio of consumed expenditures to the product in a steady state.

4 | Analysis of Model Results in the Iranian Economy

In this section, the model constructed in the previous section is addressed and examined. Initially, the model was logarithmically linearized around its stable point for this purpose. Refer to the appendix for a reminder of how to transform the model into a linear form using the logarithm method. Once the model is simplified to a linear form, its parameters are calculated based on research and empirical evidence found in the DSGE template literature.

4.1 | Calibration

In this section, the model parameters are adjusted based on research on the Iranian economy and typical values in the academic literature *Table 1*.

Table 1. Valued parameters (Calibrated)[1].

Parameter	Description	Amount	Resource or Reason
b	Consumption habits sustainability	0.3	Fakhrhosseini et al. [18]
α	Share of capital in production	0.412	Fakhrhosseini et al. [19]
δ	Depreciation rate of physical capital	0.042	Amini and Neshat [20]
β	Discount factor in the utility function	0.98	Kavend [21]
γ	Degree of cost channel	0.5 and 0.1	Different

[1] Since some of the parameters used in this model have been estimated by other researchers in their studies; and their values are not changing over time, there is no need to re-evaluate them, and only they are used by referring to references.

Table 1. Continued.

Parameter	Description	Amount	Resource or Reason
η	Reverse of stretching the supply of labor to the wage	2.17	Fakhrhosseini [22]
ψ	Operation stretch of capital relative to the rental rate of capital	100	Rabanal [3]
ω_P	Price indexing	0.545	Manzour and Taghipour [23]
ω_W	Price indexing	0.5403	Manzour and Taghipour [23]
σ_P	The standard deviation of markup-ups price disturbance	0.05	Manzour and Taghipour [23]
φ	Stretch the investment adjustment cost function	0.94	Manzour and Taghipour [23]
θ_P	The percentage of households that are unable to adjust nominal wages	0.1146	Manzour and Taghipour [23]
θ_W	The percentage of firms that are not able to adjust their prices	0.3064	Manzour and Taghipour [23]
G/y	Steady state-of-state expenses for production	0.18	Research finding
γ_y	The coefficient of production importance in the function of monetary policy reaction	0.77	Manzour and Taghipour [23]
γ_P	The coefficient of inflation importance in the monetary policy response function	1.574	Manzour and Taghipour [23]
γ_μ	The coefficient of importance of monetary growth rate in the function of monetary policy reaction	0.82	Shahhosseini et al. [24]
ϕ	Labor force succession-stretch	0.36	Fakhrhosseini [22]
σ	Consumption succession-stretch	0.92	Fakhrhosseini et al. [19]

4.2 | Simulation Results

Based on the results obtained, the conventional method in RBC models is used to evaluate how well the pattern can be explained. The sample includes yearly data from 1982 to 2022. The data in this study are based on constant 2016 prices and are segmented into populations to calculate per capita income. Following logging, they were de-processed using the Hedrick-Prescott filter ($\lambda = 100$). *Table 2* presents a comparison between the autocorrelation and standard deviation of the actual variables during periods of zero gaps and their simulation values derived from the new Keynesian model. According to this table, the model replicated the values of the variables mentioned above. The actual autocorrelation coefficients at intervals 1 and 2 for real production without oil are 0.96 and 0.21, which closely match the simulated values of 0.58 and 0.20. The standard deviation of the real data was 0.046, whereas the estimated value closely approximated 0.039. The impact on actual consumption was deemed to be satisfactory. Basically, the Autocorrelation coefficient values for real consumption in intervals 1 and 2 are 0.65 and 0.12, while the simulation values are 0.55 and 0.26, showing a high level of similarity. The deviation between the actual data and the estimated value was 0.046 and 0.048, respectively, with all other variables remaining constant.

Table 2. Comparison of autocorrelation coefficients and standard deviation of simulated variables and real data.

Simulated and Real Data	Autocorrelation Coefficient in Interruption						Standard Deviation	
	Real Data			Simulated Value			Real Data	Simulated Value
	Zero	1	2	Zero	1	2		
Oil-free production	1	0.69	0.21	1	0.58	0.3	0.047	0.039
Inflation	1	0.26	0.14	1	0.27	0.05	0.271	0.137
Real consumption	1	0.65	0.12	1	0.55	00.26	0.046	0.048
Real private investment	1	0.69	0.13	1	0.42	0.18	0.24	0.211
Real money balance	1	0.7	0.32	1	0.55	0.26	0.040	0.048

*Source: Using Matlab software.

5 | Examination of Immediate Responses

5.1 | Model Immediate Response

Here, we present the outcomes of the computations and instantaneous reaction graphs for different economic factors. It involves using the linear equations provided in the appendix to analyze and interpret the impacts of technological impulses, price markup, and tightening monetary policy (Raising the interest rate for firms) on the variables being studied in the presence of a cost channel in monetary policy.

2.5 | Technology Impulse

Due to a 2% increase in productivity spurred by improved production factors, manufacturing firms will require higher levels of capital and labor, leading to increased investments and production in the economy. An uptick in the need for resources results in higher production inputs such as actual salaries and actual interest rates. This leads to higher household income through increased capital rent and wages, leading to an increase in the consumption of goods and services in the economy. Increasing levels of consumption and investment will result in an increase in the overall demand within the economy. Simultaneously, as the total supply in the economy rises due to the increased productivity of production factors, there is not enough surplus demand, leading to a decrease in inflation levels. *Fig. 1* displays the impact of productivity shocks on total consumption variables (c), production (y), real wage (w), and inflation rate (pi) in accordance with the theoretical predictions.

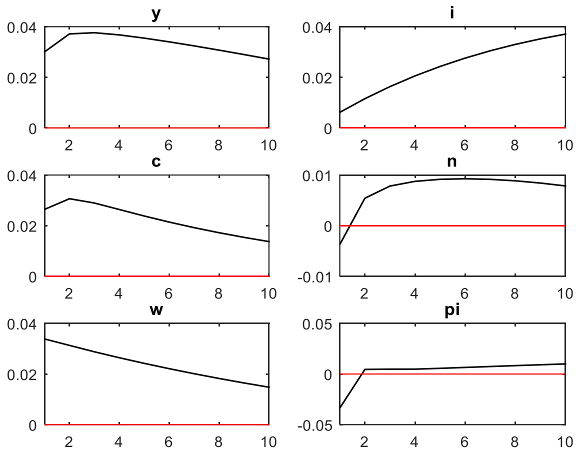

Fig. 1. Productivity shock effect.

5.3 | Price Markup Impulse

Fig. 2 compares the immediate response functions of the six production, investment, consumption, inflation, wages, and employment variables in the simulation of price markup impulse. A 5% price mark-up shock caused a 4.5% decrease in production at the start of the survey period. However, the production gradually increased and reached zero by the fourth quarter. At the start of the period, the impact of momentum on investment was approximately -0.2% and increased gradually. Inflation is positively affected by this impulse, resulting in an 80% increase in inflation. However, after two periods, the impulse effect dissipates, and inflation stabilizes. The impact of impulse on consumption starts at around -1.8 at the start of the period and then increases over time before declining in the fourth period.

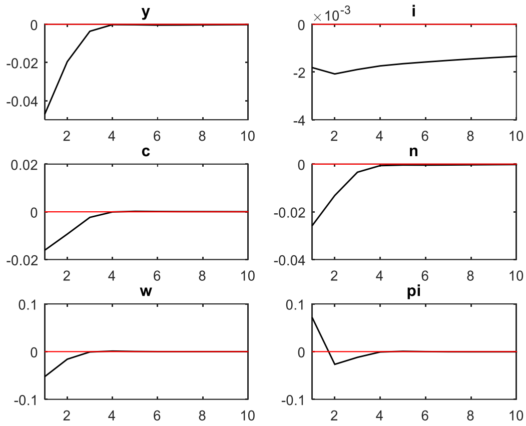

Fig. 2. Price markup shock effect.

5.4 | Monetary Policy Impulse

Fig. 3 compares the impulse response functions of six production-related variables (Production, investment, consumption, inflation, rent of capital rate, employment) with a cost channel of 0.5 (Black lines) and a cost channel of 0.1 (Blue lines) when simulating the impact of interest rate impulses on bank facilities for firms (1%), which essentially tightens monetary policy. If the cost of the channel is low, this model will consistently display a lower response rate following a tightening of monetary policy compared with when the channel cost parameter is higher. Inflation is influenced by the real cost of production, which is determined by both the wage and rental rate of capital due to Calvo's pricing. Both factors consistently declined following the implementation of a restrictive monetary policy. To demonstrate the inflation-boosting model, it is crucial that the nominal interest rate positively affects the ultimate cost. This is accomplished by adding the cost channel of the monetary policy, causing the nominal interest rate to become part of the total cost.

An increase in inflation is caused by a more substantial tightening of monetary policy, with the rate of inflation increasing further if the cost channel parameter is higher. For example, when $\gamma = 0.5$ and $\gamma = 0.1$, a 1% increase in the interest rate leads to a 4% and 1% inflationary rise, respectively. The speed of the production reaction remained constant. The impact on consumption starts negative, but as time goes on, it increases and becomes stronger in the model owing to the higher cost channel parameter value. The impact of this sudden push on job opportunities is adverse, and it will become nonexistent starting from the fourth period. In the model, the effect of this impulse on investment is initially negative and remains negative after ten periods.

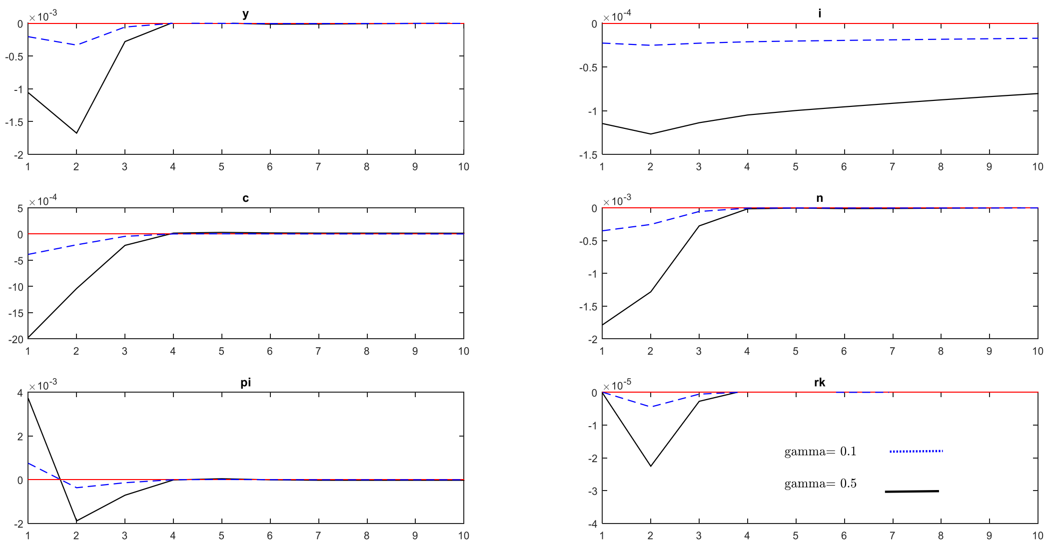

Fig. 3. Interest rate shock effect.

6 | Conclusion

This study involved creating a dynamic random general equilibrium model for the economy based on new Keynesian principles. Three driving forces–technology, price markup, and the interest rate of bank loans to companies–were identified as elements influencing Iranian economic cycles within the model. In new Keynesian models, the presence of monopoly competition and nominal rigidities (Wages and prices) results in money being non-neutral in the short term as it affects real economic variables in the short term.

Once the correct model is selected, the subsequent task is to determine the first-order conditions for optimizing active agents in the economy. Next, the static model is reversed, and the resulting nonlinear model is transformed into a linear logarithm using the Uhlig [25] method. Marginally, by setting the initial parameters of the linear model, the Autocorrelation coefficients and standard deviation of the model were simulated, and the real-life results of the Iranian economy demonstrated the relative effectiveness of these factors.

The findings of this study can be summarized as follows. To generate higher inflation after a stricter monetary policy, it is crucial to ensure that the nominal interest rate's positive impact on firms' costs is not negated by a decrease in actual wages or capital rental rates. Increased channel costs lead to higher inflation because of a more stringent monetary policy. The relationship between inflation and capital lease rates changed in opposite directions following the implementation of monetary policy. Consequently, policymakers should not consider the temporary rise in inflation following policy tightening.

Author Contributions

Both authors made equal contributions to the conceptual design, modeling, analysis, and drafting of the article.

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Data Availability

The data utilized in this research can be obtained from the corresponding author upon a reasonable request.

Conflicts of Interest

The authors report no conflicts of interest.

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